Garry oak ecosystems recovery team

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Bibliographic summary of the Ecology and Management of Invasive Species:

Lymantria dispar L. (Lepidoptera, Lymantriidae) Gypsy Moth

Prepared by

Marian McCoy, Melica Environmental, Victoria, BC

for the Garry Oak Ecosystems Recovery Team

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Andreeva, E.M., V.I. Ponomarev, and A.V. Shatalin. 2008. Morphological, physiological, and trophic characteristics of the Gypsy Moth *Lymantria dispar* L. (Lepidoptera, Lymantriidae) larvae in relation to the hydrothermal conditions and the population density. Entomological Review, Vol. 88, Number 7, pp. 755-763.

> Authors' abstract: Analysis of changes of morphometric and trophic characteristics depending on the rainfall and temperature was performed in two populations of the Gypsy Moth larvae during depression and outbreak. The data obtained were analyzed from points of view of existing hypotheses concerning the reasons of outbreaks. The narrowing of the norm of reaction of a population before outbreak explains the data obtained.

Barbehenn, R.V., A. Jaros, G. Lee, C. Mozola, Q. Weir, and J-P. Salminen. 2009. Tree resistance to *Lymantria dispar* caterpillars: importance and limitations of foliar tannin composition. Oecologia, Vol. 159, Number 4, pp. 777-788.

> Authors' abstract: The ability of foliar tannins to increase plant resistance to herbivores is potentially determined by the composition of the tannins; hydrolyzable tannins are much more active as prooxidants in the guts of caterpillars than are condensed tannins. By manipulating the tannin compositions of two contrasting tree species, this work examined: (1) whether increased levels of hydrolyzable tannins increase the resistance of red oak (Quercus rubra L.), a tree with low resistance that produces mainly condensed tannins, and (2) whether increased levels of condensed tannins decrease the resistance of sugar maple (Acer saccharum Marsh.), a tree with relatively high resistance that produces high levels of hydrolyzable tannins. As expected, when *Lymantria dispar* L. caterpillars ingested oak leaves coated with hydrolyzable tannins, levels of hydrolyzable tannin oxidation increased in their midgut contents. However, increased tannin oxidation had no significant impact on oxidative stress in the surrounding midgut tissues. Although growth efficiencies were decreased by hydrolyzable tannins, growth rates remained unchanged, suggesting that additional hydrolyzable tannins are not sufficient to increase the resistance of oak. In larvae on condensed tannin-coated maple, no antioxidant effects were observed in the midgut, and levels of tannin oxidation remained high. Consequently, neither oxidative stress in midgut tissues nor larval performance were significantly affected by high levels of condensed tannins. Post hoc comparisons of physiological mechanisms related to tree resistance revealed that maple produced not only higher levels of oxidative stress in the midgut lumen and midgut tissues of *L. dispar*, but also decreased protein utilization efficiency compared with oak. Our results suggest that high levels of hydrolyzable tannins are important for producing oxidative stress, but increased tree resistance to caterpillars may require additional factors, such as those that produce nutritional stress.

Barbosa, P., and J. Greenblatt. 1979. Suitability, Digestibility and Assimilation of Various Host Plants of the Gypsy Moth *Lymatria dispar* L. Oecologia (Berl.) 43, 111-119.

> Authors' abstract: The development and survival of Gypsy Moth (*Lymatria dispar*) larvae is strongly influenced by the host plant upon which they feed. The most rapid development and largest pupae were produced from Grey Birch fed larvae. Beech and Maple-fed larvae produced the smallest pupae while Maple-fed larvae exhibited prolonged development. White and Red oak-fed larvae exhibited development and pupal weights intermediate between the above two groups. The approximate digestibility (AD) and efficiencies of conversion of food (ECD and ECI) were generally highest among grey birch-fed individuals. The utilization of the relatively closely related Oak species, as reflect in AD and ECD values, differed. Leaves were examined for 14 elements. The content of each element varied among host plant species and over time. For example, nitrogen levels were highest in grey-birch and dropped over time in all host plants.

Bigsby, K.M., P.C., Tobin, and E.O. Sills. 2011. Anthropogenic drivers of Gypsy Moth spread. Biological Invasions, Volume 13, Number 9, pp. 2077-2090.

Author's abstract: The Gypsy Moth, *Lymantria dispar* (L.), is a polyphagous defoliator introduced to Medford, Massachusetts in 1869. It has spread to over 860,000 km^2 in North America, but this still only represents ¼ of its susceptible host range in the United States. To delay defoliation in the remaining susceptible host range, the government maintains a barrier zone and a quarantine, reflecting a presumption that anthropogenic factors are important in the spread of Gypsy Moth. We develop a model framework that relates these factors along with biophysical characteristics to a county's susceptibility to Gypsy Moth invasion. We then compile a dataset for counties within 200 km of the infested area and use trap catch data from 1999 to 2007 to estimate the probability of Gypsy Moth presence. As expected, Gypsy Moth is more likely to be found close to the population front and to traps that recorded moths in the previous year. However, when controlling for these factors, our most robust finding is that the use of wood for home heating and energy is consistently positively correlated with the presence of Gypsy Moth. In contrast, the movement of wood products by industry, which is actively regulated by state and federal governments, is rarely correlated with the presence of Gypsy Moth. This is consistent with effective regulation of the movement of goods by industry, but not by the public. Our findings provide empirical support for the importance and challenge of firewood as a vector for non-native forest insects.

Boulton, T.J., I.S. Otvos, K.L. Halwas, D.A. Rohlfs. 2009. Recovery of nontarget Lepidoptera on Vancouver Island, Canada: One and four years after a Gypsy Moth eradication program. Env Toxicology and Chem, Vol 26, Issue 4, pp. 738-748.

Authors' abstract: The Gypsy Moth (*Lymantria dispar*) is a destructive defoliator that is not established in British Columbia, Canada, because of successful eradication programs involving the microbial insecticide *Bacillus thuringiensis* var. *kurstaki* (Btk). In 1999, three aerial applications of Btk were made over two areas, totaling 12,805 ha, on southern Vancouver Island, Canada. The impacts of these Btk applications on nontarget Lepidoptera were studied from 1999 to 2004 on Garry oak (*Quercus garryana*) and common snowberry (*Symphoricarpos albus*). In 1999, Lepidopteran larvae were collected from *S. albus* foliage at 24 urban parks and from *Q. garryana* foliage at 28 oak-dominated habitats. The initial impacts (i.e., 1999 data) were published previously, and the present paper is a continuation of the same study. We tested two hypotheses: Reductions of nontarget Lepidoptera would be more severe at 12 to 13 months postspray than at one to two months postspray, and recovery would be significant, though not necessarily complete, at four years postspray. The total number of nontarget Lepidoptera on *S. albus* and *Q. garryana* was significantly reduced in the treatment sites in each year of the study: the reduction was greatest in 2000. Relative to the reference sites, each of 11 species that were initially reduced by the Btk applications showed an increase in the treatment sites between 2000 and 2003, by which time only four species remained significantly reduced in the treatment sites. The uncommon species were significantly reduced in 1999 and 2000 but not in 2003, indicating that some recovery had occurred. Limitations and economic implications of the present study are discussed.

Elkinton, J.S., W.M. Healy, J.P. Buonaccorsi, G.H. Boettner, A.M. Hazzard, H.R. Smith, and A.M. Liebhold. 1996. Interactions among Gypsy Moths, White-footed Mice, and Acorns. Ecology 77(8), pp. 2332-2342.

Authors' abstract: Low-density populations of Gypsy Moth, *Lymantria dispar*, were studied over a 10-year period in Massachusetts. Increases in Gypsy Moth density were associated with declines in density of the white-footed mouse, *Peromyscus leucopus*, a principal predator. Furthermore, changes in density of *P. leucopus* populations were positively correlated with the density of acorn crops, a dominant winter food source for these mice. To demonstrate these effects we used a novel bootstrap regression method that adjusts for spatial and temporal autocorrelation in the time series data. The findings are compatible with a dual equilibrium model of Gypsy Moth population dynamics, in which low densities are regulated by mice and high densities are regulated by other factors, notably a virus disease.

Gould, J. R., J. S. Elkinton, and W. E. Wallner. 1990. Density-Depending Suppression of Experimentally created Gypsy Moth, *Lymantria dispar* (Lepidoptera: Lymantriidae), Populations by Natural Enemies. J of Animal Ecology. Vol. 59, pp. 213-233.

Authors' abstract: Experimental manipulations of densities of Gypsy Moths revealed a strong, positive spatially density-dependent reduction in population size, a response not evident in past studies of natural populations in North America. Positive density-dependent mortality occurred during the early and mid-larval stages and was primarily due to *Compsilura concinnata*, a polyphagous parasitoid. The oviposition rate of *Parasetigena silvestris*, an oligophagous parasitoid of Gypsy Moths, was initially inversely density-dependent but became positively density-dependent during the late larval period. *Phobocampe disparis* showed an inversely density-dependent response, and predation by small mammals on pupae deployed in the litter was lower in plots with higher numbers of pupae. (5) We conclude that if Gypsy Moth population densities fluctuate asynchronously on a spatial scale of a few hectares, the density-dependent responses of *C. concinnata* and *P. silvestris* could suppress the populations to a point where small mammal predation would be able to prevent population increase. This phenomenon may explain the apparent stability of Gypsy Moth populations on a region-wide basis for the many years between outbreaks.

Gray, D.R. 2010. Hitchhikers on trade routes: A phenology model estimates the probabilities of Gypsy Moth introduction and establishment. Ecol Appl, Vol. 20, pp 2300-2309.

Authors' abstract: As global trade increases so too does the probability of introduction of alien species to new locations. Estimating the probability of an alien species introduction and establishment following introduction is a necessary step in risk estimation (probability of an event times the consequences, in the currency of choice, of the event should it occur); risk estimation is a valuable tool for reducing the risk of biological invasion with limited resources. The Asian gypsy moth, *Lymantria dispar* (L.), is a pest species whose consequence of introduction and establishment in North America and New Zealand warrants over US$2 million per year in surveillance expenditure. This work describes the development of a two-dimensional phenology model (GLS-2d) that simulates insect development from source to destination and estimates: (1) the probability of introduction from the proportion of the source population that would achieve the next developmental stage at the destination and (2) the probability of establishment from the proportion of the introduced population that survives until a stable life cycle is reached at the destination. The effect of shipping schedule on the probabilities of introduction and establishment was examined by varying the departure date from 1 January to 25 December by weekly increments. The effect of port efficiency was examined by varying the length of time that invasion vectors (shipping containers and ship) were available for infection. The application of GLS-2d is demonstrated using three common marine trade routes (to Auckland, New Zealand, from Kobe, Japan, and to Vancouver, Canada, from Kobe and from Vladivostok, Russia).

Grove, M.J., and K. Hoover. 2007. Intrastadial developmental resistance of third instar Gypsy Moths (*Lymantria dispar* L.) to *L. dispar* nucleopolyhedrovirus. Biological Control, Vol. 40, Issue 3, pp. 355-361.

Authors' abstract: Gypsy Moth larvae become increasingly resistant to lethal infection by the *Lymantria dispar* M nucleopolyhedrovirus (LdMNPV) as they age within the fourth instar. Newly molted larvae are most sensitive to infection, mid-instars are least sensitive, and late-instars display intermediate sensitivity. This resistance occurs whether the virus is delivered orally or intrahemocoelically. The present study reveals a nearly identical pattern of resistance in third instar larvae. An LD_{48} dose of polyhedra for newly molted third instars produced 18%, 10%, 8%, 25%, and 24% mortalities in larvae to which virus was orally administered at 12, 24, 48, 72, and 96 hours post-molt (hpm), respectively, which is a 6-fold reduction in mortality between newly molted larvae and mid-instars. An LD_{44} dose of budded virus for newly molted third instars produced 33%, 23%, 17%, 31%, and 31% mortalities when injected into larvae that were 12, 24, 48, 72, and 96 hpm, respectively, which is a 2.6-fold reduction in mortality between newly molted larvae and mid-instars, indicating that approximately half of this resistance is midgut-based and half is systemically based. Doubling the viral dose did not overcome developmental resistance whether the virus was delivered orally or intrahemocoelically. In addition, time to death was significantly affected by the time post-molt at which the insect was inoculated with the virus. We suggest that intrastadial developmental resistance may affect both the ecology and management of the Gypsy Moth.

Hajek, A.E. 2001. Larval behavior in *Lymantria dispar* increases risk of fungal infection. Oecologia. Vol. 126, Issue 2, pp. 285-291.

Author's abstract: Late-instar larvae of the forest defoliator *Lymantria dispar* display relatively unusual behavior for Lepidoptera. Late instars move down from the tree canopy and wander and rest in dark locations during daylight hours. When we sampled the area extending from below 3 m and within 200 cm of tree trunks during daylight hours, 71% of *L. dispar* late instar larvae were found at ground level. Providing dark resting locations on the soil surface where there was no litter resulted in rapid location and colonization of these sites by late instar larvae. *L. dispar* larvae were always more prevalent in leaf litter 0-50 cm from tree trunks compared with 50-200 cm away. In an area where the fungal insect pathogen *Entomophaga maimaiga* is established, larvae were caged on tree trunks, in the foliage, or on top of soil during photophase or scotophase to determine in which locations risk of infection was greatest. At both times of day, highest infection levels always occurred on the soil, with least infection among larvae caged in the foliage. Infection levels were greater during photophase than scotophase. When larvae were exposed to soil for shorter periods during daylight hours to mimic wandering, 4.7 and 6.1% became infected after 30- and 60-min exposure intervals respectively, with increasing infection associated with longer exposure times. The high levels of infection by *E. maimaiga* that have been documented in *L. dispar* populations since this pathogen was first found in North America are consistent with the strong litter-dwelling behavior of late-instar *L. dispar* larvae. Rarity of other lepidopteran larvae at ground level could help to explain the host specificity of this pathogen in the field.

Hajizadeh, G., M.R. Kavosi, and E.Moshashaei. 2011. Natural enemies of the Gypsy Moth *Lymantria dispar* (L.) (Lepidoptera: Lymantriidae). Int'l Research J of Agricultural Science and Soil Science. Vol. 1(8), pp. 301-306.

Authors' abstract: The Gypsy Moth, *Lymantria dispar* (L.) (Lepidoptera, Lymantriidae), is a forest pest native to Europe and parts of Asia. It was accidentally introduced from Europe into Massachusetts in 1869. The Gypsy Moth is a highly polyphagous folivore species that feeds on over 300 species of woody plants. Among its most preferred hosts are Oaks and Aspens. The research has conducted with the purpose of gathering natural enemies and pathogenic agents of Gypsy Moth. Natural enemies refer to the predators, parasitoids and pathogens that affect pest insects such as the Gypsy Moth. These natural enemies are important in helping to control Gypsy Moth outbreaks and in keeping populations low in the years between outbreaks. A diverse group of birds, mammals, amphibians, and insect predators feed on Gypsy Moth eggs, caterpillars and pupae. Mice are important predators of Gypsy Moth caterpillars and pupae.

Liebhold, A., J. Elkinton, D. Williams, and R-M. Muzika. 2000. What causes outbreaks of the Gypsy Moth in North America? Popul Ecol, Vol. 41, pp. 257-266.

Authors' abstract: The Gypsy Moth has been present in North America for more than 100 years, and in many of the areas where it has become established outbreaks occur with varying degrees of periodicity. There also exists extensive spatial synchrony in the onset of outbreaks over large geographic regions. Density-dependent mortality clearly limits high-density populations, but there is little evidence for strong regulation of low-density populations. Predation by small mammals appears to be the major source of mortality affecting low-density populations, but because these are generalist predators and Gypsy Moths are a less preferred food item, mammals do not appear to regulate populations in a density-dependent fashion. Instead, predation levels appear to be primarily determined by small mammal abundance, which is in turn closely linked to the production of acorns that are a major source of food for overwintering predator populations. Mast production by host oak trees is typically variable among years, but considerable spatial synchrony in masting exists over large geographic areas. Thus, it appears that the temporal and spatial patterns of mast production may be responsible for the episodic and spatially synchronous behavior of Gypsy Moth outbreaks in North America. This multitrophic relationship among mast, predators, and Gypsy Moths represents a very different explanation of forest insect outbreak dynamics than the more widely applied theories based upon predator-prey cycles or feedbacks with host foliage quality.

Lindroth, R.L., K.K. Kinney, and C.L. Platz. 1993. Responses of Diciduous [sic] Trees to Elevated Atmospheric CO2: Productivity, Phytochemistry, and Insect Performance. Ecology, Vol. 74, pp. 763-777.

Authors' abstract: Although rising levels of atmospheric carbon dioxide are expected to directly affect forest ecosystems, little is known of how specific ecological interactions will be modified. This research evaluated the effects of enriched CO_2 on the productivity and phytochemistry of forest trees and performance of associated insects. Our experimental system consisted of three tree species (quaking aspen [*Populus tremuloides*], red oak [*Quercus rubra*], sugar maple [*Acer saccharum*]) that span a range from fast to slow growing, and two species of leaf—feeding insects (Gypsy Moth [Lymantria dispar] and forest tent caterpillar [*Malacosoma disstria*]). Carbon—nutrient balance theory provided a framework for tests of three hypotheses; in response to enriched CO_2: (1) relative increases in tree growth rates will be greatest for aspen and least for maple, (2) relative decreases in protein and increases in carbon—based compounds will be greatest for aspen and least for maple, and (3) relative reductions in performance will be greatest for insects fed aspen and least for insects fed maple. We grew 1-yr old seedlings for 60 d under ambient (385 ± 5 μL/L) or elevated (642 ± 2 μL/L) CO_2 regimes at the University of Wisconsin Biotron. After 50 d, we conducted feeding trials with penultimate instar Gypsy Moth and forest tent caterpillars. After 60 d, a second set of trees was harvested and partitioned into root, stem, and leaf tissues. We subsequently analyzed leaf material for a variety of compounds known to affect performance of insect herbivores. In terms of actual dry matter production, aspen responded the most to enriched CO_2 atmospheres whereas maple responded the least. Proportional growth increases (relative to ambient plants), however were highest for oak and lest for maple. Effects of elevated CO_2 on biomass allocation patterns differed among the three species; root-to-shoot ratios increased in aspen, decreased in oak, and did not change in maple. Enriched CO_2 altered concentrations of primary and secondary metabolites in leaves, but the magnitude and direction of effects were species—specific. Aspen showed the largest change in storage carbon compounds (starch), whereas maple experienced the largest change in defensive carbon compounds (condensed and hydrolyzable tannins). Consumption rates of insects fed high-CO_2 aspen increased dramatically, but growth rates declined. The two species of insects differed in response to oak and maple grown under enriched CO_2. Gypsy Moths grew better on high-CO_2 oak, whereas forest tent caterpillars were unaffected; tent caterpillars tended to grow less on high-CO_2 maple, whereas Gypsy Moths were unaffected. Changes in insect performance parameters were related to changes in foliar chemistry. Responses of plants and insects agreed with some, but not all, of the predictions of carbon-nutrient balance theory. This study illustrates that tree productivity and chemistry, and the performance of associated insects, will change under CO_2 atmospheres predicted for the next century. Changes in higher level ecological processes, such as community structure and nutrient cycling, are also implicated.

Koenig, W.D., E.L. Walters, and A.M. Liebhold. 2011. Effects of Gypsy Moth Outbreaks on North American Woodlpeckers. The Condor, 113(2), pp. 352-361.

Authors' abstract: We examined the effects of the introduced Gypsy Moth (*Lymantria dispar*) on seven species of North American woodpeckers by matching spatially explicit data on Gypsy Moth outbreaks with data on breeding and wintering populations. In general, we detected modest effects during outbreaks: during the breeding season one species, the Redheaded Woodpecker (*Melanerpes erythrocephalus*), increased over pre-outbreak levels, while during the winter one species, the Yellow-bellied Sapsucker (*Sphyrapicus varius*), increased and one, the Downy Woodpecker (*Picoides pubescens*), decreased from pre-outbreak levels. Responses following outbreaks were similarly variable, and in general we were unsuccessful at predicting population responses to outbreaks from a priori knowledge of woodpecker ecology and behavior. We did, however, find evidence that the response of at least half of the species changed over the 34-year period covered by the study: except for the Northern Flicker (*Colaptes auratus*), whose response to outbreaks during the winter decreased, populations generally responded more positively to outbreaks with time. This temporal response suggests that North American woodpeckers may be taking greater advantage of the resource pulse and/or habitat changes caused by outbreaks of this exotic pest now than previously, so in the future the effects of Gypsy Moth outbreaks on these species may increase.

McEwan, R.W., L.K. Rieske, and M.A. Arthur. 2009. Potential interactions between invasive woody shrubs and the Gypsy Moth (*Lymantria dispar*), an invasive insect herbivore. Biol Invasions, Vol. 11, Number 4, pp.1053-1058.

Authors' abstract: As the range of the invasive and highly polyphagous Gypsy Moth (*Lymantria dispar*) expands, it increasingly overlaps with forest areas that have been subject to invasion by non-native shrubs. We explored the potential for interactions between these co-occurring invasions through a Gypsy Moth feeding trial using the following three highly invasive, exotic shrubs: honeysuckle (*Lonicera maackii*), privet (*Ligustrum sinense*) and burning bush (*Euonymus alatus*). We compared these with two native shrubs: spicebush (*Lindera benzoin*) and pawpaw (*Asimina triloba*). We fed Gypsy Moth caterpillars foliage exclusively from one of the five shrubs and measured their relative consumptive rate (RCR), relative growth rate (RGR), and development time (DT). The RCR of Gypsy Moth was strongly influenced by the species of foliage ($F = 31.9$; $P < 0.0001$) with little or no consumption of honeysuckle and privet. Caterpillar RGR was influenced by the shrub species ($F = 66.2$; $P < 0.0001$), and those caterpillars fed spicebush, honeysuckle or privet lost weight over the course of the assay. Caterpillar DT was also significantly ($F = 11.79$, $P < 0.0001$) influenced by the shrub species and those fed honeysuckle, privet and spicebush died prior to molting. Overall, our data suggest that honeysuckle, privet, and spicebush could benefit (indirectly) from the invasion of Gypsy Moth, while burning bush and pawpaw could be negatively impacted due to direct effects (herbivory). Similarly, invading Gypsy Moth populations could be sustained on a shrub layer of burning bush and pawpaw in the event of canopy defoliation. Further field and laboratory analysis is needed to clarify herbivore resistance of invasive shrubs, and to investigate the potential interactions among co-occurring insect and plant invasions.

Miller, J.C., P.E. Hanson, D. Kimberling. 1991. Development of the Gypsy Moth (Lepidoptera, Lymantriidae) on Garry Oak and Red Alder in Western North America. Env Entomology, Vol. 20, Number 4, pp., 1097-1101.

Authors' abstract: The suitability of Garry oak (*Quercus garryana*) and red alder (*Alnus rubra*) as hosts for the Gypsy Moth, *Lymantria dispar* (L.), was assessed under laboratory conditions by observing larval survival, larval weights, foliage consumption, developmental period, pupal weight, and ova production. Survival was not significantly different between larvae fed Garry oak (98.7%) or red alder (97.4%). The mean maximum live larval weights were significantly different between sexes but not between diets. Females weighed 2,498 mg when fed Garry oak and 2,210 mg when fed red alder. Males weighed 894 mg when fed Garry oak and 737 mg when fed red alder. The mean amount of foliage consumed was significantly different between sexes but not diet. Female larvae consumed an average of 705 cm^2 of Garry oak and 678 cm^2 of red alder foliage. Male larvae consumed 247 cm^2 of Garry oak and 253 cm^2 of red alder foliage. The mean time from egg hatch to pupation was significantly different between sexes and diets. Female larvae pupated in 39.5 d on Garry oak and 48.1 d on red alder. Male larvae pupated in 33.4 d on Garry oak and 40.6 d on red alder. Pupal weights were not significantly different between sexes or diets. Male pupae weighed 554 mg from a larval diet of Garry oak and 572 mg from red alder. Female pupae weighed 1,846 mg from Garry oak and 1,711 mg from red alder. An average of 863 ova (Garry oak) versus 758 ova (red alder) was present in the reproductive tract of 2-d-old females, an insignificant difference. Pupal weights, frass production, and ova production were highly correlated. Nutritional indices indicated that Garry oak foliage was converted into biomass slightly more efficiently than that of red alder. These data indicated that foliage of either Garry oak or red alder provided a very suitable diet for the gypsy moth.

Pitt, J.P.W., J, Régnière, and S. Worner. Risk assessment of the Gypsy Moth, *Lymantria dispar* (L), in New Zealand based on phenology modeling. Int J Biometeorology, Vol. 51, Number 4, pp. 295-305.

Authors' abstract: The Gypsy Moth is a global pest that has not yet established in New Zealand despite individual moths having been discovered near ports. A climate-driven phenology model previously used in North America was applied to New Zealand. Weather and elevation data were used as inputs to predict where sustainable populations could potentially exist and predict the timing of hatch and oviposition in different regions. Results for New Zealand were compared with those in the Canadian Maritimes (New Brunswick, Nova Scotia, and Prince Edward Island) where the Gypsy Moth has long been established. Model results agree with the current distribution of the Gypsy Moth in the Canadian Maritimes and predict that the majority of New Zealand's North Island and the northern coastal regions of the South Island have a suitable climate to allow stable seasonality of the Gypsy Moth. New Zealand's climate appears more forgiving than that of the Canadian Maritimes, as the model predicts a wider range of oviposition dates leading to stable seasonality. Furthermore, we investigated the effect of climate change on the predicted potential distribution for New Zealand. Climate change scenarios show an increase in probability of establishment throughout New Zealand, most noticeably in the South Island.

Régnière, J., V. Nealis, and K. Porter. 2009. Climate suitability and management of the Gypsy Moth invasion into Canada. Biological Invasives, Vol. 11, Issue 1, pp 135-148.

Authors' abstract: The gypsy moth has become established throughout southern Canada east of Lake Superior where the climate is suitable for the completion of its univoltine life cycle. The spread of the gypsy moth to the north and west in Canada has so far been prevented by climatic barriers and host plant availability as well as by aggressive eradication of incipient populations. Climate change is expected to increase the area of climatic suitability and result in greater overlap with susceptible forest types throughout Canada, especially in the west. At the same time, the gypsy moth is spreading west in the US into states bordering western Canadian provinces. These circumstances all lead to a greatly increased risk of further invasion into Canadian forests by the gypsy moth. Management actions need to be intensified in different ways in different parts of the country to reduce the impacts of spread in eastern Canada and to prevent the gypsy moth from invading western regions.

Roden, D.B., and W.J. Mattson. 2008. Rapid induced resistance and host species effects on Gypsy Moth, *Lymantria dispar* (L.): Implications for outbreaks on three tree species in the boreal forest. Forest Ecol and Management, Vol., 2255, Issues 5-6, pp. 1868-1873.

Authors' abstract: Field pupal weight, development time, and survival of Gypsy Moth, *Lymantria dispar* (L.), larvae on three defoliated (50%) and undefoliated tree species that are common to the forest of the Great Lakes basin were compared for one season in 1988. Host species and defoliation affected female pupal weight; male pupal weight was affected only by host species. The smallest and largest pupae of both sexes, from both defoliated and undefoliated trees, came from larvae that fed on red oak, *Quercus rubra* L., and trembling aspen, *Populus tremuloides* Michx., respectively; pupal weight of larvae that fed on white birch, *Betula papyrifera* Marsh., were intermediate. Development time was affected only by tree species; the shortest and longest development occurred on trembling aspen and red oak, respectively; development time on white birch was medial. Gypsy Moth survival was not affected by defoliation or host species. Superficially, these data obviously suggest that both defoliated and undefoliated trembling aspen and white birch are more nutritious, and will support higher Gypsy Moth fitness than its traditional hosts like red oak. However, we argue that outbreaks of Gypsy Moth will not occur in aspen and birch stands because its tri-trophic fitness is lower there due in part to the higher efficacy of certain Gypsy Moth natural enemies. We hypothesize that outbreaks on these two tree species will be limited by the nuclear polyhedrosis virus, *Entomophagus maimaiga,* and key physical features (e.g., light trunk color) of the host that deter larval host-seeking/accepting behavior. More than 20 years of Gypsy Moth outbreak records in North America support this hypothesis.

Tobin, P.C., and L.M. Blackburn. 2008. Long-Distance Dispersal of the Gypsy Moth (Lepidoptera: Lymantriidae) Facilitated Its Initial Invasion of Wisconsin. Env Entomology 37(1), pp. 87-93.

Authors' abstract: Gypsy Moth (*Lymantria dispar* L.) spread is dominated by stratified dispersal, and, although spread rates are variable in space and time, the Gypsy Moth has invaded Wisconsin at a consistently higher rate than in other regions. Allee effects, which act on low-density populations ahead of the moving population that contribute to Gypsy Moth spread, have also been observed to be consistently weaker in Wisconsin. Because a major cause of an Allee effect in the Gypsy Moth is mate-finding failure at low densities, supplementing low-density populations with immigrants that arrive through dispersal may facilitate establishment and consequent spread. We used local indicator of spatial autocorrelation methods to examine space-time Gypsy Moth monitoring data from 1996 to 2006 and identify isolated, low-density colonies that arrived through dispersal. We measured the distance of these colonies from the moving population front to show that long-distance dispersal was markedly present in earlier years when Wisconsin was still mainly uninfested. Recently, however, immigrants arriving through long-distance dispersal may no longer be detected because instead of invading uninfested areas, they are now supplementing high-density colonies. In contrast, we observed no temporal pattern in the distance between low-density colonies and the population front in West Virginia and Virginia. We submit that long-distance dispersal, perhaps facilitated through meteorological mechanisms, played an important role in the spread dynamics of the initial Wisconsin Gypsy Moth invasion, but it currently plays a lesser role because the portion of Wisconsin most susceptible to long-distance immigrants from alternate sources is now heavily infested.

Tobin, P.C., J. Van Stappen, and L.M. Blackburn. 2010. Human visitation rates to the Apostle Islands National Lakeshore and the introduction of the non-native species *Lymantria dispar* (L.). J Env Management. Vol. 91, Issue 10, pp., 1991-1996.

Authors' abstract: The introduction of non-native species has accelerated due to increasing levels of global trade and travel, threatening the composition and function of ecosystems. Upon arrival and successful establishment, biological invaders begin to spread and often do so with considerable assistance from humans. Recreational areas can be especially prone to the problem of accidental non-native species transport given the number of visitors that arrive from geographically diverse areas. In this paper, we examine camping permit data to the Apostle Islands National Lakeshore in northwestern Wisconsin, USA, from 1999 to 2007 relative to Gypsy Moth distribution, phenology and outbreak data. During this time, Gypsy Moth populations became established in this area ahead of the moving population front of the Gypsy Moth, suggesting anthropogenic introduction. The permit data revealed that the majority of visitors arrived from outside of the Gypsy Moth established area. However, there was a consistent yearly trend of visitors that arrived from areas of high Gypsy Moth populations and who arrived during the Gypsy Moth life stage (egg masses) most likely to be successfully introduced. Using available data on the Gypsy Moth and its relationship to camping permit data, we describe how recreational managers could optimize park strategies to mitigate unwanted introductions of the Gypsy Moth as well as develop analogous strategies for managing other biological invaders in recreational areas.

Traxler, E. F. 1977. General Anatomical Features of the Gypsy Moth Larva *Lymantria Dispar* (Linnaeus) (Lepidoptera: Lymantriiidae). J. of the New York Entomological Society, Vol. 85, No 2, pp. 71-97.

Author's abstract: General anatomical features of the Gypsy Moth *Lymantria dispar* (Linnaeus) (Lepidoptera: Lymantriidae) reveals a well-developed caterpillar. The head capsule shows the frons as being the antennalsegment, the epistomal sulcus invaginated internally to form a connection with the tentorium, and the absence of an ecdysial cleavage line. The head capsule does not reveal anterior tentorial pits externally. The maxillolabial-hypopharyngeal complex is attached to the head capsule proper by a membrane and is structurally designed to move independently of other mouth parts. Anatomy of the thoracic and abdominal regions shows a total of twelve segments circumvented with setae arranged in tufts. Segments four, five, ten, and eleven, which are without legs, have twelve hair tufts per segment. Segments with legs (one, two, three, six, seven, eight, and nine) have hair tufts that are reduced on the venter. Segments one, four, five, six, seven, eight, nine, ten, and eleven have paired spiracles. All segments have tubercles which form the base of the hair tuft, and the tubercles are classified in accord with their location on the insect's body: dorsal, dorsol-lateral, ventro-lateral, and ventral. Setae are located on every component structure of the insect's body and are barbed.

Other published sources

Kenis, M., and C.L. Vaamonde. 1998. Classical Biological Control of the Gypsy Moth, Lymantria dispar (L.), in North America: Prospects and New Strategies, in M.L. McManus and A.M. Liebhold, editors. 1998. *Proceedings: Population Dynamics, Impacts, and Integrated Management of Forest Defoliating Insects.* USDA Forest Service General Technical Report NE-247, pp. 213-221.

Authors' abstract: On-going programs and future strategies for the biological control of the Gypsy Moth are reviewed. The most promising directions are: a continuation of the introduction of the two tachinid parasitoids *Blepharipa schineri* and *Ceranthia samarensis*, investigations on egg predators which are important natural enemies of the Gypsy Moth in eastern Europe and North Africa, studies on parasitoids specialized in low host densities, especially in poorly investigated regions in Asia, and investigations for the existence of more efficient biotypes of *Parasetigena silvestris* and *Cotesia Melanoscelus*, two parasitoid species already established in North America.

Nealis, V. 2009. Still invasive after all these years: Keeping Gypsy Moth out of British Columbia. The Forestry Chronicle. July/August 2009, Vol. 85, No. 4, pp. 593-603.

Author's abstract: The Gypsy Moth is an alien invasive insect in North America. In Canada, management objectives and approaches have often collided with public opposition and resulted in a shifting public policy. The history of this interaction between science and policy is best illustrated in British Columbia where Gypsy Moth remains un-established after 30 years of repeated invasions and eradications. The case study provides unique lessons to improve science–public dialogue in achieving common socioeconomic objectives. It shows that despite the availability of sufficient scientific knowledge and technical capacity to reduce risk, the absence of effective risk communication can compromise the effectiveness of management action and increase the risk of invasion.

Annotation: This article provides a thorough review of the development of Gypsy Moth eradication programs and policies in BC. It also provides a number of references to the original publications that describe the early Gypsy Moth introductions to the province.

Nealis, V., J. Régnière, and D. Gray. 1999. Modeling Season Development of the Gypsy Moth in a Novel Environment for Decision Support of an Eradication Program. Pp.,124-132 in Liebhold, A.M., M. L. McManus, I. S. Otvos, and S.L.C. Fosbroke, eds. 2001. *Proceedings: integrated management and dynamics of forest defoliating insects*. 36 pp.

Authors' abstract: Observations of field-caged egg masses of the European Gypsy Moth (*Lymantria dispar* (L.)) on Vancouver Island, British Columbia, Canada, indicate that overwinter survival of the insect is very high in this area. Emergence of larvae in the spring occurred over a period of 4 to 5 weeks. These observations were used to validate a process-oriented phenology model that was, in turn, used to time pesticide applications during an eradication program against the Gypsy Moth. Based on a digital elevation model and climate normals, the phenology model was used to examine heterogeneity of seasonal development within the eradication zone and to identify areas where successful completion of the insect's life history might be unlikely because of climate.

Province of British Columbia. 2010. North American Gyspy Moth Eradication Regulation, 2010, *Plant Protection Act*. 3 pp. plus appendices.

Unpublished sources

Hajek, A.E., and P.C. Tobin. 2010. Spatial spread of introduced infectious diseases following a colonizing invasive host. Presented at the 95th ESA Annual Meeting, August 2010, Pittsburgh Pennsylvania.

Summary: The interactions between spatially structured host populations and the transmission dynamics of their macro- and microparasites can result in a range of spatial and temporal dynamic behavior. With increasing effects of globalization resulting in increasing biological invasions, there is much interest in understanding the spread of non-native species and their macro- and microparasites that follow, whether parasites are introduced with their hosts or are subsequently introduced as biological control agents. Moreover, changing climates could cause changes in the dynamics between interacting species. We studied interactions between the Gypsy Moth, *Lymantria dispar*, a non-native forest defoliator, and the entomophthoralean fungus Entomophaga maimaiga, the baculovirus Lymantria dispar nucleopolyhedrovirus (LdNPV), and larval parasitoids as they tracked newly-established Gypsy Moth populations along the leading edge of its range in central and southern Wisconsin. We collected over 4800 larvae and cadavers from a total of 37 field sites between 2005-2007, which we used to determine rates of larval infection or parasitization. We then related the presence of pathogens and parasitoids to the prior year's background Gypsy Moth abundance, long-term history of Gypsy Moth, past deliberate introductions of natural enemies, and climate.

Sopchuk, L., and K. Ovaska. 2001. Responses of songbirds to aerial spraying of the microbial insecticide Bacillus Thuringiensis var. kurstaki (Foray 48B®) in Garry Oak habitat on Vancouver Island, 1999-2000. Unpublished final report by Biolinx Environmental Research Ltd., Sidney, BC, 77 pp.

Summary: As part of ecological monitoring by the Ministry of Forests associated with the Gypsy Moth (*Lymantria dispar*) eradication program conducted in spring 1999, we investigated the responses of songbirds to a reduced food supply resulting from aerial spraying of the microbial, lepidopteran-specific insecticide *Bacillus thuringiensis* var. *kurstaki* (Btk; Foray 48B) over a 12,803 ha area in and around Victoria on three occasions, which resulted in a significant reduction in caterpillar abundance in Garry Oaks (*Quercus garryana*). We examined the hypotheses that (a) densities of breeding songbirds, particularly leaf-gleaning, insectivorous species, would be depressed in sprayed areas in relation to pre-treatment densities and when compared to densities in unsprayed areas, and that (b) the incidence of renesting and second broods, as reflected by numbers of singing males in late spring, and (c) numbers of broods produced would be lower in sprayed than unsprayed areas due to high energetic costs associated with reproduction.

The results of this 2-year study indicate that the use of Btk to control Gypsy Moth populations had few or no detectable effects on songbird abundance. However, as a precaution to prevent any potential minor effects on songbirds, particularly on rare species, future spray-programs should target only areas known to harbour Gypsy Moths or their eggs to minimize the size of continuous areas with depressed caterpillar prey.

Fact sheets, websites, and databases

Blair County Conservation District, Gypsy Moth Fact Sheet. www.blairconservationdistrict.org/pdfs/Gypsy%20Moth%20Fact%20Sheet.pdf

Annotation: This fact sheet has information about naturally occurring Gypsy Moth pathogens and a useful photo comparison with caterpillar species that may be confused with Gypsy Moth.

Bugwood Network, The. College of Agricultural and Environmental Sciences and Warnell School of Forest Resources. University of Georgia.. images.bugwood.org/

Annotation: This website provides access to an extensive selection of publicly available photographs of insects.

Canadian Food Inspection Agency. *Lymantria dispar* (Linnaeus) – Gypsy moth. www.inspection.gc.ca/english/plaveg/pestrava/lymdis/tech/lymdise.shtml

Canadian Food Inspection Agency. List of North American Gypsy Moth Infested or Suspected Infested Areas of Canada and the United States (October 7, 2011). www.inspection.gc.ca/english/plaveg/protect/dir/gmlist_e.shtml

City of Saskatoon. Invasive Pests: Gypsy Moth. www.saskatoon.ca/DEPARTMENTS/Infrastructure%20Services/Parks/PestManagement/Pages/InvasivePests.aspx

Global Invasive Species Database. 2011. *Lymantria dispar* (insect). www.issg.org/database/species/ecology.asp?fr=1&si=96

Hamilton Conservation Authority. Gypsy Moth fact sheet. www.conservationhamilton.ca/Asset/iu_files/GypsyMothFactsheet.pdf

Health Canada. 2009. Pest Notes: Gypsy Moth. Brochure produced by Health Canada Pest Management Regulatory Agency. Ottawa, Canada. 2 pp. www.hc-sc.gc.ca/cps-spc/alt_formats/pdf/pubs/pest/pnotes/gypsy-spongieuse-eng.pdf

Annotation: This brochure provides a general description of this pest's appearance and life cycle, the nature of damage it causes, suggestions for management, and government contact information. It provides some useful photographs. It also includes information on pesticide use, which should not be followed if contrary to local and provincial legislation.

HealthLink BC. Gypsy Moth Spraying. HealthLink BC File #90, 2011. www.healthlinkbc.ca/healthfiles/hfile90.stm

Kenosha County Gypsy Moth Suppression Program, Department of Planning and Development, Division of County Development, Land and Water Conservation, Kenosha County, Wisconsin. www.co.kenosha.wi.us/plandev/conservation/gypsymoth.html

Manitoba Forestry Branch. Gypsy Moth. www.gov.mb.ca/conservation/forestry/health/gypsy-moth.html

McManus, M., N. Schneeberger, R. Reardon, and G. Mason. 1989. Gypsy Moth: Forest Insect & Disease Leaflet 162. US Department of Agriculture Forest Service. na.fs.fed.us/spfo/pubs/fidls/gypsymoth/gypsy.htm

Ministry of Forests, Lands and Natural Resource Operations. 2011. Caterpillars that can be mistaken for Gypsy Moth. www.for.gov.bc.ca/hfp/gypsymoth/caterpillars.htm

Annotation: This page provides a comprehensive checklist, photos, and drawings for differentiating Gypsy Moth from other, similar-looking species.

Ministry of Forests, Lands and Natural Resource Operations. 2011. Fact Sheet: Gypsy Moth Impacts to the Garry Oak Ecosystem. www.for.gov.bc.ca/hfp/gypsymoth/garryoak.htm

PennState College of Agricultural Sciences, Cooperative Extension. Entomological Notes: Gypsy Moth. ento.psu.edu/extension/factsheets/pdf/gypsymoth.pdf

Saskatchewan Ministry of Environment. Forest Pest Fact Sheet – European Gypsy Moth, (*Lymantria dispar*). www.environment.gov.sk.ca/adx/aspx/adxGetMedia.aspx?DocID=3630,184,121,104,81,1,Documents&MediaID=4170&Filename=Gypsy+moth.pdf

Seattle & King County Public Health. Gypsy moths and the use of *Bacillus thuringiensis kurstaki* (B.t.k.) pesticide. www.kingcounty.gov/healthservices/health/ehs/gypsymoths.aspx

Toronto Parks, Forestry & Recreation, Urban Forestry Branch. 2010. Fact Sheet: Forest Health Care – European Gypsy Moth. www.toronto.ca/trees/pdfs/factsheets/European_Gypsy_Moth.pdf

Toronto Public Health. 2008. Backgrounder: Control of Gypsy Moth. www.toronto.ca/health/pesticides/pdf/gypsyMoth.pdf

Annotation: This fact sheet provides information about Btk and its use by the City of Toronto as part of its Gypsy Moth control program.

US Forest Service, Global Invasive Species Database. 2011. *Lysmantria dispar* (insect). www.issg.org/database/species/ecology.asp?si=96&fr=1&sts=&lang=EN

Annotation: This database focuses on invasive alien species that threaten native biodiversity and covers all taxonomic groups from micro-organisms to animals and plants in all ecosystems. Species information is either supplied by or reviewed by expert contributors from around the world

Wikimedia Commons. *Lymantria dispar*.

commons.wikimedia.org/wiki/Category:Lymantria_dispar

Personal communications

Ebata, Tim. Forest Health Officer, Resource Practices Branch, BC Ministry of Forests, Lands and Natural Resource Operations. 10 January 2012.

"Asian Gypsy Moth (AGM) is a federal responsibility because its presence is a regulatory problem. However, treatments for North American race of European Gypsy Moth (NAGM) are a provincial responsibility because NAGM Is officially established in Canada, so the [Canada Food Inspection Agency] (CFIA) will only regulate movement of potentially infested goods originating from "regulated areas". Because the pheromone used in provincial monitoring attracts both AGM and NAGM, CFIA continues to do national monitoring for Gypsy Moths and does DNA testing on each positive sample coming from the west as well as in selected samples from eastern ports. If AGM is identified from a BC location, leadership for further management switches to CFIA, with the Province becoming a cooperating agency – usually the Province does the spraying [if that is the method chosen], but this is paid for by CFIA."

Nealis, Vince. Insect Ecologist, Pacific Forestry Centre, Victoria, BC. 14 January 2012.