Utilization of life table data in a model prediction for population dynamics of Gypsy moth (*Lymantria dispar*) – A case study

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Abstract
Gypsy moth is considered as a severe pest in some parts of the world. And there are some important aspects of the environment that might influence population growth and realized life history of the gypsy moth. These factors were incorporated in a model to predict population dynamics of gypsy moth for a fifty year period. Life table data were used to construct a life cycle graph and a projection matrix for gypsy moth. Trajectory summary indicated time to time fluctuations in the gypsy moth abundances probably giving an idea about outbreaks of the pest which are said to be destructive. As gypsy moth is considered as a severe pest this type of predictions will be very informative to people who are interested in pest management and can start to apply control strategies before population reaches to outbreak densities.

Key words: gypsy moth, population dynamics, pest

1. Introduction

1.1 Natural History and Life History

Gypsy moth is distributed in some parts of Asia, Europe eastern North America and Canada and found to inhabit deciduous oak forests (Hoch,G. *etal*, 2001, Weseloh, R.M., 1997, Elkinton, J.S. and Liebhold, A.M., 1990). In the US, gypsy moths are known to feed on hundreds of different tree species (e.g. oak, alder, birch) (Davidson et al., 2001). Some tree species, such as the oak in Eastern US, are preferred by gypsy moth. (Davidson et al., 2001). Stands with a large component of highly preferred species (e.g. oaks) are likely to be defoliated (Davidson et al., 2001) by the moth. Larvae are herbivorous. Adults do not feed.

Egg masses can be found on the tree stems and branches, rocks and fallen branches on the forest floors or on the forest edges and on man-made objects. (Elkinton, J.S., and Liebhold, A.M., 1990). There are some important aspects of the environment that might influence population growth and realized life history of the gypsy moth. Average temperature especially during the winter season (November) was confirmed as a factor which positively influences gypsy moth gradation. Contrary to this, above average precipitation which periodically occurs in the winter-spring period (March) significantly influences a decline in the population density and confirmed as a negative factor. According to similarities of periodical fluctuations in some monthly climate data series and gypsy moth outbreaks, weather affects the survival and development of the gypsy moth population during its various life stages. Temperatures and precipitation in years are significantly related to the gypsy moth population cycle. (Pemek, M. *etal* , 2008). Major sources of mortality include small mammal predators, avian predators and invertebrate predators (ground beetles [Family-Carabidae] and ants [Family-Formicidae]. Parasitoids can be egg parasitoids, larval parasitoids or pupal parasitoids. The major pathogen is considered to be gypsy moth nuclear polyhedrosis virus (NPV) (Elkinton, J.S., and Liebhold, A.M., 1990). Age at maturity, it takes like nearly a year to get into the reproductive stage from the egg stage. (Pemek, M. *etal* , 2008). So gypsy moth life cycle is said to be an annual one. High density populations of gypsy moth mature more rapidly and attain the adult stage 2-3 weeks ahead of adjacent low-density populations. (Elkinton, J.S., and Liebhold, A.M., 1990). Number of eggs per egg mass is affected by the healthiness of the population. It varies from 100-1200 per egg mass. Life table data were difficult to find for gypsy moth except for very few publications even in those all life stages are not covered.

1.2 Population ecology and dynamics

The Gypsy moth is very difficult to sample. Densities are most frequently expressed as numbers per unit area of ground rather than per unit of foliage. (Elkinton, J.S., and Liebhold, A.M., 1990) Density can be given by number of egg masses/ha. Population density of gypsy moths varies widely over a period of years. According to Liebhold et al. (2000), gypsy moth population densities vary by several orders of magnitude, often reaching epidemic densities that have spectacular effects (i.e., total defoliation of host trees). It is common for gypsy moth populations to persist for many years at densities so low that it is difficult to detect any life stages (Liebhold et al., 2000). Population densities occasionally tend to increase quickly over several generations, often to defoliating levels (5000 egg masses/ha) (Liebhold et al., 2000). The timing of outbreaks is irregular and often difficult to predict, although there is some statistical evidence of a ten to eleven year cycle (Liebhold et al., 2000). High-density populations then will persist for few more years (2-3 years) (Liebhold et al., 2000). Various aspects of Gypsy moth dispersal have been investigated. Natural dispersal occurs through wind borne travel of first-instar larvae, which are hairy and also spin silk strands that aid them in "ballooning". Cambell *et al.* (1975) found that, in a sparse population, gypsy moth egg mass density was related to abundance of large larvae only in the immediate vicinity of egg masses. When population sizes are high, late stage larvae that have defoliated trees readily move to others, and in the process orient via perception of polarized light. (as reviewed in Liebhold et al., 1986). When population sizes are low, large larvae may move among adjacent trees (Liebhold *et al*. 1986). Based on changing proportions of larvae in different kinds of resting sites, Campbell *et al*. (1975) suggested that some dispersal occurs just prior to pupation, but little movement takes place before then. Knowledge about natural dispersal of the gypsy moth is still incomplete. Models have included assumptions that may or may not be realistic. (Weseloh, M.R., 1997). Females of the European gypsy moth rarely fly, they lay their eggs very much closer to a place where they pupate (Elkinton, J.S., and Liebhold, A.M., 1990).

Therefore the key issues which are important for my species, will be the effect of environmental stochasticity, catastrophic effect mainly due to temperature effect on eggs and other life stages and demograghic stochasticity which are intrinsic, deterministic factors make impact on various life stages of the insect on their vital rates. So temperature effect on eggs (which is the over wintering stage) and the dispersal of larvae due to wind currents and mortality due to predators, parasitoids and pathogens will be important factors which should be considered and incorporated while modeling.

2. Methods

A model was constructed to predict how this gypsy moth will behave during a 50 year time period with regard to set criteria/aspects. Those set criteria should answer the following questions at the end.

- How does this population will behave in a density dependent way with Scramble competition (logistic, Ricker)
- What kind of fluctuations will it give with the demographic and environmental stochasticity?
- Which stage/stages will mostly affect the overall behavior of the gypsy moth population?
- How the behavior of this population make an impact on the host plants as a major pest?
- How do I address on a management strategy for this pest?

RAMAS Metapop (Version 5.0) was used to construct the model with set criteria determined in reference to natural history, life history and population dynamics information obtained for the gypsy moth. I used life table data (Table.1) to construct the life cycle graph for gypsy moth (Fig.1). Life table data were then fed to RAMAS Metapop (Version 5.0) to get the further results. I set density dependence to scramble because gypsy moth is a pest so the larvae may experience resource limitations when overcrowded. When setting demographic stochasticity, I used time series data for No. of egg masses/ha-1 (Liebhold et al., 2000) to calculate corresponding λ values and thereby calculate average λ and standard deviation for λ. (Table3). Then I used that standard deviation to set standard deviation matrix. Environmental Stochasticity, was set to lognormal and set default values. For Catastrophes; Temperature, "Affects" was set as abundances and stage specific multipliers were set as 1.0 for egg stages and 0.5 for all other stages as egg stages are mostly affected by the temperatures. Initial abundance was set to 100000. Carrying capacity K was set to 300000. Then I ran the model for 50 time steps and 100 iterations.

3. Analysis and Results

Growth rate (λ) was given as 1.0922 (approximate) by the model which indicates that the population tends to grow with the time.

4. Discussion

Trajectory summary (Fig.2), indicates time to time fluctuations in the gypsy moth abundances probably giving an idea about outbreaks of the pest which are said to be destructive according to Liebhold, et al., 2000. This was actually the trajectory I was expecting to get when I set demographic and environmental stochasticity and also the temperature effects on eggs as catastrophes. But I was not able to insert dispersal effects here which must have been an important aspect on the population dynamics of gypsy moth. Average stage abundances (Fig.3) gives a similar sort of fluctuations as trajectory summary, as it should be. Stable age/stage structure (Fig.6) indicates that stability is high in the initial stages of the life cycle of the gypsy moth and highest in the egg stage. Sensitivity analysis (Table4) gives an idea about which stage/stages are

more sensitive in the gypsy moth life cycle. So according to Table4, if control/management strategies are to be implemented egg and the initial larval stages will be the most effective stages those should be applied.
As gypsy moth is considered as a severe pest this type of predictions will be very informative to people who are interested in pest management and can start to apply control strategies before population reaches to outbreak densities. So at the end, most of my set goals were achieved for this model. But I think it was better if I could have addressed few populations instead of taking one, so in which I could have inserted larval dispersal as well. But due to lack of available data it was not possible in this case.

Table1: Gypsy moth (*Lymantria dispar* L.) life table in New England (modified from Campbell 1981) (Source: www.gypsymoth.ento.vt.edu)

Stage	Mortality factor	Initial no. of insects	No. of deaths	Mortality (d)	Survival (s)	k-value [-ln(s)]
Egg	Predation, etc.	450.0	67.5	0.150	0.850	0.1625
Egg	Parasites	382.5	67.5	0.176	0.824	0.1942
Larvae I-III	Dispersion, etc.	315.0	157.5	0.500	0.500	0.6932
Larvae IV-VI	Predation, etc.	157.5	118.1	0.750	0.250	1.3857
Larvae IV-VI	Disease	39.4	7.9	0.201	0.799	0.2238
Larvae IV-VI	Parasites	31.5	7.9	0.251	0.749	0.2887
Prepupae	Desiccation, etc.	23.6	0.7	0.030	0.970	0.0301
Pupae	Predation	22.9	4.6	0.201	0.799	0.2242
Pupae	Other	18.3	2.3	0.126	0.874	0.1343
Adults	Sex ratio	16.0	5.6	0.350	0.650	0.4308
Adult females		10.4				
TOTAL			439.6	97.69	0.0231	3.7674

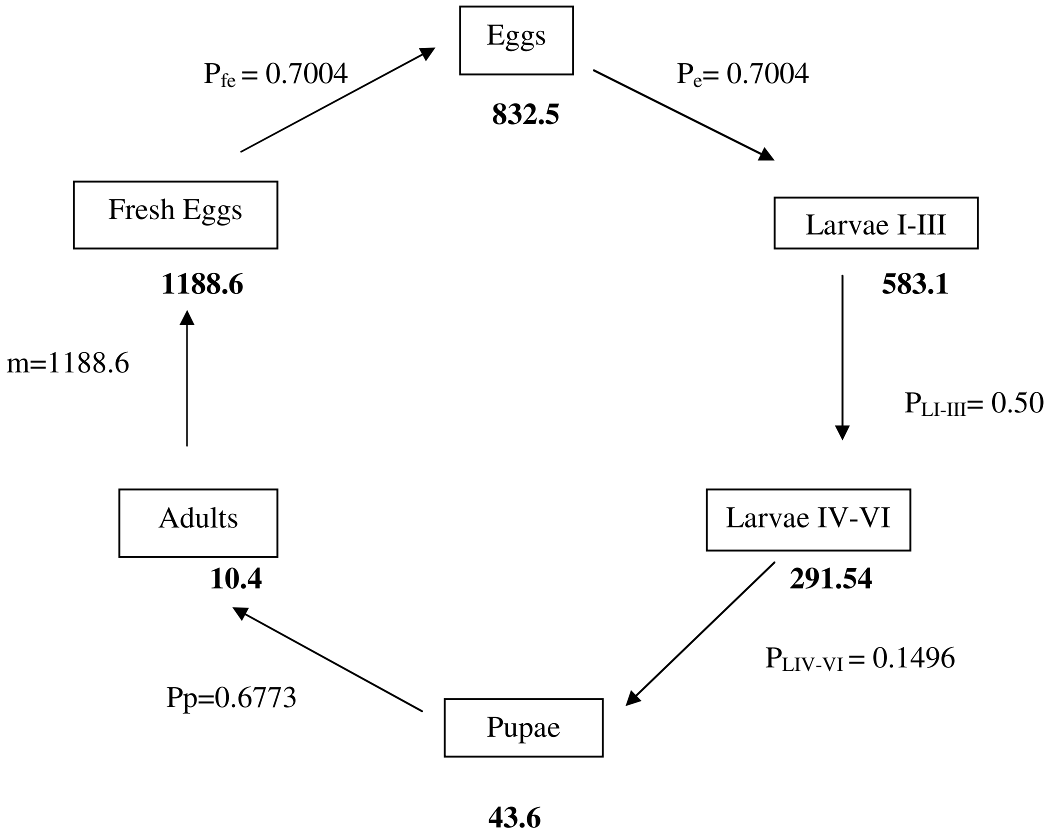

Fig.1:Life cycle graph for Gypsy moth – *Lymantria dispar*

(P values indicate the survival rates and m value indicates the fecundity. Numbers (bold) indicate the actual numbers per a stage derived from the life table data (Table1). Ex. 832.5 eggs per an egg mass laid by one female. This is an annual life cycle. Adults die after they mate. Therefore no survival rate for adult female here).

Table2: Projection matrix constructed using Life table data (Table1)

	Eggs	**Larvae I-III**	**Larvae IV-VI**	**Pupae**	**Adults**	**Fresh Eggs**
Eggs	0.7004	0.5000	0.1496	0.6773	0.0000	0.7004
Larvae I-III	0.7004	0.0000	0.0000	0.0000	0.0000	0.0000
Larvae IV-VI	0.0000	0.5000	0.0000	0.0000	0.0000	0.0000
Pupae	0.0000	0.0000	0.1496	0.0000	0.0000	0.0000
Adults	0.0000	0.0000	0.0000	0.6773	0.0000	0.0000
Fresh Eggs	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table3: Time series data for egg masses, calculated λ values and standard deviation for λ

Year	No. of egg masses/ha-1	λ
1910	8,00	
1911	12,000	1.500
1912	11,500	0.958
1913	11,500	0.956
1914	10,500	0.954
1915	10,000	0.952
1916	9,000	0.900
1917	8,500	0.940
1918	8,000	0.940
1919	10,500	1.315
1920	7,000	0.700
1921	7,500	1.070
1922	7,750	1.030
1923	3,000	0.387
1924	200	0.060
1925	250	1.250
1926	350	1.400
1927	650	1.860
1928	750	1.540
1929	1,000	1.330
1930	200	0.200
	Average	1.0121
	Standard deviation	0.443

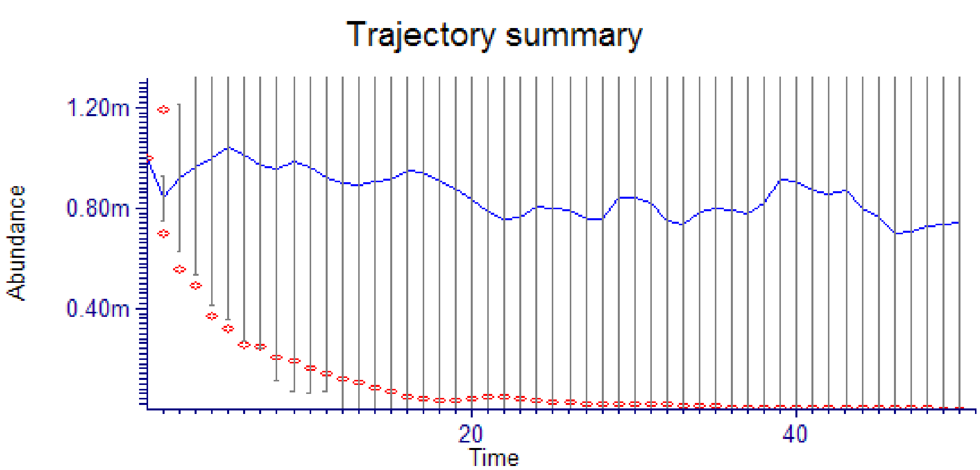

Fig.2: Trajectory summary for Gypsy moth abundance for 50 year time period

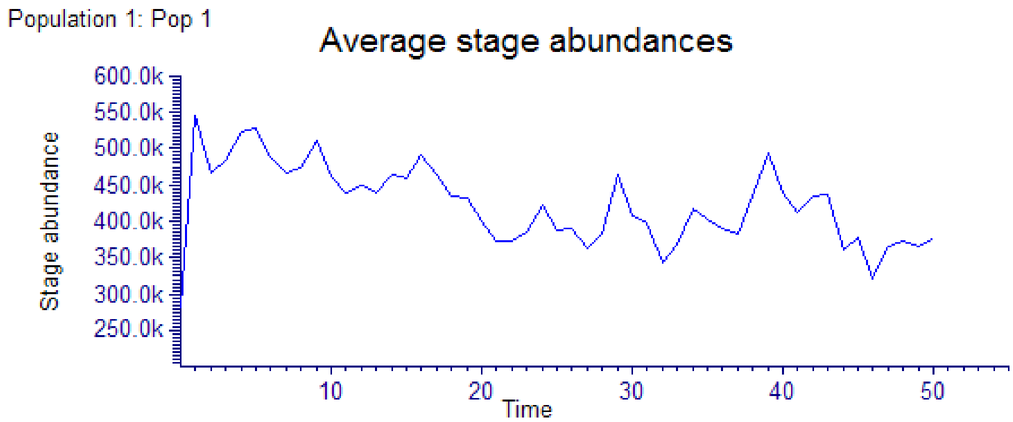

Fig.3: Average stage abundances for Gypsy moth for 50 year time period

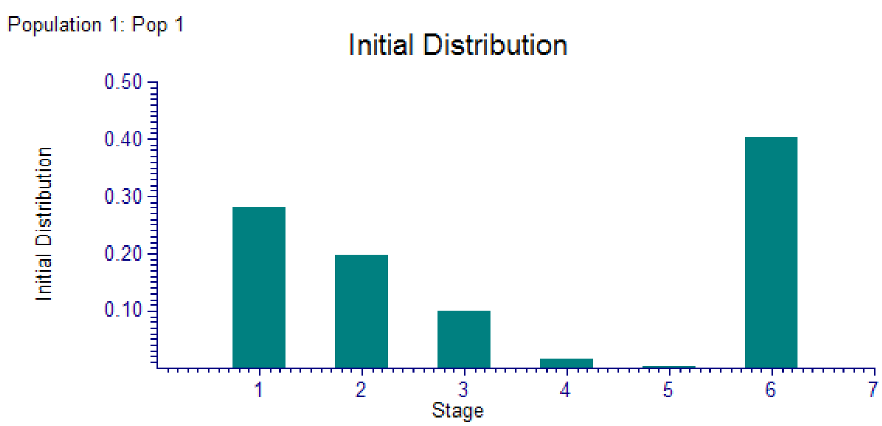

Fig.4: Initial distribution of the life stages for Gypsy moth

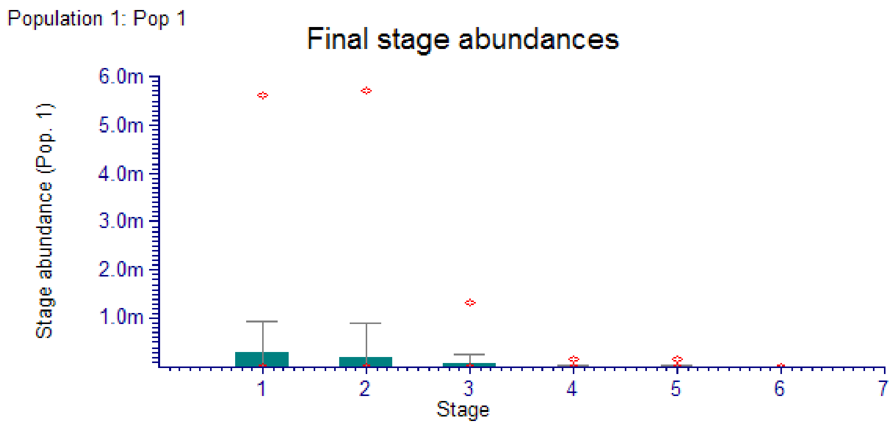

Fig.5: Final stage abundances of the life stages for Gypsy moth

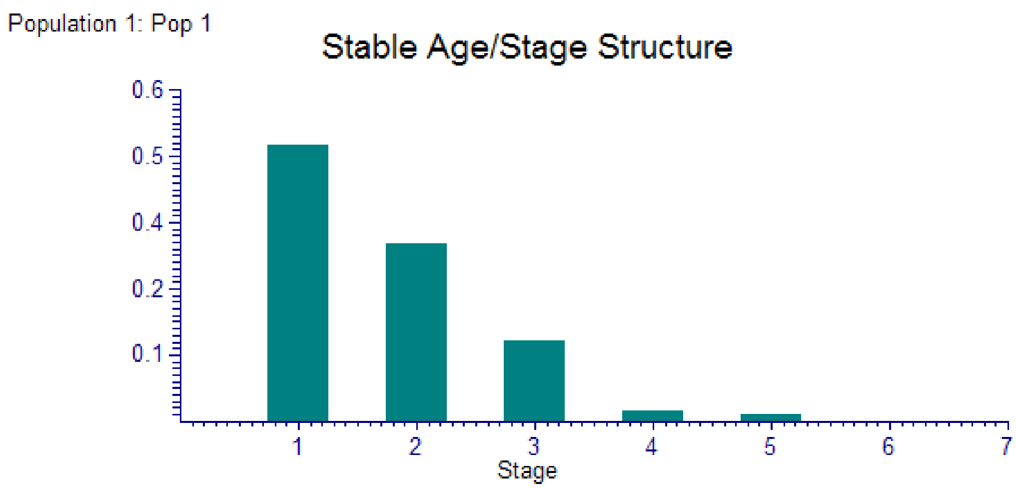

Fig.6: Stable age/stage structure for Gypsy moth

Table4: Sensitivity analysis for gypsy moth life stages

	Eggs	**Larvae I-III**	**Larvae IV-VI**	**Pupae**	**Adults**	**Fresh eggs**
Eggs	0.6902	0.4426	0.2026	0.0278	0.0172	0.0000
Larvae I-III	0.3861	0.2476	0.1133	0.0155	0.0096	0.0000
Larvae IV-VI	0.1532	0.0982	0.0450	0.0062	0.0038	0.0000
Pupae	0.4280	0.2745	0.1257	0.0172	0.0107	0.0000
Adults	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Fresh eggs	0.4426	0.2838	0.1299	0.0178	0.0110	0.0000

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