A MONITORING SYSTEM FOR GYPSY MOTH MANAGEMENT

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ABSTRACT

Within the last ten years considerable research has been directed toward the development of a gypsy moth monitoring system for project planning at a regional level and for making control decisions at a local level. Pheromones and pheromone-baited traps have been developed and widely used and several egg mass sampling techniques have also been developed. Recently these sampling techniques have been combined into a pheromone trap-based monitoring system which uses pheromone trap results to assist in prioritizing areas to received egg mass samples. This approach has also made extensive use of graphical presentations using geographic information systems. This paper describes the status of monitoring tools and systems for determining gypsy moth densities for management purposes and areas in need of continued research.

INTRODUCTION

As late as 1984, major management units (states or areas of similar geographic scale) in the United States used a wide variety of methods for making gypsy moth control decisions. These methods focused primarily on egg mass sampling using an underlying assumption that egg mass density is related to defoliation in the subsequent larval generation (Ravlin et al. 1987). Several studies have found a significant relationship between egg mass density and defoliation (Gansner et al. 1985, Wilson and Talerico 1981, Montgomery in press). However, the question of how to arrive at precise and/or accurate estimates of egg mass density for management purposes within the constraints of pest management programs has only begun to be explored. Questions related to when in the gypsy moth population cycle to begin egg mass sampling, how many samples to collect, how to spatially distribute those samples, and how to present the results from these samples to determine treatment areas have also been only recently been addressed. The objective of this paper is to present developments in sampling and monitoring technology and how they have or have not addressed these questions.

THE BASIS FOR MAKING CONTROL DECISIONS

The Relationship Between Egg Mass Density and Defoliation

The basis for control decisions in gypsy moth management programs is an assumed relationship between egg mass density and defoliation. The question is whether or not a given level of defoliation will occur as a result of the subsequent larval population. Consequently, it is necessary to only specify whether or not to treat based on a threshold egg mass density. The earliest thresholds mentioned in the literature were published in "The Comprehensive Gypsy Moth Management System" study where Etter discusses 250, and 1,000 egg masses per acre as possible action thresholds (Appendix K-9, National Gypsy Moth Management Board 1979). These thresholds have continued to be used by most gypsy moth management programs through the 1980's (Ravlin et al. 1987) even though there are no studies which provide economic or biological reasons for their use. Nevertheless, they have provided managers with a decision criterion.

Egg Mass Density Estimates

In 1981 the so-called "compendium" (Doane and McManus 1981) was produced and with it came a wealth of information for researchers and managers. The title "Research Toward Integrated Pest Management" was very appropriate because it was clear that many components of an IPM system were ready for implementation or were being used but a functional "system" had not been delivered to the manager community. Monitoring tools such as pheromone-baited traps, hazard rating models, knowledge of gypsy moth population cycles, and chemical and microbial controls were available for use on a day-to-day basis. The concept of how these components might be integrated was also presented but it was still clear that one of the weak links in the chain of management activities was an approach to predict the amount and spatial extent of defoliation based on egg mass density. Wilson and Fontaine (1978) developed the fixed- and variable-radius sampling method that could generate egg mass densities with any desired level of precision, given infinite resources, and this method was promoted throughout both the research and management communities. It became clear that the fixed- and variable-radius method was not suitable for most management situations because of their time-intensive nature and limited spatial coverage. In 1983 Eggen and Abrahamson devised a method which simply required field personnel to walk through areas of interest for five minutes, count all egg masses, and then relate the counts to absolute egg mass densities using regression models. However, Eggen and Abrahamson state that "More accurate surveys must be conducted when densities are at or near egg mass treatment thresholds". In other words, the technique is useful for gross categorization of populations and not a precise sampling tool. There are several variables that contribute to variability in density estimates based on five-minute walks. Bellinger et al. (1989) showed that the distribution of gypsy moth egg masses is affected by proximity to an "edge". Here edge is defined as the change from one habitat to another, such as where roads are cut through continuously forested areas or pastures. In the Bellinger et al. study an edge effect was so prevalent that significant differences occurred between the "edge side" of trees and the "forest side" of trees. Depending on the side of the tree that one walked by, different egg mass density estimates would be obtained using the timed walk method. In a study done by Fleischer et al. (unpublished manuscript) the timed walk method was compared to 1/40 acre fixed radius plots. Analysis of variance of these data showed that significant amounts of variability could be attributed to location, habitat, the agency responsible for taking the data, and the individual taking the samples. Thus, the five minute timed walk method does not produce consistent egg mass density estimates and cannot be relied upon for treatment decisions.

In an effort to simplify and reduce the time spent taking fixed- and variable-radius plot samples for the Maryland Gypsy Moth IPM Pilot Project Kolodny-Hirsch (1986) compared fixed- and variable-radius plot sampling (Wilson and Fontaine 1978) with fixed-radius plots. His findings were that 1/40 acre fixed-radius plots far exceeded the other methods tested in terms of relative net precision[1]. Using 1/40 acre sampling as the sample unit, Kolodny-Hirsch developed a sequential egg mass sampling protocol for making treatment decisions, although implementation and validation data were not presented. Sequential sampling protocols are dependent on the underlying statistical distribution (e.g., poison, negative binomial) of data used to develop protocols and the amount of error that decision makers are willing to accept. Statistical distributions of gypsy moth egg mass samples are a result of the number and physical size of a sample unit and the spatial pattern of egg masses which, in turn, is dependent on habitat. Kolodny-Hirsch used randomly distributed 1/40 acre samples taken from 14 oak/sweetgum woodlots in urban/suburban Maryland. These woodlots were in flat terrain and had not experienced outbreak gypsy moth populations. Thus, it cannot be assumed that factors affecting the underlying egg mass distribution will stay constant for other types of populations, habitats, and terrain. Making this assumption, Fleischer et al. (unpublished manuscript) developed sequential sampling protocols from several data sets

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[1]Relative net precision (RNP) is defined by: $RNP = [1/(C_s)(RV)]100)$ and relative variation (RV) is defined as $RV = (SE/x)100$ (Pedigo et al. 1972).

collected in northwestern Virginia in continuously wooded areas. This resulted in the development and validation of four sequential sampling protocols used in the Appalachian Gypsy Moth Integrated Pest Management demonstration project (AIPM).

USE OF PHEROMONE-BAITED TRAPS TO PRIORITIZE AREAS FOR EGG MASS SAMPLING

The Moths per Trap Model

Egg mass sampling is expensive and methods for prioritizing areas to receive egg mass samples are essential to working within budgetary constraints. There are no universal methods for prioritizing areas and research conducted during the last five years has sought to address this problem through the use of pheromone-baited traps for male gypsy moths. Pheromone-baited traps have been universally used in gypsy moth detection, eradication, and management programs in the United States (Ravlin et al. 1987). However, decision-makers have not had models that relate pheromone trap results (moths per trap) with the density of other gypsy moth life-stages, particularly egg masses. Thus, management programs are forced to expend more of their resources on expensive egg mass sampling without the benefit of using pheromone trap results to assist in the process of prioritizing areas to receive egg mass samples.

For gypsy moth management programs it would be useful if the number of pheromone trap-captured moths could be used to estimate one or more of the following parameters: egg mass density, egg density, the probability of occurrence of an unacceptably high population (i.e., exceeding a treatment threshold), or be used to trigger and target egg mass sampling for more precise population estimates. Regression techniques for determining if a relationship exists between moths per trap and egg mass density have been described for the Douglas-fir tussock moth (Daterman 1978, Shepherd et al. 1985) and the spruce budworm (Allen et al. 1986). Regressions have been performed on gypsy moth data taken from the Maryland Integrated Pest Management Pilot project, Shenandoah National Park, and plots distributed throughout Virginia. In all cases there are significant regressions between moths per trap and egg mass density. But, like the tussock moth and budworm, there were differences between locations and years with the proportion of variability explained ranging from 30 to 80%. While there is some utility in these relationships, data from Massachusetts do not always support them (Elkinton, 1987). Reasons for this are not known. Many factors affect the dynamics of pheromone trap/moth interactions and the relationship between trap catch and egg mass density. Male moth dispersal and behavior are particularly important. More importantly, because male moths move away from the location from which they emerged it is not reasonable to assume that there will always be a good relationship between moths and egg masses when data are taken from a single location. Developing relationships over larger areas (e.g., a radius 250-500 m) may provide more insight into this problem. Another approach to this problem is to stratify egg mass and moth data into density categories and determine the probability of exceeding different egg mass densities (Table 1). This approach has the advantage of providing managers with a measure of risk and alleviates the need to project egg mass densities given moth counts.

Table 1. Probability of exceeding a given egg mass density based on the number of moths captured in a pheromone-baited trap.

	Moths Captured per Trap		
Egg Masses / Acre	0 - 500	501 - 1000	>1000
0 - 250	0.88	0.40	0.10
251 - 500	0.00	0.20	0.05
501 - 1000	0.00	0.10	0.25
>1000	0.12	0.30	0.60

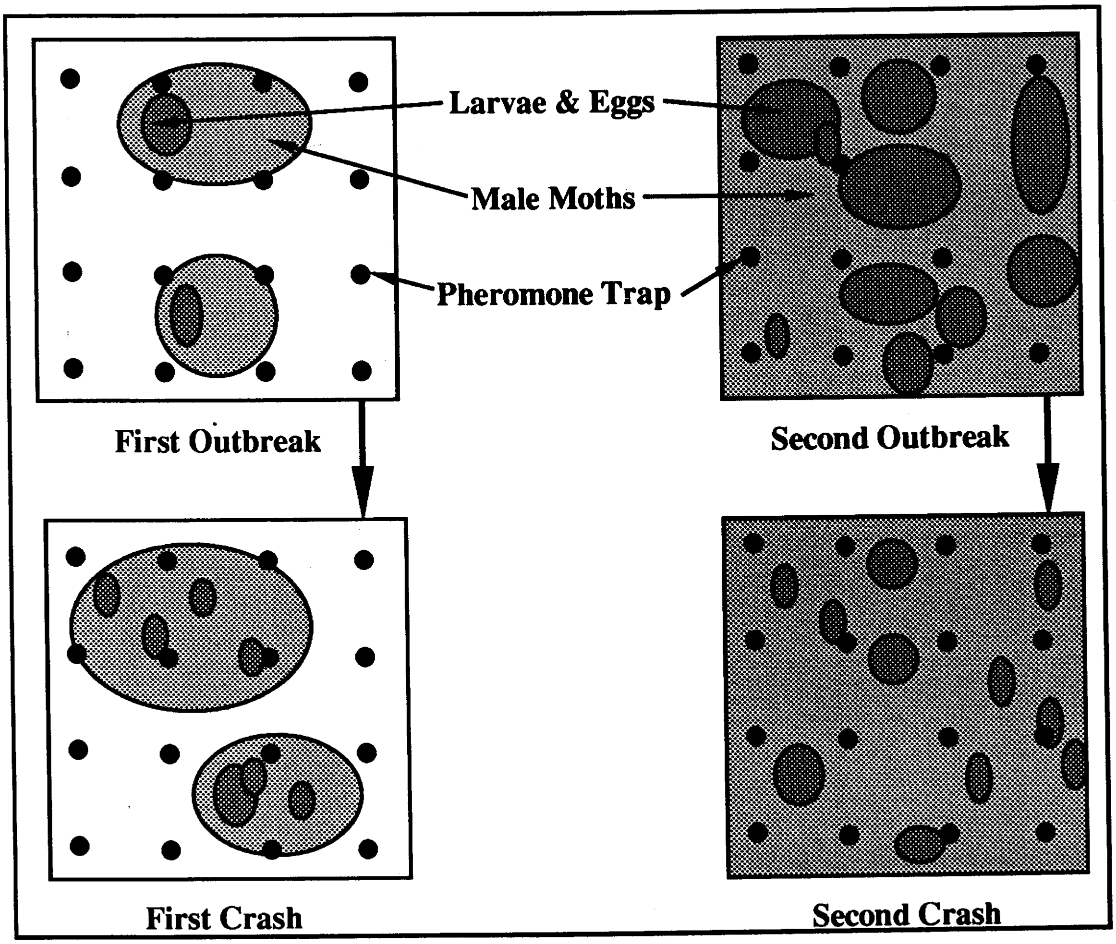

Figure 1. Hypothetical spatial pattern of eggs, larvae and male moths during and after the first two outbreak episodes in a leading edge area.

Other factors contribute to variability in the egg mass density-moths per trap relationship. Elkinton (1987) has shown that the standard gypsy moth milk carton-type pheromone trap decreases in efficiency after about 400 moths have been captured (i.e., increasing numbers of moths enter but subsequently leave traps). Also, traps that have accumulated water often contain rotten moths and presumably, volatiles from these rotting moths can decrease trap efficiency independent of the number of moths caught. Finally, it is not uncommon in the northeastern states (e.g., Massachusetts) to completely fill pheromone traps with male moths and yet fail to find egg masses or other life-stages in the immediate vicinity of the trap (Elkinton 1987). It may well be that the dynamics and/or spatial distribution of populations may contribute to this discrepancy. In theory, when populations first invade new areas their distribution tends to be highly aggregated (Fig. 1, top left) and it is not until after one or more outbreaks (defoliation episodes) that isolated populations begin to coalesce and become more generally distributed (Fig. 1, bottom left). The result would be male moths emanating from several sources creating a "cloud of moths" over the entire area even when other life-stages are highly aggregated and at low density (Fig. 1, right top and bottom).

The Male Wing Length Model

Use of a density index independent of the number of pheromone trap-captured moths would, in part, circumvent some of the problems listed above. Leonard (1968) reported that there was a relationship between body size and density of the gypsy moth and Hinckley (1970) suggested that male moth size, as measured by wing length, varied inversely with the level of defoliation. It follows that egg mass density should be directly related to larval density however, the relationship between defoliation and larval density is less direct. Wilson and Talerico (1981) and Gansner et al. (1985) found a relationship between egg mass density and defoliation, but there is significant variability in these relationships presumably due to population, site characteristics, and sample method. Despite the tenuous nature of these relationships we might expect to find a correlation between male moth size and population fecundity (eggs per unit area) based on the assumption that density dependent stress and defoliation will produce populations of smaller individuals. In 1984, field observations in the Shenandoah National Park indicated that the size of male gypsy moths and egg mass density were correlated and that some measurement of male moths might be used as an index of egg mass density and eggs per mass. We began a study to examine the relationship between male moth wing length and other population parameters. Data were collected in the Shenandoah National Park in Virginia and throughout Maryland. Male wing length and eggs per mass were correlated ($r = .70$) and wing length and egg mass density were also well correlated ($r = .72$) (Bellinger et al. in press). Additional research has found that moths falling into the smallest size classes may be produced only after larvae experience a defoliation episode (> 40% defoliation). The relative frequencies of small (< 19 mm) and large (> 19 mm) moths may then predict an egg mass density category but not necessarily an absolute density estimate (Carter et al. unpublished manuscript)

INTEGRATION OF PHEROMONE-BAITED TRAPS AND EGG MASS SAMPLING

Figure 2 describes how pheromone trap results and egg mass sampling can be combined with other variables to determine areas requiring more intensive sampling. The basis for this system is an area-wide grid of pheromone traps, the results of which, serve as a trigger for initiating egg mass sampling at the local level. Research into methods for delimiting egg mass sample blocks and treatment blocks has been conducted primarily through AIPM methods development and has been described by Fleischer et al. (these proceedings);. Geographic information systems play an essential role in the spatial representation of male moth data, egg mass distributions, and subsequent treatment areas. Using the results of male moth surveys to determine egg mass sample areas requires that point data from pheromone traps be converted to a continuous surface and lines of constant moth density (contours) determined. For the AIPM project, this was done using the ARC/INFO geographic information system. At this point a male moth threshold for egg mass sampling was determined by managers based on the probability of exceeding an egg mass treatment threshold (Table 1) and the risk associated with not sampling (treating) a location. Following the selection of a male moth threshold and generation of contours, a 1 km grid was overlaid on areas to be managed and all 1 km grid cells that were intersected by a contour line greater than or equal to the moth threshold were candidates for egg mass sampling. Other factors that influence the selection of areas for egg mass sampling are last year's egg mass density, population trend (previous moths/current moths), susceptibility, accessibility of sites for sampling, and political and economic considerations. All of these factors can be combined using a geographic information system to produce a composite map used in conjunction with USGS topographic maps and other relevant information (Fig. 3).

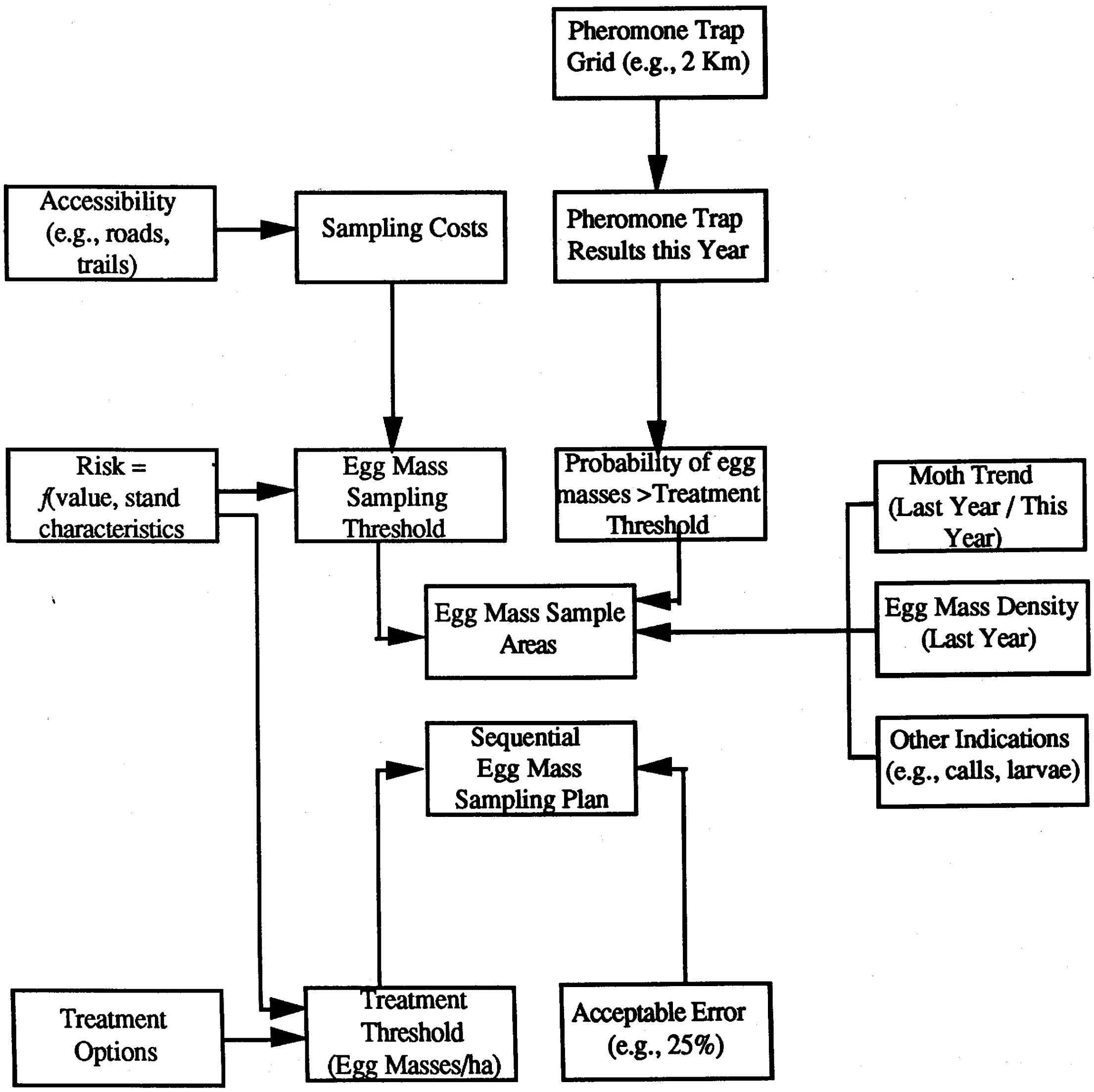

Figure 2. Sequence of events and flow of information to determine the location and number of egg mass samples to be taken for a given geographic area (figure by L. Schaub).

Once an area has been targeted for sampling, sequential egg mass sampling schemes can be generated based on treatment thresholds and sampling error selected by managers. Treatment thresholds should be determined on the basis of expected levels of defoliation (e.g., Montgomery in press) and the efficacy and cost of treatment options (e.g., diflubenzuron vs *Bacillus thuringiensis* (Berliner)). Methods for implementation of sequential egg mass sampling schemes are described in Rutherford and Fleischer (1989). Treatment blocks can then be delimited based on egg mass density, landscape features, and management objectives. For AIPM this threshold was 200 moths in 1988 and 500 in 1989. Results of egg mass surveys can be analyzed similar to pheromone trap results to produce treatment blocks.

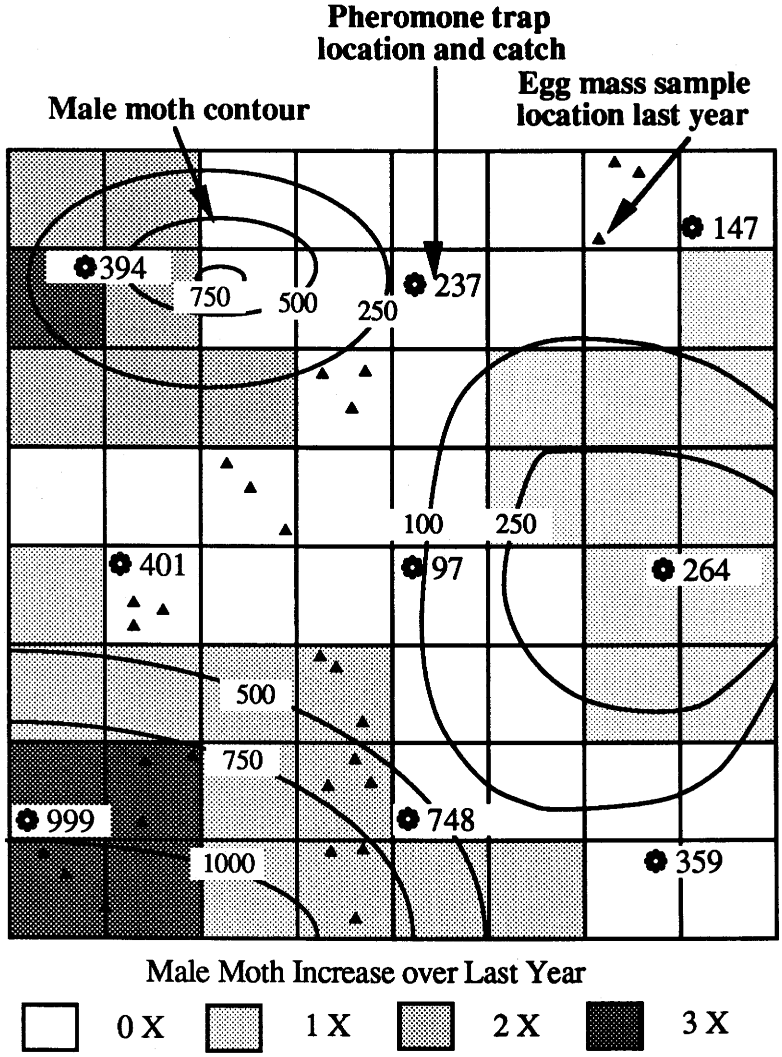

Figure 3. Map used for determining egg mass sample areas in the Appalachian Gypsy Moth Integrated Pest Management demonstration project.

SUMMARY AND CONCLUSIONS

Several problems remain in the development of gypsy moth monitoring systems. As yet, the pheromone trap-based system described above can be used only in areas which are not generally infested (i.e., at or in front of the leading edge). Problems with trap saturation and lack of a reliable moth-to-egg mass relationship prohibits its use in northern Virginia and areas to the north and east. We now have a sequential egg mass sampling scheme that has been field tested and appears to produce the best results to date, but cost remains a constraint to sampling large geographic areas. Systems to access land-use and habitat-related variables could reduce the number and size of areas requiring egg mass sampling. Thus, the cost of this approach would also be reduced. Alternative egg mass sampling approaches need to be developed. These approaches may include stem counts which relate the proportion of stems with egg masses to the probability of exceeding treatment thresholds. This approach would satisfy the need to cover large areas of land and provide decision makers with an estimate of the risk associated with not treating a given area. Stratified sampling in residential situations may also provide risk and density estimates while reducing the cost of intensive searches around houses and man made objects. Burlap bands placed around trees to collect larvae, pupae, and egg masses may also generate useful information.

No matter what type of systems are developed, they must be evaluated in a variety of management situations including leading edge populations and generally infested areas with endemic and increasing populations. The idea that only one monitoring system needs to be developed must be challenged. Yet, standardized protocols need to be put in place to allow good interpretation of data and a wide area perspective of data collected from adjoining geographic regions. One approach may be useful in generally infested areas but may not be appropriate for leading edge populations or data may not lend themselves to spatial presentations essential to making good treatment decisions over large land areas. Evaluation criteria for monitoring systems must include accuracy and precision of population estimates, ease of use, and cost effectiveness. The entire process of data collection, data base management, and data presentation must also be considered before making global sampling recommendations to the gypsy moth manager community.

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