# *LYMANTRIA MONACHA* (NUN MOTH) AND *L. DISPAR* (GYPSY MOTH) SURVIVAL AND DEVELOPMENT ON IMPROVED *PINUS RADIATA*

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## ABSTRACT

The lymantriid forest defoliators, *Lymantria monacha* L. (nun moth) and *Lymantria dispar* L. (gypsy moth) are particularly severe pests in other countries in the world, but the ability of these moths to utilise and complete development on *Pinus radiata* D. Don had never been established. In laboratory trials, colonies of central European *L. monacha* and Russian far east (flight capable) *L. dispar* were fed on foliage from three mature *P. radiata* trees originating from three different advanced-selection families from New Zealand. The results showed that both moths were capable of completing their development from egg to adult on these families of *P. radiata*. However, *P. radiata* was a less suitable host for development of *L. dispar* than *Quercus velutina* Lam. (black oak), as evidenced by higher mortality and slower growth. *Lymantria monacha* developed faster and survived better on *P. radiata* than it did on mature foliage of *Picea glauca* (Moench) Voss. Neonate *L. monacha* larvae favoured male pine cones from *Pinus strobus* L. as a food source, but when these were absent did complete their development on *P. radiata* needles. There was no difference in larval development between those on the three *P. radiata* families tested. The study suggests an accidental introduction of *L. monacha* to New Zealand, even more so than *L. dispar*, could have a serious impact on *P. radiata* plantations.

**Keywords**: Lymantriidae; larval feeding; development; survival; fecundity; no-choice trial; biosecurity risk; *Lymantria monacha*; *Lymantria dispar*; *Pinus radiata*.

## INTRODUCTION

Despite the extensive literature on *Lymantria monacha* and *L. dispar* (Lepidoptera: Lymantriidae), there is little information available for assessing the potential impact on New Zealand exotic plantation forestry, should an accidental introduction and successful establishment occur. *Pinus radiata* (Coniferopsida: Pinaceae) constitutes 95% of New

Zealand's plantation forest estate. To predict the risk of successful establishment in New Zealand exotic plantation forests and the potential damage to these plantations, knowledge is required about the ability of these moths to survive and develop on advanced breeding lines of *P. radiata*.

In Eurasia, *L. monacha* feeds and thrives on the foliage of many coniferous and deciduous trees (Lipa & Glowacka 1995). The preferred and most-often damaged species are *Picea abies* (L.) Karsten (Norway spruce) and *Pinus sylvestris* L. (Scots pine) (Lipa & Glowacka 1995). Sliwa (1987) published an extensive list of the intensity of natural feeding of *L. monacha* larvae on trees and shrubs in Poland during the major outbreak that occurred in 1978–84, but laboratory investigations of *L. monacha* preferences and utilisation of Eurasian host plants have provided limited and contradictory information (Bejer 1988). For example, some laboratory studies rank the species that are preferred in Europe — *Picea*, *Pinus,* and *Larix* — as intermediate-to-low in food value (Bejer 1988). The USDA Forest Service has identified *L. monacha* as a potential threat to forests in North America due to its preferred hosts and the high likelihood that egg masses will be transported unnoticed on containers, pallets, and ships (Keena *et al.* 1998). This same risk of importation exists for Australasian ports.

Keena (1999) undertook extensive laboratory testing of the host range of a strain of *L. monacha* from the Czech Republic against a number of North American host trees. The North American conifers *Abies concolor* (Gordon) Hildebr., *Picea pungens* Engelm., *Picea glauca*, *Pseudotsuga menziesii* subsp. *glauca* (Beissn.) E.Murray, and *Tsuga canadensis* (L.) Carrière were suitable for *L. monacha* development and survival (Keena 1999). Research has revealed that host phenology, such as the timing of bud burst, is as important as host preference in determining the survival and successful development of *L. monacha* larvae. For example, when neonate larvae hatch before bud burst in early spring, the presence of male cones (strobili) is critical to larval survival and development (Bejer 1988). Keena (1999) stated that *L. monacha* larvae did not develop as well during their first two instars on *P. sylvestris* in the absence of male cones. When male cones were provided for the first 2 weeks, larvae initially fed exclusively on these (M.Keena unpubl. data). Therefore it is important to assess the ability of neonate *L. monacha* larvae to establish on coniferous hosts (especially pines) in both the presence and the absence of male cones.

Because of the ability of *L. monacha* to survive on many different coniferous species, it is expected to be a greater threat to the *P. radiata* estate in New Zealand than is Asian gypsy moth. *Lymantria dispar* is not a conifer specialist, and the larvae do best on broadleaf trees, particularly *Quercus* species. A flightless (European) strain of *L. dispar* was introduced into the United States in 1869; it has since caused devastating damage to tree species in the north-eastern United States, and has been the subject of extensive research. Montgomery (1991) and Liebhold *et al.* (1995) reviewed the experiments on *L. dispar,* which have examined its host range. In one published laboratory trial, five (European strain) *L. dispar* larvae were reared successfully on *P. radiata* in no-choice feeding assays, although development was slow and adults did not attain their maximum size (Miller & Hanson 1989). Recently Matsuki *et al.* (in press) also found that a Beijing population of Asian *L. dispar* would complete development (74% survival) on an ancestral (unimproved) *P. radiata*. During an outbreak of the European strain of *L. dispar* in 1952–53 in the province of Pontevedra, severe damage occurred to forests of *P. radiata* (Romanyk 1973). A similar

observation was also reported from Spain when young *P. radiata* trees were apparently killed by a single defoliation (Rabasse & Babault 1975). These data suggest that, despite the insect's lower preference for Pinaceae hosts, *P. radiata* could potentially be at risk from Asian or European *L. dispar*.

The New Zealand forest industry has been selectively breeding *P. radiata* for increased growth and desirable wood traits for 50 years (Shelbourne *et al.* 1986). Because of this, advanced breeding lines of *P. radiata* may differ somewhat in growth and form from their ancestral populations from California. Concern is sometimes expressed that such tree selection leads to a narrowing of the genetic base, and increases vulnerability to diseases and pests (Gadgil & Bain 1999). It is also generally accepted that fast-growing vigorous trees can be less susceptible to insect damage than suppressed or less vigorous ones (Gadgil & Bain 1999). These different possibilities made it vital to assess the vulnerability to defoliation by *L. monacha* and *L. dispar* of foliage from advanced selections of *P. radiata*, rather than foliage from unimproved or ancestral populations.

## MATERIALS AND METHODS

### Insects and Plants

The survival and developmental success of *L. monacha* and *L. dispar* was tested using no-choice larval feeding assays carried out in the USDA Forest Service Quarantine Laboratory in Ansonia, Connecticut, United States, between May and July 1999. The *L. monacha* originated from the Predin, Czech Republic, strain (sixth laboratory generation, reared on artificial diets for all but one generation which was reared on host plants). The *L. dispar* originated from the Mineralni, in the Russian far east (originally collected in 1993, flight-capable, tenth laboratory generation reared on high wheat-germ diet).

The *P. radiata* host plant material was obtained from three, different, advanced-selection, control-pollinated, full-sib families from the New Zealand breeding programme, planted in 1984 at the Russell Reservation, California. Trees A and C were from two families of good growth and form resulting from the 1968 New Zealand selection and testing programme, while tree B was from one of the better families from the 1950 programme.

The treatments for *L. monacha* were:

(1) Needles without male cones of *P. radiata* trees (families A, B, and C),

(2) *Pinus radiata* A needles supplemented with *P. strobus* male cones, with all needles removed, for the first 14 days (male cones of *P. radiata* were not available in May), and

(3) *Picea glauca* needles without cones.

There were three containers for each of the treatments with different advanced-selection trees without cones (270 larvae in total), and six containers for each of the treatments with *P. glauca* and *Pinus radiata* plus cones (180 larvae each).

The different host plant treatments for *L. dispar* were:

(1) Needles of *P. radiata* A without cones, and

(2) Leaves of *Q. velutina*.

Six containers were set up for each host (a total of 180 larvae per treatment).

The following experimental methods were common to both moth species. Eggs were held at 5° ± 1°C and ~100% RH (L:D of 16:8) for a minimum of 120 days before use to ensure that diapause requirements had been met. Standard surface sterilisation and incubation techniques were used (ODell *et al.* 1984) to initiate hatch. Eggs were checked daily. When most eggs had hatched they were transferred to a cabinet at 5° ± 1°C and ~100% RH (L:D of 16:8) for up to 4 days until initiation of the experiment. Larvae in groups of 30 were moved with a fine brush into 50 × 9-mm Petri dishes with tight-fitting lids, which were pre-weighed to determine the approximate initial weight of the larvae. The dishes of larvae were randomly assigned to each foliage treatment.

Short branch tips with foliage were obtained from trees (>4 m in height) in Ansonia, except for the *P. radiata* foliage which was cut in California each week, sealed in plastic bags, and, within 4 hours of cutting, placed in an insulated box which was couriered overnight. The cut *P. radiata* foliage was used within 14 days of cutting, *Picea glauca* within 7 days, and *Q. velutina* foliage was always cut on the day of each foliage change. The ends of each branch tip were inserted through a hole in a plastic lid that fitted a 0.24-litre plastic cup that was used as a de-ionised water reservoir. The branch tip was re-cut while in the de-ionised water, then the lid was snapped in place. One or two branch tips were placed in each cup, depending on the amount of foliage the larvae required.

Initially, one cup with foliage in it and 30 larvae were placed in each 3.8-litre paper container with a clear plastic wrap lid. The containers were held at 25°C and 60% RH (L:D of 16:8). Foliage was changed two to three times a week. At each foliage change, the original foliage was removed and replaced. Each time, all larvae were removed from the foliage and the total number of live larvae in each container was recorded before the larvae were placed on the new foliage. Subsequent foliage changes repeated this pattern until either the test for that host plant ended at 14 days or all larvae had pupated or died. At 14 days, the weight and instar of each larva were recorded and the number of larvae per container was reduced to a maximum of 15 by increasing the number of containers used, as needed.

Individual pupae were removed every second day, weighed, and sexed, and any pupal deformities were recorded. Pupae were held separated by sex in 236.5- or 473-ml paper cups at 25°C and 60% RH (L:D of 16:8). For both *L. dispar* and *L. monacha*, containers were checked daily, adults were removed and weighed, and successful eclosion was recorded. Adult female *L. monacha* were individually placed in 473-ml paper cups for single-pair matings within host plant species, and strips of smashed corrugated cardboard were supplied for females to oviposit into.

## Data Analyses

The average percentage of surviving larvae was calculated for each container as the ratio of the live larvae found at the end of the 14-day period to the number of larvae used to initiate the test, minus those that were counted as missing or accidentally squashed during the 14-day period. Each instar class at 14 days was assigned a numerical score, i.e., 2 for second instar, 3 for third instar, and this was used in the statistical analysis. The proportion of larvae attaining any one instar was calculated as the ratio of larvae present in each instar divided by the total number of surviving larvae at 14 days. The weight gained was calculated as the difference between the larval weight and the mean weight of a larva in that container at the day of initiation of the test.

All data were tested for normality and for homogeneity of variances using Levene's Test and when necessary were made homogeneous using an appropriate transformation (Fernandez 1992). Survival and development data during the first 14 days were tested for both host plant and individual container effects using a Generalised Linear Model procedure. When host-plant only effects existed, comparisons of mean were performed using Fisher's pairwise test at $p< 0.05$ (Minitab Version 12 for Windows) to ascertain differences between the host plants for each parameter measured. Where heteroscedasticity remained, median values were compared between plant species using a Kruskal-Wallis test at $p< 0.05$. Measures of pupal weight and time to pupation were tested for host plant effects using a one-way ANOVA procedure.

## RESULTS

### *Lymantria monacha* Survival and Development

*First 14 days*

*Lymantria monacha* caterpillars initiated feeding on *Pinus radiata* foliage without difficulty. When only *P. radiata* foliage was present, they would tend to scrape and cut the needles, leaving them bent or completely cut and fallen to the ground. At least half the larvae in the treatments where male cones of *P. strobus* were also supplied for the first 14 days of feeding were found ingesting pollen grains from these cones. Larvae appeared to have difficulty initiating feeding sites on *Picea glauca* needles, and were often found wandering about the container.

The survival of *L. monacha* caterpillars reared on *Pinus radiata* with and without male cones, and on *Picea glauca* foliage (without male cones) was compared after 14 days. There was a significant effect of host foliage on the proportion of larvae that survived, and there was no effect contributed by the container they were in (GLM where Host $F$=19.7, df=2, $p$<0.0001, Container $F$=2.15, df=8, $p$>0.13). The highest mean percentage survival of larvae was in the treatment where *Pinus radiata* foliage was supplemented with male cones and this percentage was significantly better than in either of the other two treatments (Table 1).

The mean weight of each larva at the beginning of the test was 0.54 mg and there was no significant difference between containers (97% were within 0.01 mg of the median,

TABLE 1–Larval survival to 7 and 14 days, and the mean larval weight gain (mg) after 14 days' feeding per container of *Lymantria monacha* and *L. dispar*, by plant species.

| | Host plant | N containers | Survival to 7 days (%) | Survival to 14 days (%) | 14 days' weight gain (mg) |
|---|---|---|---|---|---|
| *L. monacha* | *Pinus radiata* A | 3 | 30.4 | 16.5 | 12.7 |
| | *P. radiata* B | 3 | 51.7 | 40.7 | 12.2 |
| | *P. radiata* C | 3 | 41.4 | 32.2 | 10.3 |
| | *P. radiata* A + male cones of *P. strobus* | 6 | 73.4 | 66.5 | 14.3 |
| | *Picea glauca* | 6 | 34.8 | 19.1 | 2.1 |
| *L. dispar* | *Pinus radiata* A | 6 | 59.9 | 42.5 | 5.1 |
| | *Quercus velutina* | 6 | 95.4 | 95.4 | 236.2 |

Wilcoxon Signed Rank Test). The amount of weight gain by *L. monacha* caterpillars in the first 14 days of feeding was compared when they were reared on *P. radiata*, either with or without male cones, or on *Picea glauca* foliage that lacked male cones. There was a significant effect of host foliage on weight gain, and no effect contributed by the container in which they were fed (GLM where Host $F$= 35.1 df=2, $p$<0.0001, Container $F$=1.48, df=8, $p$>0.167). Mean weight gain was highest when larvae were reared on *Pinus radiata*, with or without male cones, and was significantly higher than on *Picea glauca* (Table 1). This significantly retarded development on *P. glauca* was also reflected in the instar that larvae had reached by 14 days. Larvae on *P. glauca* were most commonly still first instar, with some second instar, whereas larvae on *Pinus radiata* were mainly second and third instar (Fig. 1).

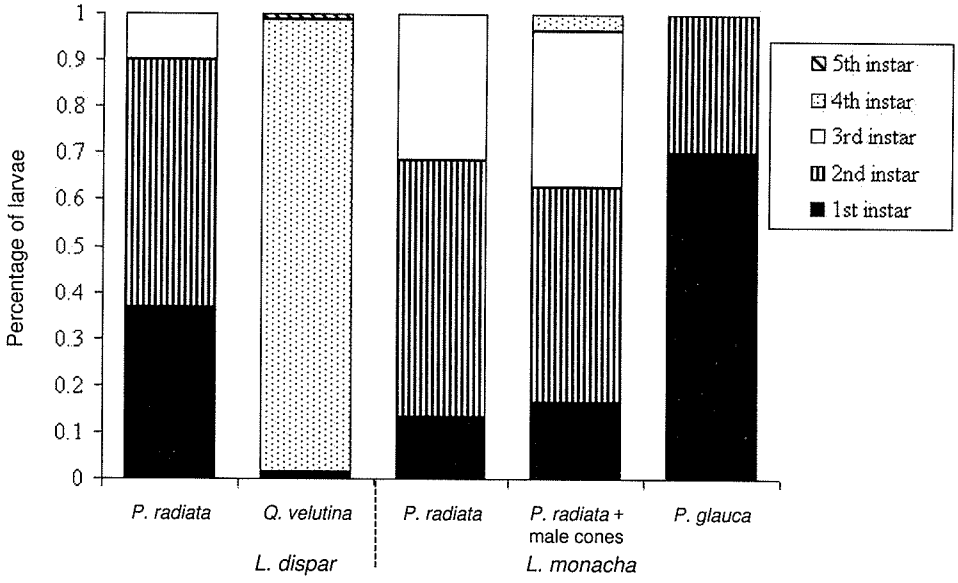


FIG. 1—Percentage of *Lymantria monacha* and *L. dispar* larvae that had reached different instars after 14 days' feeding on foliage of different plant species

The treatments in which *L. monacha* larvae fed on *P. radiata* foliage without male cones, were further separable into the three advanced-selection trees (A, B, or C). There was no significant difference in either weight gain (Kruskal-Wallis $H$=0.75, df=2, $p$>0.69) or the mean percentage of larvae surviving per container ($H$=3.2, df=2, $p$>0.2) according to the *P. radiata* tree from which the foliage had been taken. In all treatments, larvae by 14 days had most commonly developed to second instar. All further analyses on this treatment combined the larvae from the three different *P. radiata* trees.

### *Development to pupation, and eclosion success*

There was little larval mortality in the period between 14 days feeding and pupation (Table 1), as most of the larval mortality occurred during the first 10 days (Fig. 2). Survival was highest when larvae were fed *P. radiata* needles as well as having male cones of *P. strobus* for the first 14 days (Fig. 2).

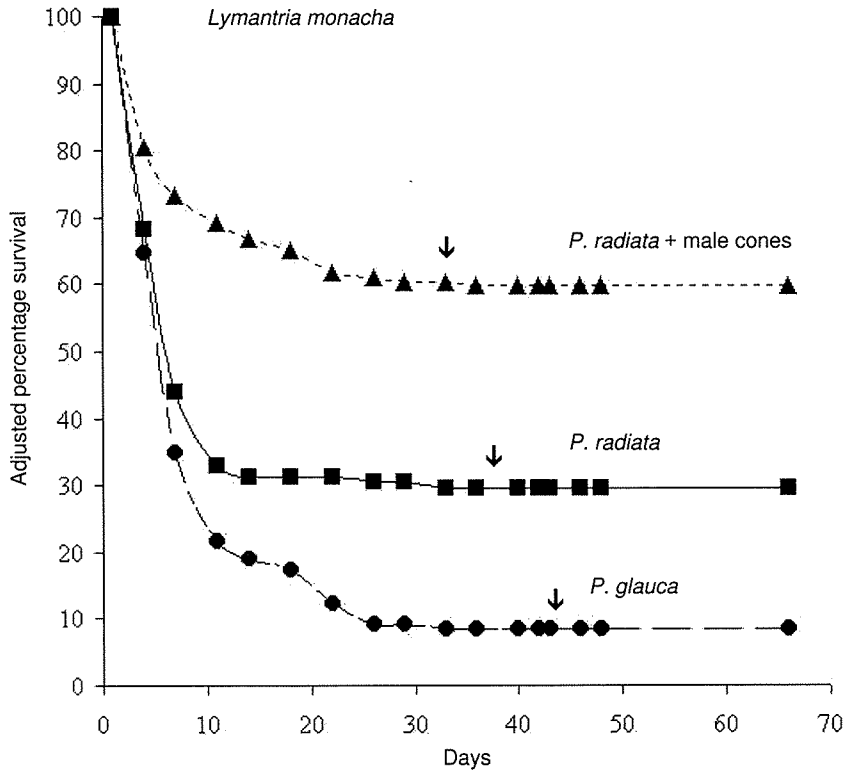


FIG. 2–*Lymantria monacha* larval survival adjusted to remove from calculations those larvae that were killed accidentally or disappeared during the study. The arrow indicates the modal time of pupation in each treatment.

The number of days that surviving larvae took to pupate was significantly influenced by host plant for male pupae (One-way ANOVA $F$=23.4, df=2, 76, $p$<0.0001), but not for female pupae ($F$=1.8, df=2, 70, $p$>0.17). In both sexes, time to pupation was longer when larvae were feeding on *Picea glauca* than on *Pinus radiata* needles (Table 2). Female larvae

TABLE 2–*Lymantria monacha* mean time to pupation, mean pupal weight, and eclosion success according to plant species larvae were reared on.

| | *Pinus radiata* no male cones (A+B+C) | | *Pinus radiata* A + male cones of *P. strobus* for 14 days | | *Picea glauca* no male cones | |
|---|---|---|---|---|---|---|
| Time to pupation | | | | | | |
| Male larvae | 35.2 days | n 18 | 35.8 days | n 56 | 46.4 days | n 5 |
| Female larvae | 40.1 days | n 20 | 40.2 days | n 45 | 43.5 days | n 8 |
| Pupal weight | | | | | | |
| Male | 0.380 g | n 18 | 0.384 g | n 56 | 0.366 g | n 5 |
| Female | 0.772 g | n 20 | 0.731 g | n 45 | 0.841 g | n 8 |
| Eclosion success | | | | | | |
| Male pupae | 88% | | 98% | | 60% | |
| Female pupae | 98% | | 100% | | 100% | |

tended to take longer to pupate than male larvae. Pupal weight, measured on the second day after pupation, was significantly influenced by the host plant on which larvae had been fed only for female pupae (One-way ANOVA $F$=3.4, df=2, 70, $p$<0.041), not for male pupae ($F$=0.24, df=2, 76, $p$>0.78) (Table 2). Female pupae were heavier than male pupae.

Apart from the male pupae of *L. monacha* that had fed on *Picea glauca*, where only three out of five pupae emerged, eclosion success was generally high in all treatments (Table 2). Viable egg masses were produced by *L. monacha* pairs that successfully mated after being reared on all three host treatments. After the eggs went through the normal chill period, an average (standard deviation in parentheses) of 82% (6%) of the embryonated eggs laid by females reared on *P. glauca* hatched, 73% (16%) on *Pinus radiata* with cones, and 64% (11%) on *P. radiata* without cones. The hatched larvae all grew normally, with those from *Picea glauca* females growing the fastest.

## *Lymantria dispar* Survival and Development

*First 14 days*

*Lymantria dispar* larvae placed on *Q. velutina* foliage initiated feeding almost immediately, and development was rapid. In comparison, *L. dispar* larvae placed on *P. radiata* foliage initially did not feed. Larvae spun large quantities of silk and spent much time wandering about the container. When feeding was finally initiated (often after many days), only the youngest unexpanded needles were fed upon. Generally needles were chewed through at the base and feeding continued within or around the area of the young needle sheath.

The survival of *L. dispar* larvae fed *Q. velutina*, one of the suitable host species for *L. dispar*, at 14 days was compared with those fed *P. radiata* foliage. There was a significant effect of host foliage on survival rates but no significant effect contributed by the container (GLM where host $F$=128.3, df=1, $p$<0.0001, and container $F$=4.1, df=5, $p$>0.07). Mean percentage survival was more than twice as good on *Q. velutina* as it was on *P. radiata* (Table 1).

*Lymantria dispar* larvae that fed for 14 days on *Q. velutina* weighed almost 50 times more than those that fed on *P. radiata* foliage (Kruskal-Wallis test $H$=148.24, df=1, $p$<0.0001) (Table 1). From this result it was not possible to completely rule out a potential side-effect, resulting from which rearing container the larvae had grown in ($H$=28.8, df=5, $p$<0.001). The significantly retarded growth rate of larvae on *P. radiata* was also reflected in the instar that larvae had reached after feeding for 14 days. Most *L. dispar* larvae on *P. radiata* were at the second instar stage, while those on *Q. velutina* were most commonly fourth instar (Fig. 1). The mean weight of each larva at the beginning of the test was 0.7 mg and there was no significant difference between containers (95% were within 0.01 mg of the median, Wilcoxon Signed Rank Test).

*Development to pupation, and eclosion success*

*Lymantria dispar* larvae continued to feed until pupation on both *P. radiata* and *Q. velutina* foliage. Larvae feeding on *Q. velutina* pupated significantly sooner than larvae feeding on *P. radiata* (Table 3). The suitability of the two hosts for development was reflected in the weight attained by the pupae and the percentage of larvae that successfully pupated. Significantly more larvae that fed on *Q. velutina* developed into pupae and the

TABLE 3–*Lymantria dispar* mean time to pupation, mean pupal weight, and eclosion success according to plant larvae were reared on.

| | *Pinus radiata* A | | *Quercus velutina* | | ANOVA |
|---|---|---|---|---|---|
| Time to pupation | | | | | |
| Male larvae | 46.0 days | n 31 | 26.9 days | n 96 | $F$=365.4, $p$<0.0001 |
| Female larvae | 47.0 days | n 33 | 29.8 days | n 69 | $F$=620.6, $p$<0.0001 |
| Pupal weight | | | | | |
| Male | 0.489 g | n 31 | 0.632 g | n 96 | $F$=68.05, $p$<0.0001 |
| Female | 1.053 g | n 33 | 1.496 g | n 69 | $F$=58.5, $p$<0.0001 |
| Eclosion success | | | | | |
| Male pupae | 100% | | 100% | | |
| Female pupae | 96.9% | | 95.6% | | |

pupae were significantly heavier (both male and female) compared to those that fed on *P. radiata* (Table 3). There was virtually no mortality at the pupal stage, and eclosion success was similar in both sexes and treatments. No matings were attempted although viable adults were obtained.

## DISCUSSION

The dominance of *P. radiata* in the plantation landscape in New Zealand means that the consequences of serious attack from exotic pests and pathogens would be significant (Gadgil & Bain 1999). The principal pathways by which forest pathogens and pests enter New Zealand are on containers, or in wood packaging and dunnage and debris inadvertently trapped in cargo (both sea and air), and in imported used vehicles (Ridley *et al.* 2000). Even the most stringent quarantine and biosecurity practices are unlikely to completely remove the risk of importation of a Northern Hemisphere pest or pathogen that would be capable of significant impact on the health of New Zealand's exotic plantation forests.

### *Lymantria monacha*

*Lymantria monacha* is one of the most important insect pests of conifers in Europe (Jensen 1991). Outbreaks have occurred in central European countries such as Poland and adjacent countries, but can also occur in forests further to the north (e.g., Denmark) and south (Jensen 1991). *Lymantria monacha* has been identified as a potential threat to forests in North America (Keena *et al.* 1998). It is univoltine and adults are active in July to August in the Northern Hemisphere. The female moth lays one or more batches of about 40 eggs, deep within cracks and crevices or under lichen and, because of the difficulty in detecting them, the egg masses may easily be transported on containers, pallets, and ships (Keena *et al.* 1998). Furthermore, both male and female are relatively large moths and strong fliers. In Russian far east ports, adult moths are regularly observed flying to lights (Munson *et al.* 1995). These characteristics suggest accidental introductions into other countries could easily occur.

The embryo completes development and then enters diapause over winter until hatching in early spring. The larvae feed through five to seven instars before pupating, generally on tree trunks in mid-summer (Bejer 1988). The larvae are polyphagous and, although showing preferences for Pinaceae hosts, during outbreak conditions they can feed on numerous plant genera including *Salix*, *Populus*, and *Malus* (apples) (Lipa & Glowacka 1995).

In the present study *Pinus radiata* foliage was presented to larvae in no-choice feeding trials, either with or without male cones picked from another host pine, and the control host was *Picea glauca*. The low survival and poor growth of *L. monacha* larvae on *P. glauca* was unexpected, as in previous experiments (Keena unpubl. data) survival had been approximately 75% after 14 days' feeding on this species. The discrepancy was attributed to the new foliage on *P. glauca* in Connecticut having already begun to toughen when the present study was carried out (mid-June). The low initial survival on *P. glauca* can therefore be attributed to poor synchrony with *P. glauca* bud burst, and illustrates *L. monacha*'s need for synchrony to the phenology of its host plants. However, the egg mass production, hatch success, and growth of the resulting larvae all indicated that *P. glauca* was still a better host than *Pinus radiata* for *L. monacha*.

In comparison, the survival and development of *L. monacha* larvae on *P. radiata* was moderate in the replicate where no male cones were present, and good where male cones of *P. strobus* were present for the first 14 days. At this time larvae on *P. radiata* without male cones were second and third instar, and those supplemented with male cones second, third, and some fourth instar. On optimal host trees, the majority of larvae could be expected to have reached the fourth instar by this age (Keena unpubl. data). All trees from the three New Zealand advanced-selection families of *P. radiata* were equally suitable for survival and development of *L. monacha* in the first 14 days. The larvae were often found feeding along older *P. radiata* needles, and there was no evidence to suggest that even fully expanded needles were too tough for the young larvae to ingest. When male cones of *P. strobus* were present, a high proportion of larvae fed on the pollen grains and the cones themselves, although rarely to the exclusion of the *P. radiata* needles. The differences between the treatments could not be attributed to *L. monacha* larvae feeding on *P. strobus* needles, as these had carefully been removed from the sprigs carrying the male cones. The better development and higher survival for these first 2 weeks was attributed to the superior quality of pollen as a food source for newly hatched *L. monacha* larvae. Further research is needed to determine whether *P. radiata* male cones provide the same high quality food source as *P. strobus* male cones.

Adult *L. monacha* that developed on *P. radiata* attained weights comparable to those attained on other hosts in laboratory experiments, such as *Picea abies*, *Pinus sylvestris*, and *P. strobus* (Keena unpubl. data). These species are among those severely damaged in outbreaks in Europe (Sliwa 1987). The present study therefore shows that *P. radiata* is both an acceptable and a suitable host for *L. monacha*. Advanced breeding lines of *P. radiata* would be at serious risk should *L. monacha* establish in New Zealand, resulting in serious impact on the forestry sector. The presence of male cones (present in July and August in New Zealand) would probably increase the survival and growth rate of *L. monacha* larvae; however, even in their absence, *L. monacha* is likely to have little difficulty in feeding and developing exclusively on needles of *P. radiata*. Furthermore, *Pseudotsuga menziesii*, the second most-abundant plantation forestry species in New Zealand, is also known to be highly susceptible to *L. monacha* (Sliwa 1987; Keena 1999).

## *Lymantria dispar*

*Lymantria dispar* is also considered to be a serious insect pest of forests (Montgomery & Wallner 1988) and has been found on more than 600 species of plants (Baranchikov 1989).

*Lymantria dispar* is native to most temperate areas of Europe, Asia, and North Africa (Montgomery & Wallner 1988). A hardwood rather than a conifer specialist like *L. monacha*, the preferred hosts of the European strain of *L. dispar* include species of *Quercus, Malus, Liquidambar, Alnus, Tilia, Betula, Populus, Salix*, and *Crataegus* (Liebhold *et al.* 1995). Young larvae are generally limited to these preferred host genera, while older larvae are capable of feeding on a wider range of genera. In North America during outbreak conditions, which can occur at intervals of 4–12 years and last from 2 to 5 years, *L. dispar* larvae will feed on virtually all plant species present (Liebhold *et al.* 1995).

Generally most species within the Pinaceae can be considered as either "virtually resistant" or only "partially susceptible" to *L. dispar* (Liebhold *et al.* 1995). One published laboratory study tested the susceptibility of *P. radiata* to the European strain of *L. dispar* and concluded that development occurred through to the adult moth, but that pupation was less than 100%, and resulting pupae were <700 mg in weight (Miller & Hanson 1989). In comparison, pupae from preferred host plants are commonly over 1000 mg in weight and survival from egg hatch to pupation can be close to 100% (Liebhold *et al.* 1995).

The results of the present study confirm that the Russian strain of *L. dispar* can feed as a newly hatched larva, and complete development, on foliage from advanced selections of *P. radiata*. Larvae were able to feed only on the youngest needles on the tips of branches until approximately third instar. Those larvae that did survive the first 2 weeks on *P. radiata* subsequently fed on all ages of needles and survived to pupate and eclose successfully, and the weight of female pupae often exceeded 1000 mg. We would predict that *P. radiata* in New Zealand would be under a low to moderate threat from *L. dispar*, should this species ever establish.

The behaviour of newly hatched *L. dispar* larvae, in particular the spinning of copious quantities of silk, suggests that *P. radiata* needles are not preferred by this life stage. In the natural environment, ballooning neonate larvae landing on *P. radiata* needles would probably move off this plant and settle on a more preferred host. The degree to which this would be successful, however, would depend on the availability of more palatable host plants in the immediate vicinity. To what extent native New Zealand forest trees in the families Podocarpaceae and Nothofagaceae would be at risk from Asian *L. dispar* is currently under investigation (M.Kay unpubl. data).

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