Special Technology Development Program New Project Proposal

PROJECT NUMBER: NA-2001-04

PROJECT TITLE: Improving and Validating a Model of the Gypsy Moth Pathogen *Entomophaga maimaiga*

PROJECT STATUS: New

EXPECTED PROJECT DURATION: 2 years

EXPECTED COMPLETION DATE OF THE PROJECT: 2002

SUBJECT: Biological Control__2_, Fungus Pathogen_1_, Invasive Species__2_, Models_2_, Monitoring_2_, Population_2_.

STATUS OF SUBJECT SPECIES: non-native noxious

PROJECT OBJECTIVES: Refine and validate a previously developed computer model of the gypsy moth pathogenic fungus, *Entomophaga maimaiga,* and develop the validated model as a tool to determine the susceptibility of newly infested or uninfected forests to damage by the gypsy moth, and predict future interactions between the pathogen and host in the generally-infested areas.

BRIEF DESCRIPTION OF PROJECT: R. Weseloh has developed a computer model that integrates rainfall patterns, temperature, gypsy moth density, and the numbers of resting spores of the gypsy moth fungus in soil so that infection rates of caterpillars can be predicted (Weseloh 1999). However, the model has not been validated, and some of its parameters must be adjusted to fit experimental data. The purpose of this proposal is to validate the model and develop it for use by others. This will be done over two years by choosing 10 separate forested sites in the generally infested area where the gypsy moth and fungus are abundant. At each site, resting spores in the soil will be sampled. Automated rain gauges and temperature and humidity data loggers will monitor weather conditions. Gypsy moth population density will be sampled, and field collections of gypsy moth larvae will be made to determine fungus disease incidence. Laboratory-reared gypsy moths will be exposed on trees in these same sites to obtain information about infection rates. Data will be used to refine and validate the model in the first and second years, respectively. The finished model will be most valuable as an aid in determining the susceptibility of newly infested or uninfested areas to damage by the gypsy moth. The model will be developed into a form with documentation that can be easily used by gypsy moth managers and will be made available to them and other interested parties. Results of the work will be published in appropriate journals.

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COOPERATORS:

Name	Affiliation (Office or Dept.)	Phone, E-mail, Fax
Win McLane	USDA-APHIS, Otis, MS	508-564-9303 Fax 508 564 4398

COOPERATOR INVOLVEMENT:

Name	Role	Time Commitment
Win McLane	Provide gypsy moth eggs	Two hours per month

JUSTIFICATION: Many millions of dollars have been spent on the gypsy moth since its first outbreak in 1889. Fortunately, *Entomophaga maimaiga*, a fungus pathogen, now usually controls the gypsy moth in the generally infested areas. But the fungus has at least partially decoupled the usual indicator of future gypsy moth defoliation, pre-season egg mass counts, from actual defoliation. Ironically, the success of the fungus has made it more difficult to accurately predict future gypsy moth outbreak severity and thus complicates the planning for future control efforts. This can lead to unnecessary control or lack of control where it is really needed. A successful completion of this project will provide information to forest managers as to when and where *E. maimaiga* will control the insect. This will lead to more targeted, economical control efforts.

URGENCY: Because of the sudden, conspicuous appearance of *E. maimaiga* in North America in 1989, there has not been enough time to study population effects. This has lead to a decreased ability to plan control procedures. Unless a better understanding occurs, uneconomical control programs will be carried out that can cause environmental and political problems. The project is urgent because economic savings will occur as soon as results are implemented.

NATIONAL FHP TECHNOLOGY DEVELOPMENT PRIORITY: Priority 1.

TECHNICAL COMMITTEE DEVELOPMENT PRIORITY: Priority 7.

SCOPE OF APPLICATION: Results will be applicable throughout the Northeastern United States and Southeastern Canada, and should be useful indefinitely.

RESEARCH BASIS: Some progress has been made toward predicting the future impact of *E. maimaiga*. The number of resting spores in the soil probably has a large impact on how effectively *E. maimaiga* can control gypsy moths. Li et al. (1988) and Hajek and Wheeler (1994) have devised means for separating resting spores from soil so they can be directly counted. But the viability of spores cannot be determined this way, and resting spores of related species are morphologically indistinguishable from those of *E. maimaiga*. Weseloh (submitted) bioassayed moist soil samples in Petri dishes by exposing them to gypsy moth larvae for 24 hrs. It was possible to show that soils collected in sites that had been defoliated most recently had more spores than other areas. These results confirm that the bioassay procedure gives reasonable results.

Resting spores only germinate when the forest floor has been damp for at least a day (Weseloh and Andreadis 1992). Secondary conidia are only produced and can only survive if humidity is close to saturation (Hajek, et al. 1990). Infection of exposed caterpillars in forests is also closely correlated with rainfall (Weseloh and Andreadis 1992). Computer models based on temperature, humidity, and rainfall records clearly show how timing of gypsy moth infection depends on weather (Hajek et al 1993, Weseloh et al 1993).

The model described by Weseloh et al (1993) and subsequently modified (Weseloh 1999) deals with infection of gypsy moth larvae by resting spores. Temperature and rainfall records drive the fungus model. A given number of gypsy moth larvae are assumed to hatch over a specified period of time. Larvae can become infected with fungus as neonates when they crawl over the forest litter as they disperse. Instars 1 (after dispersal) through 3 stay on the leaves of trees day and night, and are not very likely to be infected by germinating resting spores (Weseloh and Andreadis 1992). Gypsy moths develop according to a degree-day model as determined by daily maximum-minimum temperature records (10 ^{o}C threshold), and after 170 degree-days they reach the 4th instar. At this point they again became more vulnerable to being infected by germinating resting spores, because large larvae generally rest in forest litter or on tree trunks during the day, feeding only at night (Leonard 1970). Weseloh (1999) used data obtained by exposing tethered larvae in the litter to determine a linear relationship between 5-day running totals of rainfall and probability of infection of larvae. This relationship was used in the model to infect larvae *via* resting spores. Fungus in infected sub-cohorts of larvae developed by a degree-day model with a 10 ^{o}C threshold, and after 80 degree-days fungal development was complete and larvae died. The model was quite successful at reproducing actual infection rates at the location where the relationship was measured, but the regression equation had to be multiplied by a site-specific parameter to fit rates at other sites. This is probably due to differences in resting spore load in the soil at different sites (Weseloh 1999), and will be addressed in this project.

The knowledge so far obtained explains part of the dynamic interactions between pathogen and host. Some of the known interactions cannot easily be used for prediction because they are driven by daily weather information. However, resting spore load and gypsy moth abundance can be measured in advance and will have a predictable impact on the pest. In fact, *E. maimaiga* has caused substantial mortality since 1989 even though weather conditions in some of the years have been unfavorable. This is most likely due to heavy resting spore loads in the soil (Weseloh 1998). Only in 1999, when a severe drought occurred, did the pathogen falter.

METHODS: In each year of this project, 10 separate forested sites will be chosen in the generally infested area of the Northeastern United States where the gypsy moth and fungus are abundant. To determine the number of overwintering fungus resting spores at each site, soil samples from under the litter layer will be taken from the base of 10 oak trees in February of each year. Measured amounts of these soils will be moistened and held in the laboratory for 10 days in 2.8 x 14.5 cm diam Petri dishes. Second instar gypsy moth larvae will be exposed to these soil samples for 24 hours and reared individually to determine how many are infected with the fungus. In each plot, automated rain gauges and temperature and humidity data loggers will monitor weather conditions from before caterpillars hatch to pupation. Gypsy moth population density will be sampled by making preseason egg mass counts in five 5 x 5 m^2 (0.025 ha) subplots in each site, by doing weekly counts of numbers of caterpillars on 20 cm branch terminals of favored food plants (mainly oaks) while larvae are 3rd instar or smaller, and by making weekly counts of caterpillars under twenty-five 20 x 20 cm burlap bands stapled to favored trees while caterpillars are 4th instars and larger. In addition, weekly collections of up to 100 larvae will be made while caterpillars are present. The amount of time needed to collect these larvae will be recorded and used as another estimate of gypsy moth population density. The collected larvae will be reared individually in the laboratory on artificial diet to determine weekly frequency of fungus infection in each plot. In addition to infection by resting spores, gypsy moths are also infected *via* short-lived secondary conidia produced by infected caterpillars. To obtain information about the incidence of infection of gypsy moths by these secondary conidia, laboratory-reared gypsy moths of the same size as forest larvae will be marked by placing a black dot on their back using a felt-tipped marker. Preliminary results show that these marks do not harm larvae. Ten of these larvae will be placed on a 20 cm terminal branch of an oak tree or other favored food plant and left for 24 hours. Tangle-trap will be placed in a band around the base of the branch to prevent larvae from escaping. Larvae will be exposed on 10 such branches in each plot. After exposure, larvae will be reared in the laboratory to determine disease incidence. Attempts will be made to exposure larvae at least 2 times per week in each plot.

The field results from the first year of the study will provide useful information that can be used to refine the computer model. Of particular interest will be to correlate gypsy moth density with infection rates due to secondary conidia and resting spore load in the soil with infection of forest larvae. Currently, Weseloh is obtaining laboratory information on the production of secondary conidia by infected larvae of different sizes and under different humidity conditions. These data will also be integrated into the model after the first field season. During the second year, the same kinds of data will be collected from 10 forest plots, but these plots will not necessarily be the same ones as used during the first year. The data collected during the second season will be compared to outputs of the refined model in order to validate it.

Once validated, the model will be documented and made available to potential users through publications and the Internet. Results will be written up and submitted for publication in scientific journals.

MEASURES OF SUCCESS:

Standard of Success: Success of this project will, in the short-term, be measured by how well the computer model has been validated. In the long-term, success will be measured by the degree to which gypsy moth populations can be predicted and unnecessary control prevented.

Expected Outcomes: It is expected that further refinements of the model will improve performance so that rigorous validation is possible. Having in hand a tool that will allow the prediction of gypsy moth population behavior will enable the long-term goal to be met.

Implementation of Products/methods: Documentation and model will be made available on the Internet. Documentation will be distributed through in-house publications, and research results will be published in scientific journals.

PRODUCTS AND DUE DATES: January, 2002—The computer model of fungus activity will be refined to incorporate data from the 2001 field season.
October 2002—The computer model will be validated using data from the 2002 field season.

PUBLICATIONS: Results of the work will be reported in scientific journals.

TECHNOLOGY TRANSFER: The model will be adapted for general use and made available through the Internet. Knowledge about the availability of the model will be made through bulletins and announcements by the Connecticut Agricultural Experiment Station and Forest Service.

LONG-TERM BUDGET REQUEST: (STDP funds to pay salary of 1 summer worker per year, weather instruments year 1, supplies, and state car rental both years. Other source funding used to pay ½ salary of permanent research aid both years.)

	Item	Requested FHP STDP Funding	Other-Source Funding	Source
FIRST YEAR				
Administration	Salary	$2100.00	$14200.00	Conn. Agr. Exp. Station
	Overhead	$620.00	$5900.00	Conn. Agr. Exp. Station
	Travel	$1200.00	0.00	
Procurements	Contracting	0.00	0.00	
	Equipment	$5500.00	0.00	
	Supplies	$600.00	0.00	
Year Totals		$10020.00	$20100.00	
SECOND YEAR				
Administration	Salary	$2200.00	$14500.00	Conn. Agr. Exp. Station
	Overhead	$660.00	$6200.00	Conn. Agr. Exp. Station
	Travel	$1200.00	0.00	
Procurements	Contracting	0.00	0.00	
	Equipment	0.00	0.00	
	Supplies	$600.00	0.00	
Year Totals		$4660.00	$20700.00	
Project Totals		$14680.00	$40800.00	

BENEFIT AND COST:

STDP PRODUCTION FUNCTION

PROJECT NUMBER: NA-2001-xx

PROJECT COST:

Year	0	1	Total
STDP request	$10,020	$4,660	$14,680
Other	$20,100	$20,700	$40,800
Total	**$30,120**	**$25,360**	**$55,480**

PROJECT OBJECTIVES:
The objective of this project is to refine and validate a previously developed computer model of the gypsy moth pathogenic fungus, *Entomophaga maimaiga,* to develop the validated model as a tool to determine the susceptibility of newly infested or uninfested areas to damage by the gypsy moth, and predict future interactions between the pathogen and host in the generally-infested areas. A realistic model will make it possible to accurately determine which areas where gypsy moths are abundant will likely be controlled by the fungus. The benefit of the project used in the economic analysis is to decrease the use of pesticide applications for gypsy moth control through a better understanding of the pest's population dynamics as affected by the pathogen. Other benefits include reducing anxiety of the general public and lowering the level of pesticides in the environment.

ASSUMPTIONS:

- Economic benefits will begin 3 years in the future and continue indefinitely, but for this analysis will go to 25 years into the future.
- Spraying that can be avoided through using the result of this proposal is 25% of that which would occur without this information.
- Without this project, an average of 100,000 acres/year will be sprayed for the gypsy moth in North America.

BACKGROUND DATA:

- Cost of spraying per acre is $5.00.

EXPENDITURE & OUTPUT VALUES (EOV) WITHOUT PROJECT:
EOV Without Project = (100,000 acres) * ($5) * (25 years) = $12,500,000 = discounted to **$8,123,482**

EXPENDITURE & OUTPUT VALUES (EOV) WITH PROJECT:
EOV With Project = (100,000 acres) * ($5) * (3 years) + (75,000 acres) * ($5) * (22 years) = $9,750,000 = discounted to **$6,453,373**

BENEFIT (CHANGE IN EOV) ATTRIBUTABLE TO PROJECT:
Benefit Attributable to Project = without project – with project = $8,123,482-$6,453,373 = **$1,670,109**

BENEFIT/COST RATIO:
Benefit/Cost Ratio = $1,670,109/$54,505 = **30.64**

BENEFIT ATTRIBUTABE TO STDP:
Benefit attributable to STDP Funds = 30.64 * $14,502 discounted STDP cost = **$444,334**

PNV OF PROJECT:
PNV of Project = $1,670,109 - $54,505 discounted total cost = **$1,615,604**

PNV OF STDP:
PNV of STDP = $444,334 - $14,502 = **$429,832**

LITURATURE, CITATIONS, ATTACHMENTS, etc.:

References to Project Description

Hajek, A. E., and M. M. Wheeler. 1994. Application of techniques for quantification of soil-borne entomophthoralean resting spores. J. Invert. Path. 64: 71-73.

Hajek, A. E., R. I. Carruthers, and R. S. Soper. 1990. Temperature and moisture relations of sporulation and germination by *Entomophaga maimaiga* (Zygomycetes: Entomophthoraceae), a fungal pathogen of *Lymantria dispar* (Lepidoptera: Lymantriidae). Environ. Entomol. 19: 85-90.

Hajek, A. E., T. S. Larkin, R. I. Corruthers, and R. S. Soper. 1993. Modeling the dynamics of *Entomophaga maimaiga* (Zygomycetes: Entomophthorales) epizootics in gypsy moth (Lepidopera: Lymantriidae) populations. Environ. Entomol. 22: 1172-1187.

Leonard, D. E. 1970. Feeding rhythm in larvae of the gypsy moth. J. Econ. Entomol. 63: 1455-1457.

Leibhold, A. M., J. A. Halverson and G. A. Elmes. 1992. Gypsy moth invasion in North America: A quantitative analysis. Journal of Biogeography 19: 513-520.

Li, Z., R. S. Soper, and A. E. Hajek. 1988. A method for recovering resting spores of Entomophthorales (Zygomycetes) from soil. J. Invert. Path. 52: 18-26.

Weseloh, R. M. 1998. Possibility for recent origin of the gypsy moth (Lepidoptera: Lymantriidae) fungal pathogen *Entomophaga maimaiga* (Zygomycetes: Entomophthorales) in North America. Environ. Entomol. 27: 171-177.

Weseloh, R. M. 1999. *Entomophaga maimaiga* (Zygomycetes: Entomophthorales) resting spores and biological control of the gypsy moth (Lepidoptera: Lymantriidae). Environ. Entomol. 28: 1162-1171.

Weseloh, R. M., and T. G. Andreadis. 1992. Mechanisms of transmission of the gypsy moth (Lepidoptera: Lymantriidae) fungus, *Entomophaga maimaiga* (Entomphthorales: Entomophthoraceae) and effects of site conditions on its prevalence. Environ. Entomol. 21: 901-906.

Weseloh, R. M., T. G. Andreadis, and D. W. Onstad. 1993. Modeling the influence of rainfall and temperature on the phenology of infection of gypsy moth, *Lymantria dispar*, larvae by the fungus *Entomophaga maimaiga*. Biol. Control. 3: 311-318.