Field Estimation of Fecundity of Gypsy Moth (Lepidoptera: Lymantriidae)

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ABSTRACT A method for rapid field estimation of gypsy moth, *Lymantria dispar* (L.), fecundity was developed and validated. A log-transformed linear regression ($y = 1.58x + 0.29$) was used to estimate number of eggs per mass from egg-mass length over a range of 8–54 mm in length and a range in fecundity of 26–1,509 eggs per mass ($r^2 = 0.71$). The model was tested against two independent data sets and data were pooled to produce parameter estimates that are independent of insect density, year, and locale.

KEY WORDS fecundity, regression model, egg-mass dimensions, *Lymantria dispar* L., egg masses

INSECT OUTBREAKS are caused by changes in fecundity, survivorship, or movement. Predicting insect densities and damage necessitates estimation of these population parameters. We report a simple, rapid field method for estimating fecundity of the gypsy moth, *Lymantria dispar* L., a pest introduced to North American forests, that undergoes episodic outbreaks.

Gypsy moth females lay a single mass of eggs mixed with abdominal scale hair. Fecundity can vary from <100 to >1,000 eggs per mass (Leonard 1981). Changes in fecundity could contribute significantly to changes in density. However, in most surveys of gypsy moth density, fecundity is assumed to be constant and only the number of masses is used to make predictions of damage (Wilson & Fontaine 1978, Gansner et al. 1985). Qualitative estimates of egg-mass size (such as "dime," "nickel," and "quarter") have been used for management purposes to characterize populations (DeGroff 1969; P. Innis, personal communication), but such estimates are of limited accuracy (unpublished data). Estimates of the mean number of eggs per mass have been used in a few studies, employing methods such as a direct counting of eggs or an estimate of fecundity from a measure of total volume of the mass (Campbell 1967, 1976). Both of these methods are time-consuming and require collection of masses before hatching, and neither approach is suitable for noninvasive monitoring of natural populations, particularly at low densities when destructive sampling may markedly affect population dynamics.

A rapid, accurate, and nondestructive field method for estimating gypsy moth fecundity is most desirable. Studies of fecundity relationships indicate that several egg-mass size and weight variables might serve as estimators of fecundity. Campbell (1967) found a low variance in the number of eggs per cm^3 of mass, which suggests that eggs are uniformly packed into a mass. Luciano & Prota (1980) used egg-mass dimensions to estimate gypsy moth fecundity in Sardinia. From our observations of these data, it appears that the geometry or simple dimensions of an egg mass could be used as potential estimators of fecundity.

Materials and Methods

Variables. Egg-mass dimensions were recorded in situ before larva emergence for intact, undamaged masses on trees. Length, defined as the longest dimension of the egg-containing portion of the mass, and width, defined as the longest dimension of the egg-containing portion of the mass perpendicular to length, were measured to the nearest millimeter. Depth at the maximum point of relief, as viewed from the side of the mass, was measured with a caliper depth gauge to an accuracy of 0.05 mm. Masses were then collected individually and weighed in the laboratory (±0.001 g). The number of eggs was counted to relate the field and laboratory variables to actual fecundity.

Sample Sizes. Egg masses were sampled for three generations of gypsy moths at two different sites. Masses oviposited in 1981 ($n = 138$) and 1982 ($n = 57$) were sampled in a variety of habitats at the Mary Flagler Cary Arboretum, Millbrook, N.Y. These masses were distributed evenly across a gradient of egg-mass length classes to avoid any distributional bias in a fecundity relationship derived from these data. Additional masses oviposited in 1984 ($n = 12$) were collected at Pachaug State Forest, North Stonington, Conn. In 1985, five more masses from wild females collected in New Jersey were used to test a new egg-separation technique. Masses were sampled over the widest range of sizes found in the field (8–54 mm length) to ensure the

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Table 1. Coefficients of simple (r^2) and multiple (R^2) determination for estimating the dependent variable fecundity (number of eggs per mass) from several independent variables

Independent variable	Coefficient of determination for the dependent variable
Egg-mass length (mm)	0.68
Egg-mass width (mm)	0.56
Egg-mass depth (mm)	0.23
Egg-mass wt (g)	0.73
Egg wt (g)	0.71
Egg-mass length and width	0.74
Egg-mass length and wt	0.78
Egg-mass width and wt	0.81
Egg-mass length, width, wt	0.83

New York, 1981 oviposition (n = 138); all $P \leq 0.0001$.

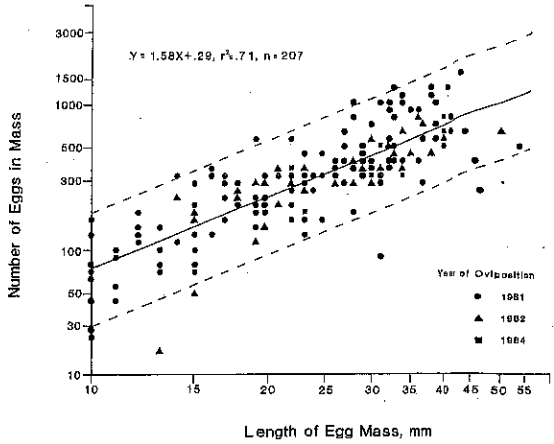

Fig. 1. Log_{10}-transformed regression function (——) with 95% CL (- - -) for 3 yr of combined data from two sites (New York, Connecticut). The log_{10}/log_{10} plot is shown with untransformed axes values. Some observations are hidden where points are overlaid.

applicability of any relationship between fecundity and egg-mass dimensions or weight.

Egg-separation Technique. Egg masses were dehaired by abrading each mass with a small quantity of 40–140 mesh silica gel in the palm of the hand. Eggs were gently scoured with the forefinger of the free hand for ≤3 min. Plastic gloves were worn to protect the hands. The mixture of eggs, scale hair, and silica gel was sieved (0.45-mm mesh). Scale hair passed through the sieve with the silica gel, leaving intact eggs on the surface of the mesh. To determine whether eggs were damaged or pulverized by this method, five masses were carefully teased apart before dehairing and the initial number of eggs was counted. Scale hair and eggs were recombined and the masses were individually dehaired using silica gel for increasing periods of time. Eggs were recounted at 1-min intervals and processing continued for 3 min. No damage or disintegration of eggs was observed for either unparasitized or parasitized eggs, so we proceeded to dehair a total of 207 masses using silica gel.

Statistical Methods. Data were analyzed using linear regression procedures available in the SAS version 82.3 statistical package (SAS Institute 1982). Residuals from regressions were plotted to detect nonlinearity, lack of constancy of error variance, lack of independence of error terms, lack of normality in error distribution, potential omission of key variables, and the presence of outlier values for each regression (Neter & Wasserman 1974). Homogeneity of variance for the regressions was tested using the Bartlett test and a comparison of slopes and intercepts was made using a simple linear test based on an F ratio (Neter & Wasserman 1974).

Results and Discussion

Selection of Variables. All field and laboratory egg-mass variables for 1981 oviposition data accounted for large amounts of variation in the number of eggs per mass, with the exception of depth (Table 1). Several univariate, bivariate, and multivariate linear regressions were performed to identify the best variable or combination of variables that accounted for the highest proportion of variation in fecundity for the least sampling effort (Table 1). Although weight was the best single variable model (r^2 = 0.73), it required labor-intensive collection, destructive sampling, and weighing of masses on a laboratory balance. Egg-mass length was the best single field variable predictor of fecundity (r^2 = 0.68) and had the added advantage of being nondestructive. The addition of width to length in a bivariate regression improved the R^2 by 6%, but was later rejected because it made no appreciable improvement (3%) in data that were transformed to satisfy the regression assumptions. Polynomial functions were used to model relationships such as surface area and volume, but these regressions did not account for as much variance in fecundity as the simple linear models.

Linear-model Validation. The assumptions of linear regression were tested for the simple univariate model of length for 1981 oviposition data. A plot of the standardized residuals revealed that the regression assumptions of constancy and normality of error variance were not met by the length model. Therefore, a log/log transformation was performed on the data to satisfy these regression requirements.

The log-transformed regression function for length as a predictor of fecundity for the 1981 sample was then compared with regressions of two independent populations (1982 and 1984 ovipositions). A general linear test was used to test for equality of these three regression functions (Neter & Wasserman 1974). There was no significant difference between the slope and intercept terms of the three regression lines (α = 0.05). For this reason, the data from three populations were pooled and a new regression model was fitted to the combined data to increase the precision of prediction of the final regression equation (Fig. 1): $y = 1.58x + 0.29$ ($r^2 = 0.71$), where $y = \log_{10}$(number of eggs per mass), and $x = \log_{10}$(length of the mass in mm), and the intercept term is expressed in log units.

Use of the Model. Confidence intervals were calculated for the individual predicted log values from $y_i \pm t(1 - \alpha/2; n - 2)s_i$ (Neter & Wasserman 1974), where s_i is equal to the square root of the mean squared error of the regression (0.191 for our model), t is the t value for the $(1 - \alpha)$ confidence interval, with the risk of making a type I error controlled at α, and n is the sample size. The 95% CL appear as straight rather than curved lines (Fig. 1) because the data are log-transformed and the independent variable is evenly distributed across its full range. To illustrate the use of the regression model and 95% CL, assume that the mean length of egg masses in a sample population is 20 mm. Then $y_i = [1.58(1.30) + 0.29] = 2.344$ or 221 eggs per mass. The 95% CL are calculated from $2.344 \pm 1.960\ (0.191)$ and range from 93 to 523 eggs per mass. The CL are wide because of the natural variation in fecundity within gypsy moth populations. Some of the residual variance in the model may be attributable to variation in egg size and the amount of scale hair oviposited with eggs. However, whether or not egg size varies significantly within or among masses is uncertain (Capinera & Barbosa 1976, Capinera et al. 1977, Richerson et al. 1978).

Estimates of fecundity can be used in several ways. Mean fecundity can be used to make comparisons among populations or monitor fecundity for a given population over time. Such comparisons require relatively small sample sizes. For example, a sample size of 30 egg masses is sufficient to estimate mean fecundity ± 50 eggs ($\alpha = 0.05$) for the 1981 New York sample, which maximizes the variation in egg-mass sizes sampled (unpublished data). Mean fecundity may also be used to increase the precision of gypsy moth density estimates by multiplying mean fecundity by egg-mass density, producing an estimate of egg density.

The confidence limits for a given population can be used to determine density thresholds using either lower or upper limits to create a best- or worst-case scenario. For example, for the population with a mean egg-mass length of 20 mm and mean fecundity of 221 eggs, 95 out of 100 times, mean fecundity will not exceed 523 eggs. This value, multiplied by egg-mass density, provides a worst-case egg-density estimate. This value can be compared with threshold densities used to make management decisions.

The final log-transformed regression model is broadly applicable because it covers a wide range of egg-mass sizes and is not confined to one point in time, one population, or one locale. The reliability of the fecundity estimate is based on a model that reflects an underlying geometric relationship between the egg-mass dimension of length and the number of eggs contained in a mass. The validation of the model using independent data demonstrates that such a generalized regression model is appropriate for estimating fecundity.

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