Control of Leafrollers in Wine-grapes in the Wairarapa with Beneficial Insects and Insecticides.

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Executive Summary

The Wairarapa wine-grape region has provided large populations of leafrollers, allowing the testing and extension of ideas on the biological control of leafrollers.

Three generations of caterpillars are seen on the leaves and two on the bunches. Identification of these generations was improved with the use of activity measurements that provided "shadow" peaks displaced in time. Use of logarithms when graphing data helped to pinpoint early peaks. These peaks were most easily seen in the unsprayed vineyard (E).

The introduced Light Brown Apple Moth (*Epiphyas postvittana,* LBAM) was the only significant species present on three vineyards. One vineyard contained numbers of the native *Ctenopseustis* sp. in addition to LBAM.

Large numbers of caterpillars appear in December. In the unsprayed vineyard (E) 37% of the caterpillars survive in February and March. This is sufficient to allow a steady increase in numbers as the season moves to harvest.

Dolichogenida tasmanica is the most common wasp parasitoid present in vineyard E, with significant numbers of *Goniozus jacintae*. *Glyptapanteles demeter* was rare. Numbers of beneficials increase steadily, taking 63% of the caterpillars from December to March but are insufficient to contain the leafroller population. These results are very similar to the results from a single collection from this vineyard in March the previous year.

Though live caterpillars were present in 10% of the bunches at harvest and evidence of insect activity (beneficial wasp cocoons, empty excavations etc) was found in 78% of the sample of 100 bunches, only one sour rotted berry (and no *Botrytis*) was found.

Two vineyards were sprayed with Mimic, vineyard F spraying in December (80% cap-fall) and vineyard G in January (pre-bunch closure).
The vineyard spraying in December had a history of heavy infestation the year before. Large leafroller caterpillars were found feeding on the freshly opened buds in October and had clearly moved up the vine from the sward. The Mimic spray reduced the leaf population to low levels and completely controlled the leafrollers on the bunches. At harvest (April 20th) there were no signs of the leafroller on the bunches and the LBAM leafroller on the leaves were completely controlled by *Dolichogenida tasmanica* and *Goniozus jacintae*.
The other vineyard (G) using Mimic showed complete control of leafroller on the leaves. Empty shelters were seen but no live caterpillars. The caterpillars on the bunches were all dead, either killed in characteristic fashion by the Mimic or

producing *Dolichogenida tasmanica*. This vineyard had a heavy infestation of mealybug (61% of bunches with *Pseudococcus calceolariae*).
The last vineyard (H) used two timed sprays of the biological insecticide *Bacillus thuringiensis* aimed at the large population of leafroller caterpillars that arrived in January. The first spray reduced the leafroller population by half. This was sufficient to allow the sizeable population of beneficial wasps to maintain control. Only 17% of the leafroller population survived between February and April and this was insufficient to allow the leafroller population to increase.

The population of caterpillars arrive in greatest numbers during the flush of leaf growth in December and January. Early action to reduce the mass of leaves by leaf plucking will reduce this feeding opportunity.

<u>Conclusions for growers in the Wairarapa</u>

- The difference between 37% survival of caterpillars and 17% survival is the difference between an expanding population and a population under good control.
- The beneficials alone are unable to control leafroller unless assisted by sprays of *Bacillus thuringiensis*
- A single Mimic spray completely controls leafroller on the bunches.
- The leafroller returning to the leaves on a Mimic sprayed orchard are met and completely controlled by beneficials.
- Early leaf plucking to reduce the excess leaf growth in December-January will minimise the feeding opportunities for leafroller.

Introduction

This study is a part of an exploration of the methods used by the New Zealand Wine-grape industry to control leafrollers. Work began in the Gisborne region and demonstrated the value of preserving the beneficial species that can make a large contribution to control.

The Wairarapa region offers a great deal to a researcher studying leafroller. A visit to an unsprayed vineyard in March 2000 found the highest population of leafroller on the vines of any region. The larger the data set, the more reliable the inferences. The large population in this region is likely to provide the severest test of theories on the biological control of this pest. I also wished to further define the extent to which leafroller are responsible for the development of the rots and diseases on harvested fruit. Results so far obtained suggest that other factors that lead to damage to the skins may be more important. The weather this season has been very variable and the opportunity was taken to compare and contrast the results from regions that have had a dry pre-harvest period with other regions that have been very wet.

The microbial insecticide *Bacillus thuringiensis* is a well established tool of organic farmers but suffers from a variable reputation as to its effectiveness. Use of a waterproofing agent can greatly improve the effectiveness of this material (Anon 1983). Trials by the Greek Institute of Forest Research showed that Thuricide ® HP with Nu-film-17 was more effective (20-40% more caterpillars killed) and outlasted Bt. alone (100% kill at 3 weeks compared with no kill for BT without Nu-film-17).

Mimic® (Rohm and Haas) is a new type of insecticide that selectively controls lepidopterous larvae by initiating a pre-mature lethal moult (Anon. 1994). The Light Brown Apple Moth, (LBAM, *Epiphyas postvittana*), the key grape leafroller in New Zealand is susceptible to this compound. Mimic has a half life of 32 to 52 days in orchards. Ninety two species of beneficial insects were found to be unaffected by this compound. Mimic has been found to be effective against LBAM infesting grapes in Australia (Hamblin *et al* 1998)

Methods

The sampling system used for Gisborne vineyards was modified slightly for the Wairarapa. Because blocks were smaller, the spacing was tighter with every fifth row used instead of every eighth row. Three entire vines were sampled per row and a sample of 30 vines was collected each month. Where more frequent samples were needed, the sample row was offset by one each time to ensure that a vine was not re-sampled before it could be replenished with leafroller from the next generation.
Some varieties of grapes are much more prone to attack by leafroller than others. Chardonnay and Pinot in Australia have relatively higher numbers of caterpillars than Shiraz and Cabernet (Clancy 1997).

Vineyard E has been free of insecticide sprays for over five seasons. Minimal sprays of sulphur for mildew control are the sole materials applied and the management and workers have a strong commitment to sustainable growing methods. A large block of Pinot Noir made up the main sample area with a smaller area adjacent to Hotels placed for *Ancistrocerus gazella* wasps. Flowering manuka plants were planted nearby to placed food for adult wasps.
A Chardonnay block was sampled at vineyard F. No insecticide sprays were applied the previous season and the grapes were crawling with leafroller at harvest. A single spray of Mimic was applied on the 14th December 2000. This Insect Growth Regulator(IGR) was claimed to be selective and not toxic to predators (Anon 1994).
A block of Pinot Noir provided the study site at Vineyard G. A single spray of Mimic was applied at standard rates on the 5th January 2001(pre-bunch closure). Mimic had also been used the previous season (29th December 1999).
Two varieties were studied in vineyard H. Riesling grapes were sampled from row 54 to 82 and Cabernet Sauvignon from row 26 to 44. A spray of *Bacillus thuringiensis* (Bt.) and Nufilm-17 was applied at dusk on 12th January and 15th February 2001 to control leafroller. Each 550 litre tank contained 350 gms Dipel (Nufarm) and 0.7 l. Nufilm-17 (Key Industries) and the spray was applied at 785 L./ ha. (minimum possible with this equipment). The excess leaves were plucked the 1-2 days before the reference sample was taken on 12th January.

Results

(A) Vineyard E, the unsprayed Vineyard.

The first vineyard studied (E) was unsprayed and provides a reference point for the other sprayed vineyards.

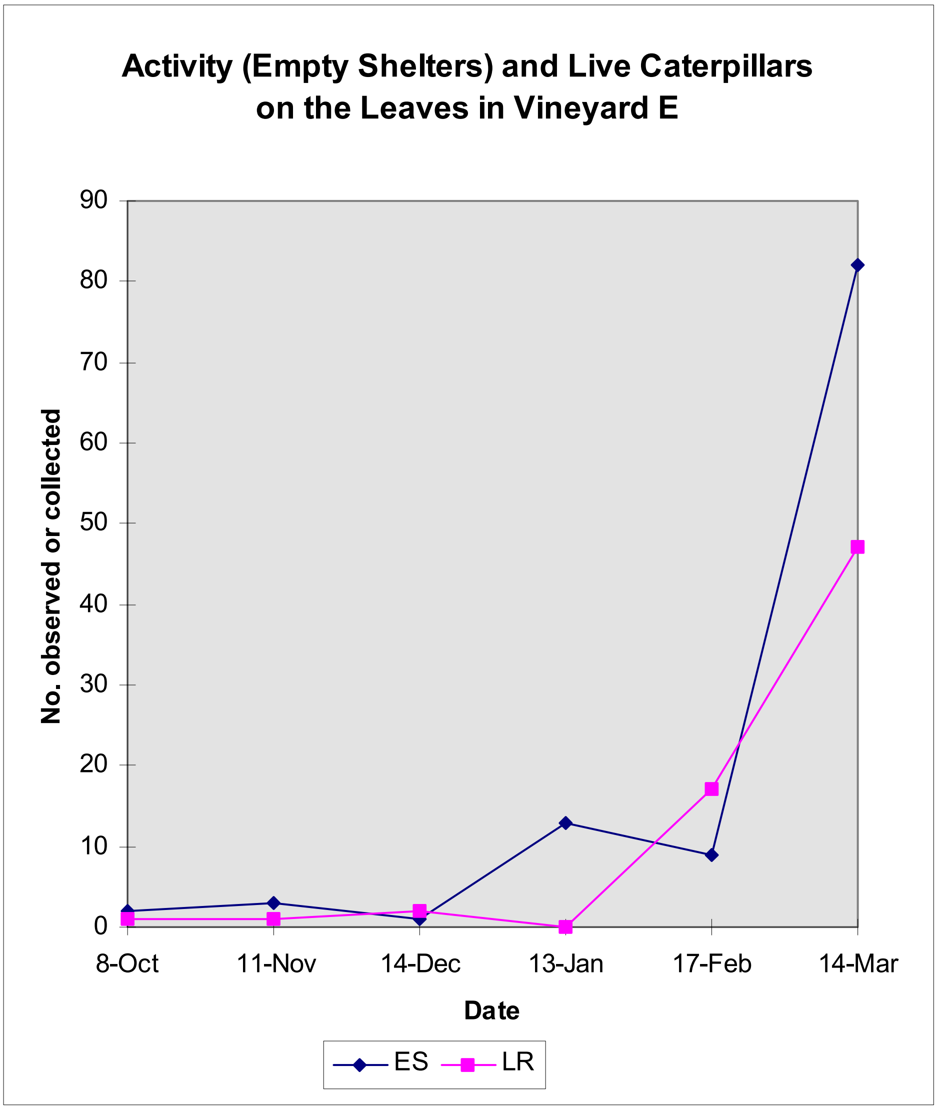

Fig 1 . Activity (ES) and caterpillar (LR) numbers on the leaves in Vineyard E. Field collected data. The whole of thirty Pinot Noir Vines from ten rows were sampled. The first noticeable caterpillar activity is seen in January with a larger peak beginning in March. The activity peak is steadily increasing to a maximum in March.

The two sets of data from caterpillar counts and caterpillar activity complement each other. The empty shelters are a record of the chewing and silk weaving of caterpillars that remains on the vine as the builder moves on to new sites. These evidences last longer than the leafroller and effectively provide a "shadow" displaced in time. Each leafroller generation will consist of the rise and fall of the numbers of caterpillars with a matching, displaced by up to one month, peak of empty shelters. A single caterpillar may produce many shelters in the course of its caterpillar-hood. When populations are low the progress of a single caterpillar can be traced as it moves from shelter to shelter along the leaves of a branch. The chewing scars are fresher and the shelters are larger as the caterpillar grows. The activity peaks are therefore larger and may clearly show the presence of a generation that is poorly shown by the number of caterpillars. Generations may be even more apparent when the data is presented logarithmically (fig.2).

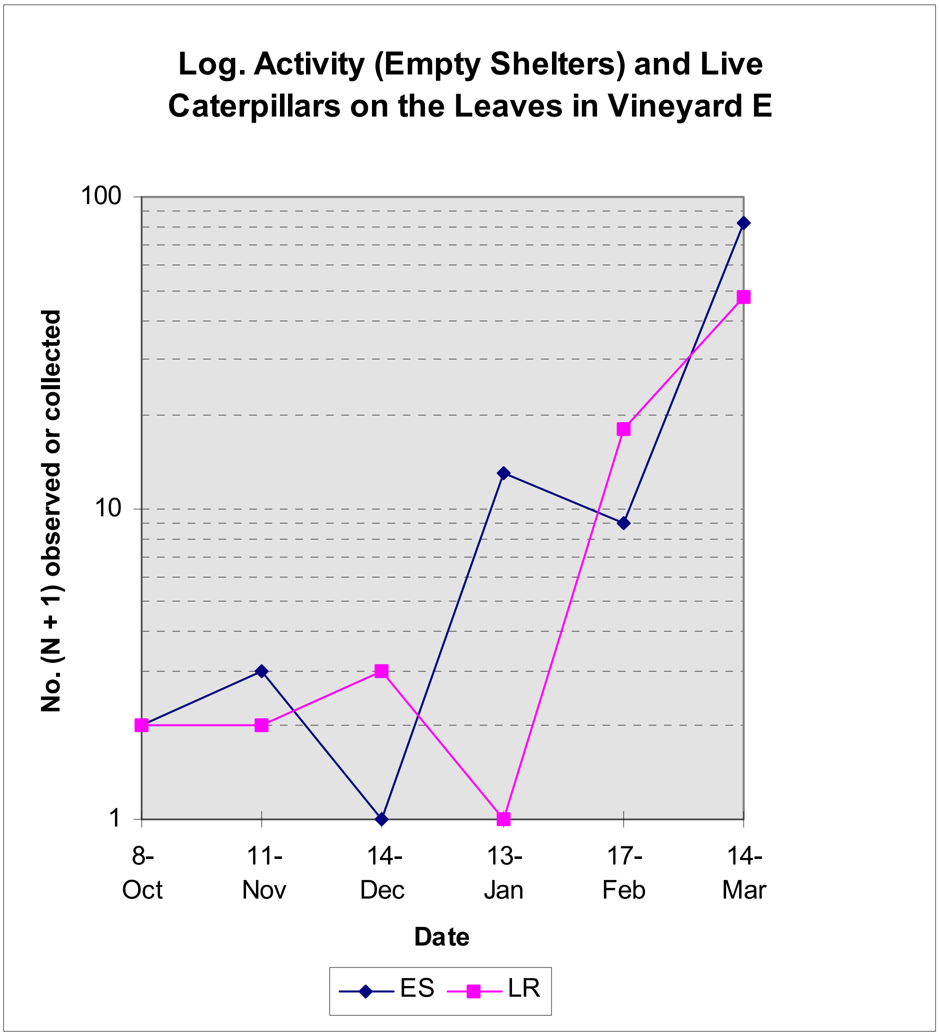

Fig. 2 .Activity and caterpillar numbers on the leaves in Vineyard E presented logarithmically . Field collected data. The whole of thirty Pinot Noir Vines from ten rows were sampled.

The first caterpillar activity peaks in November suggesting that leafrollers were present in small numbers in October (fig.2). Leafrollers were indeed collected in October but in numbers too low to be visible as any sort of peak. Small numbers of leafrollers are collected in December with a corresponding "shadow" of activity seen in January. This is generation 2. Leafroller numbers climb sharply in February and continue in March. The "shadow" for generation 3 is appearing in March.

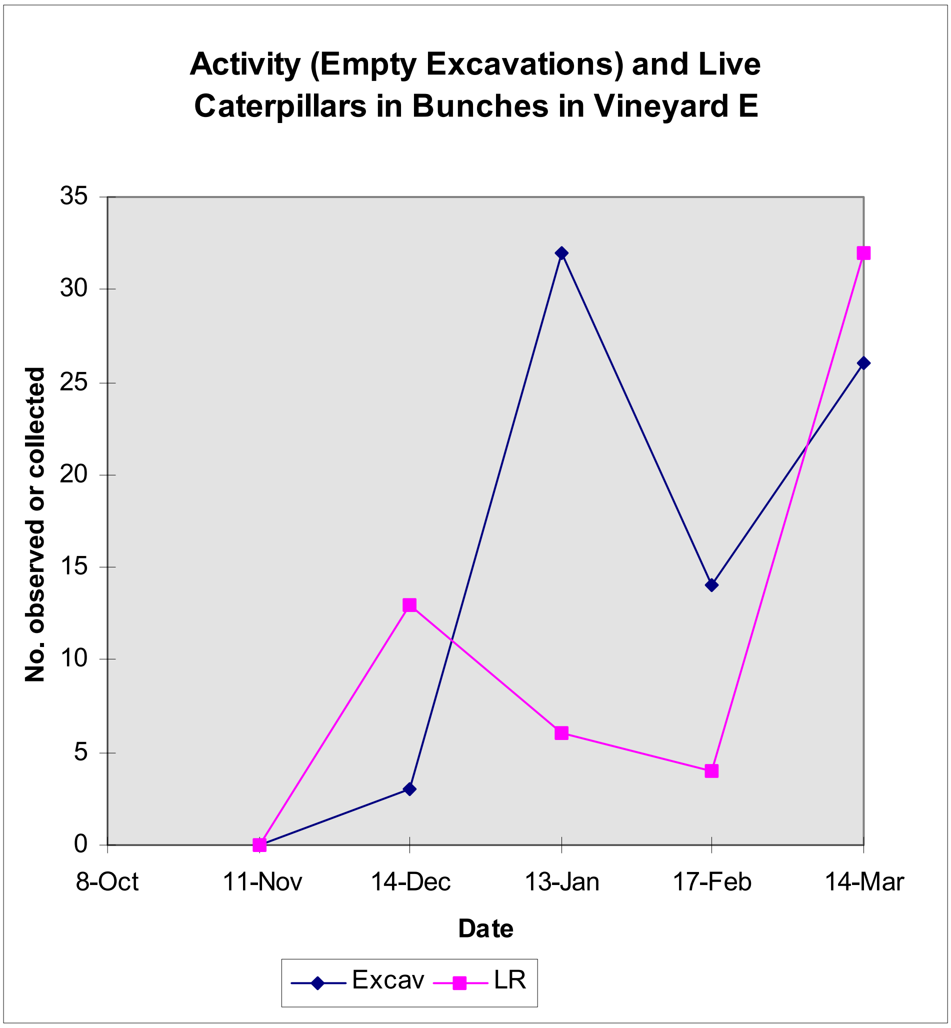

Fig. 3 Activity (empty excavations) and leafrollers in the bunches in vineyard E. Field collected data. The whole of thirty Pinot Noir Vines from ten rows were sampled.

Grape flowers appear in November and following fertilisation, the “caps” fall revealing the new berries in December. Two generations of leafroller caterpillars appear on the bunches, the first peaking in December on the very small “shot-size” berries. The activity “shadow” for this generation appears in January, as seen before on the leaves much larger than the associated live leafroller peak. The leafrollers collected on the berries in February were all very small early instars. (The seminar field trip the day before similarly collected small caterpillars) Caterpillars of this size are easily detected on the leaves by the scar next to the leaf midrib produced by the feeding activity underneath. More feeding by a larger caterpillar in the bunches is necessary to detect the “raisins” (slightly shrivelled berries that show a caterpillar feeding on the stalk and impeding the fluid flow to the berry). For this reason, the number of caterpillars sampled in February from bunches should be suspected to be low. The largest catch of caterpillars came in March.

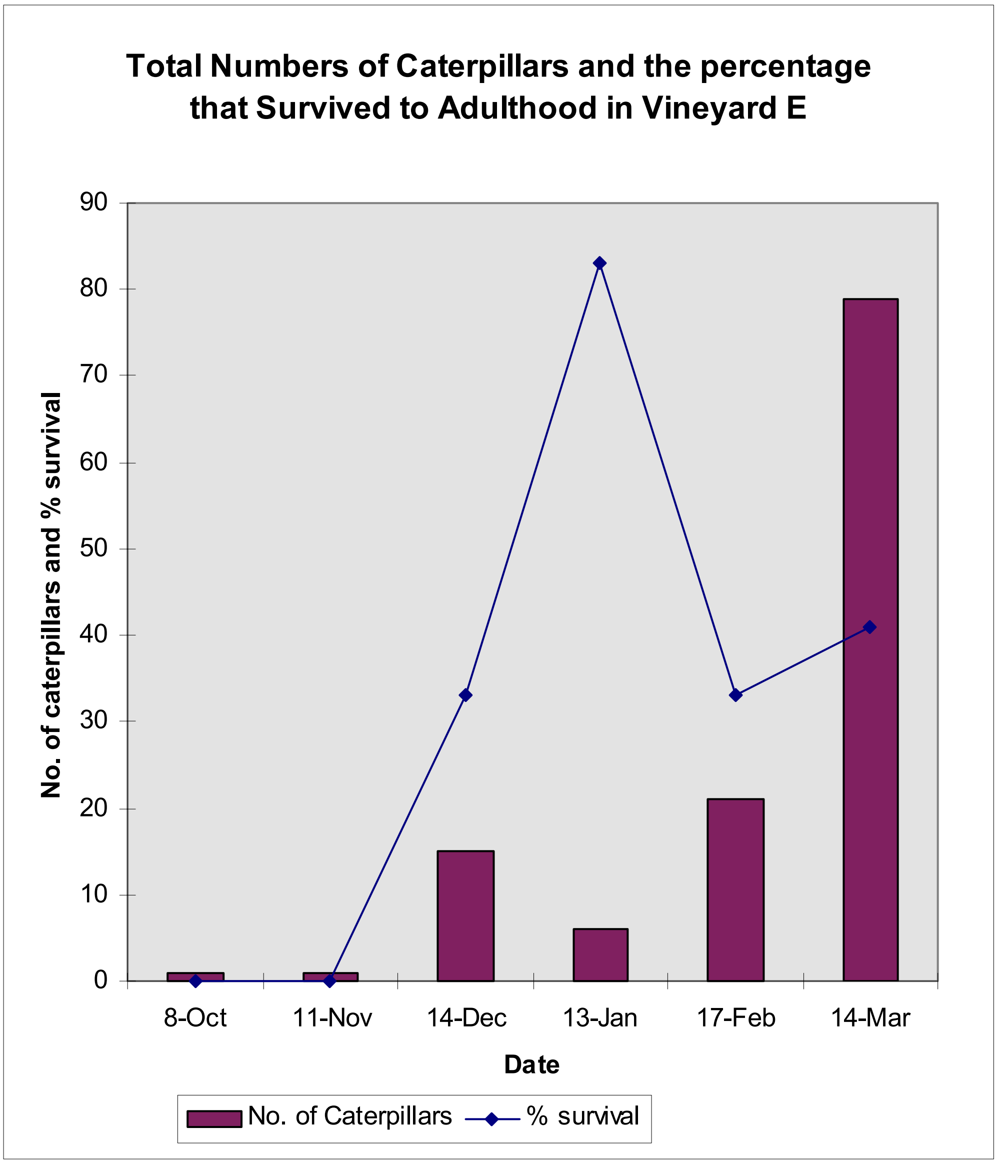

Fig. 4 All of the caterpillars collected and their survival to adult moths in vineyard E. The whole of thirty Pinot Noir Vines from ten rows were sampled.

Numbers of caterpillars climb steadily from January to March(fig.4). Survival drops sharply from January (83%) to February (33%) before steadying in March (41%). Very different outcomes from a similar base are observed in December and February. Survival is identical on 33% and actual numbers present are similar but numbers decrease in January and sharply increase in March, the months following. The distribution of these caterpillars differed between December and February, with most in the bunches in December and most in the leaves in February. All the moths produced from this vineyard (50) were *E. postvittana*(LBAM).

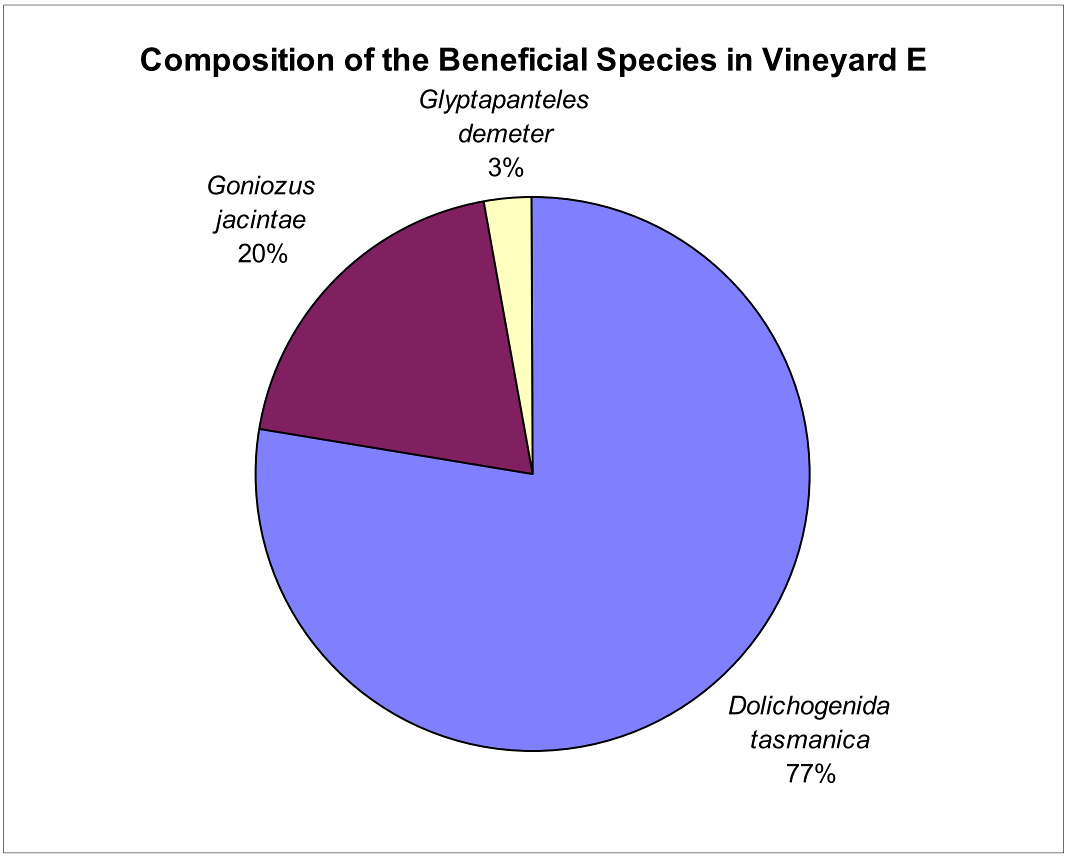

Fig. 5 Proportions of the beneficial species present in the Vineyard E Total of 111 insects.

Most (77%) of the beneficial wasps found were the solitary parasitoid *D. tasmanica,* with 20% *G. jacintae* and a small percentage of *Gl. demeter.*

Table 1 Total beneficial insects, both collected as empty and full cocoons and reared from caterpillars. *D. tasmanica* is solitary, with one new wasp produced from every caterpillar taken. *G. jacintae* and *Gl. demeter* produce more than one new wasp. Numbers of new wasps in brackets, numbers of caterpillars un-bracketed.

	Dolichogenida tasmanica		*Goniozus jacintae*		*Glyptapanteles demeter*	
Date	Leaf	Bunch	Leaf	Bunch	Leaf	Bunch
8-Oct	2		0		0	
11-Nov	1		0		0	
14-Dec	1	5	0	1(2)	0	2(17)
13-Jan	5	20	0	0	0	1(7)
17-Feb	8	5	0	0	0	0
14-Mar	30	9	5(6)	16(39)	0	0

Numbers of *D. tasmanica* are equally distributed between leaves(47) and bunches (39), while *G. jacintae* prefers the bunches (17) rather than the leaves(5).

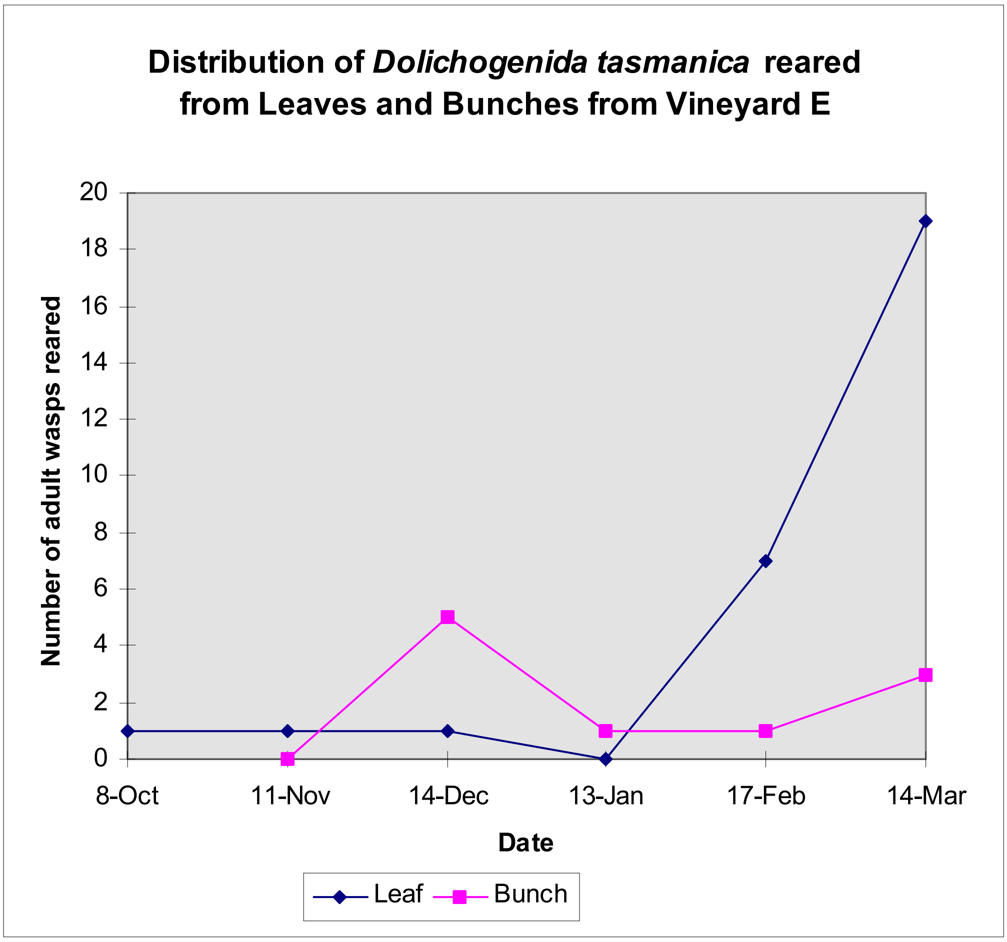

Fig.6 *D. tasmanica* reared from caterpillars collected from leaves and bunches. The whole of thirty Pinot Noir Vines from ten rows were sampled.

The distribution of the wasp follows closely the distribution of their prey. The wasp from the leaves (fig.6) matches the distribution of caterpillars on the leaves (fig.1) and the wasps from the bunches matches the caterpillars from this source (fig.3).

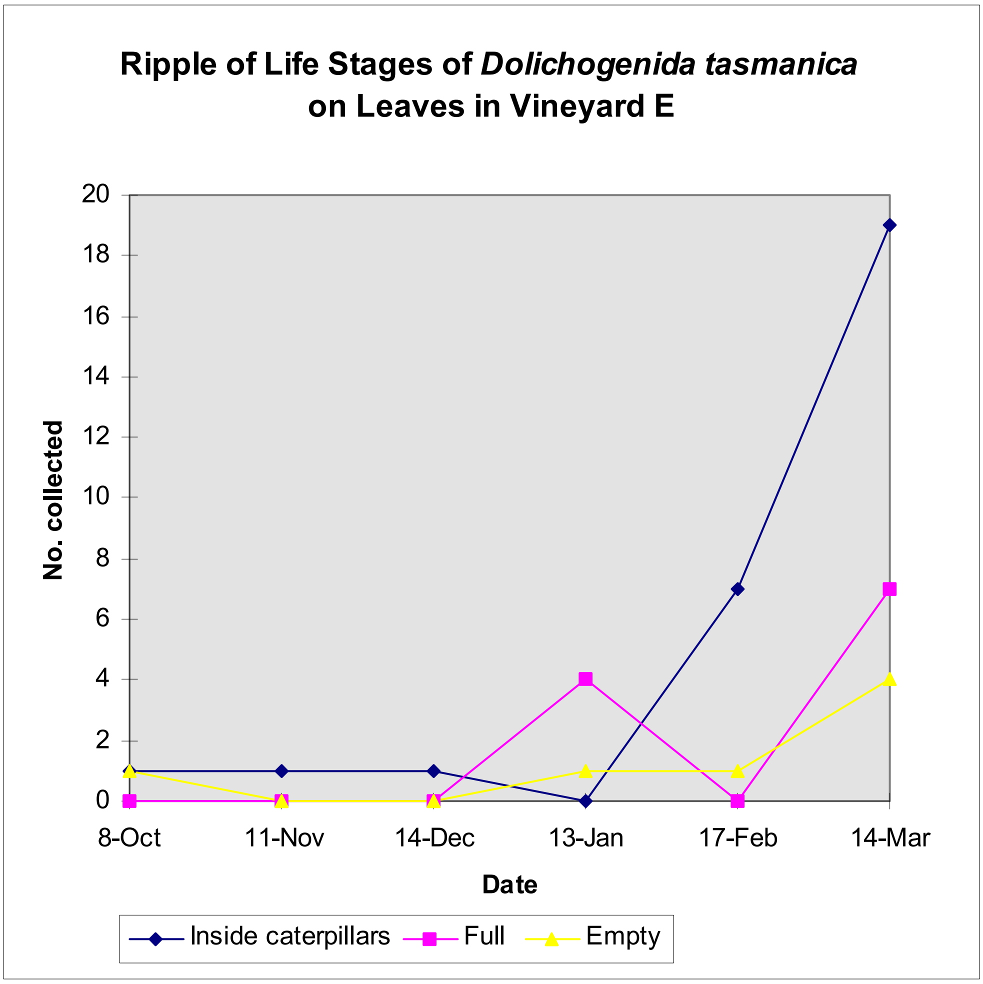

Fig.7 The various life-stages of *D. tasmanica* on leaves can be graphed to fill out the impression of each generation. The grubs inside the caterpillar are estimated from the numbers of adult wasps emerging from the rearing tubes, the full and empty cocoons are collected from the field. The whole of thirty Pinot Noir Vines from ten rows were sampled.

The peak of full cocoons observed in January suggests the presence of a first generation of wasp grubs inside caterpillars on the leaves in November - December (fig.7). The steady rise of grubs from January to March is followed up first by the full cocoons and then by the empty.

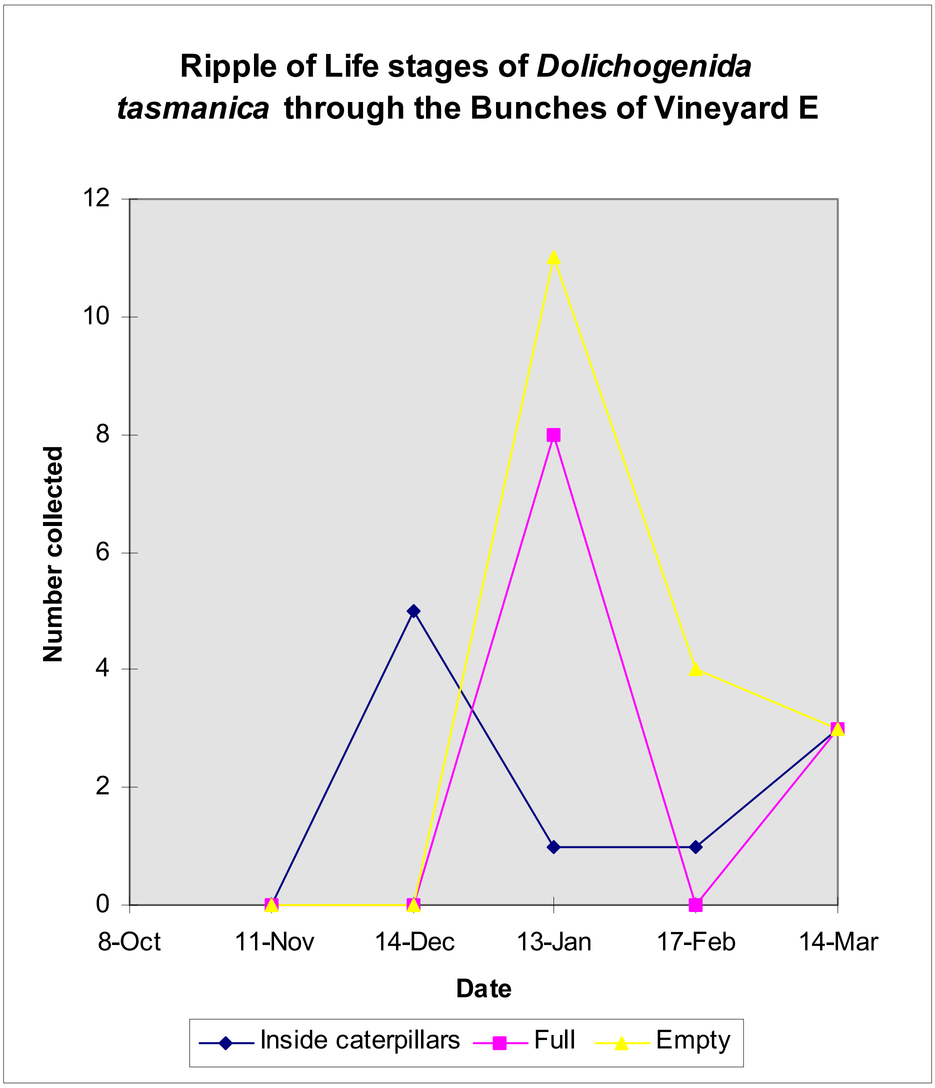

Fig.8 The various life-stages of *D. tasmanica* can be graphed to fill out the impression of each generation. The grubs inside the caterpillar are estimated from the numbers of adult wasps emerging from the rearing tubes, the full and empty cocoons are collected from the field. *D. tasmanica* from the field on bunches. The whole of thirty Pinot Noir Vines from ten rows were sampled.

The peak of wasp grubs on the bunches in December is "shadowed" by simultaneous peaks of full and empty cocoons the following month. There a very slight indication that the empty cocoon numbers fall behind the full ones.

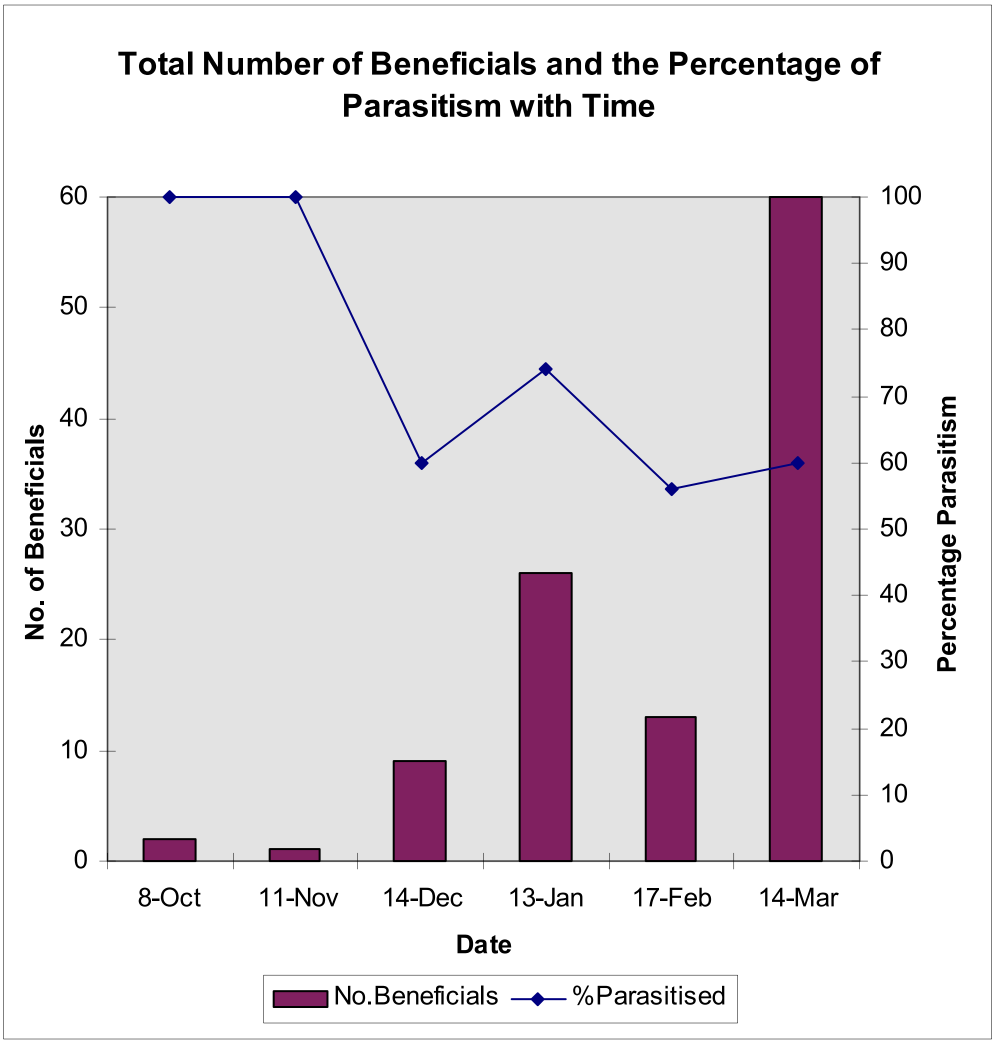

Fig. 9 Totals of all beneficials from Vineyard E with measures of the proportion of caterpillars parasitised. The whole of thirty Pinot Noir Vines from ten rows were sampled.

There is a general, if irregular increase in beneficial numbers as the season progresses. The percentage parasitised in the first part of the season (October-November) based as it is on small numbers is not terribly meaningful. Once the numbers have increased (December onwards) the proportion taken by the beneficials remains rather stable (56-74%, average = 63%).

With an expanding pest population, it was not surprising to find much evidence of insect activity in the bunches (fig. 10). Only 22% of the bunches were free of insects. Half of the bunches had parasitoids, almost equally divided between *D. tasmanica* and *G. jacintae*. The remaining quarter of the sample was infested by leafrollers, half evidence of their past presence and half live insects. Despite this heavy infestation, only one Pinot Noir berry was sour rotted out of the sample of 100 bunches. A live leafroller was feeding nearby.

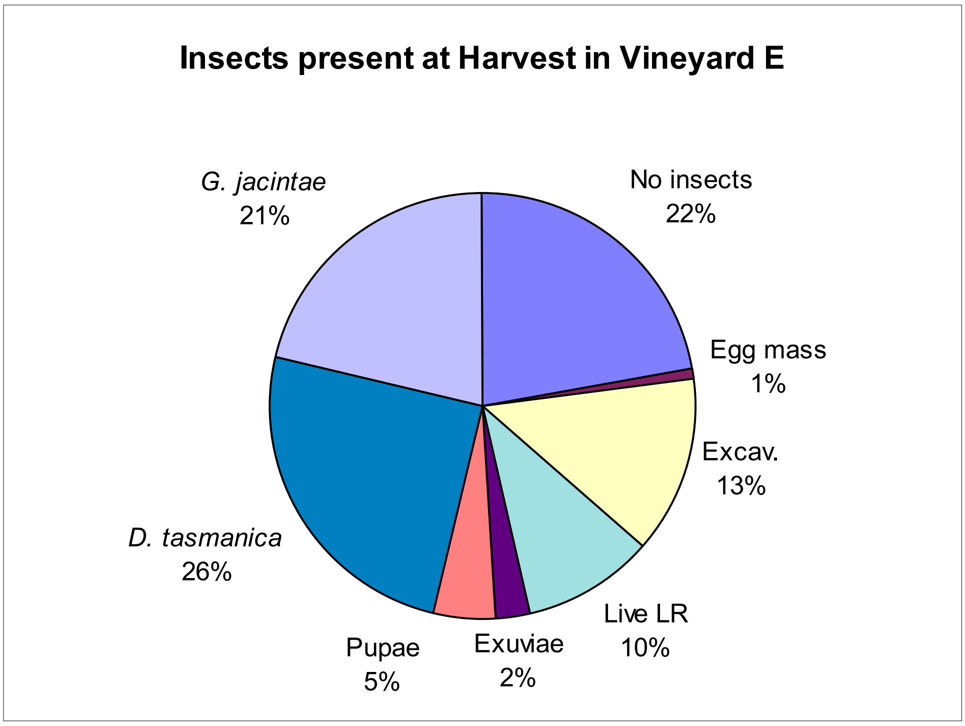

Fig.10 Insects, beneficials and pests present at harvest. Grapes were harvested by the grower and cool-stored till analysed on the 21st April. Sample of 98 bunches.

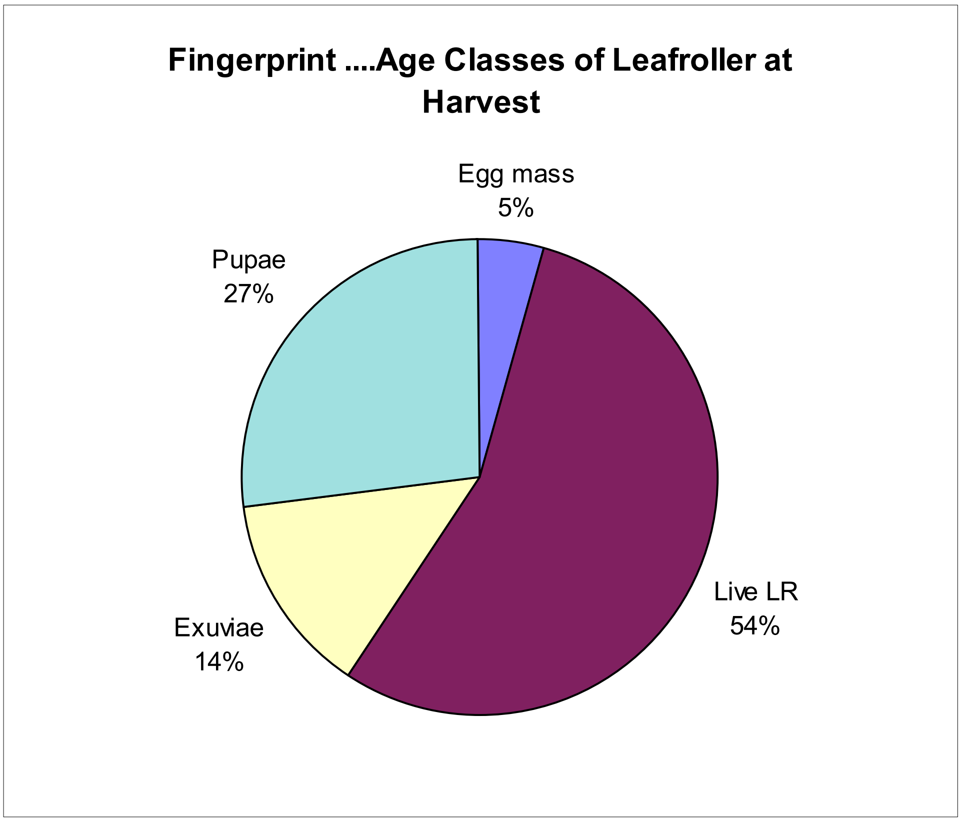

Fig 11 Age classes on the harvested bunches from Vineyard E. Sample of 98 bunches. (Subset of the data in fig. 10). An exuviae is the shell left behind as the moth emerges from the pupae.

The population has a high proportion of older age classes (pupae plus exuviae = 41%) and thus further indicates that the leafrollers are not under good bio-control.

(B) Vineyard F, early use of Mimic.

Few caterpillars or signs of activity were recorded from this vineyard. Compared with the first vineyard meaningful patterns were difficult to pick out……this should be expected for any data set with small numbers collected. The vines were in bud and had produced a small number of leaves by the 8th of October. Six caterpillars were collected(fig.12). Four of these were large but had been collected from buds that showed little sign of feeding and without neighbours that had been feed on. The conclusion was unescapable that the caterpillars had migrated onto the bud rather than had grown by feeding on the vine.

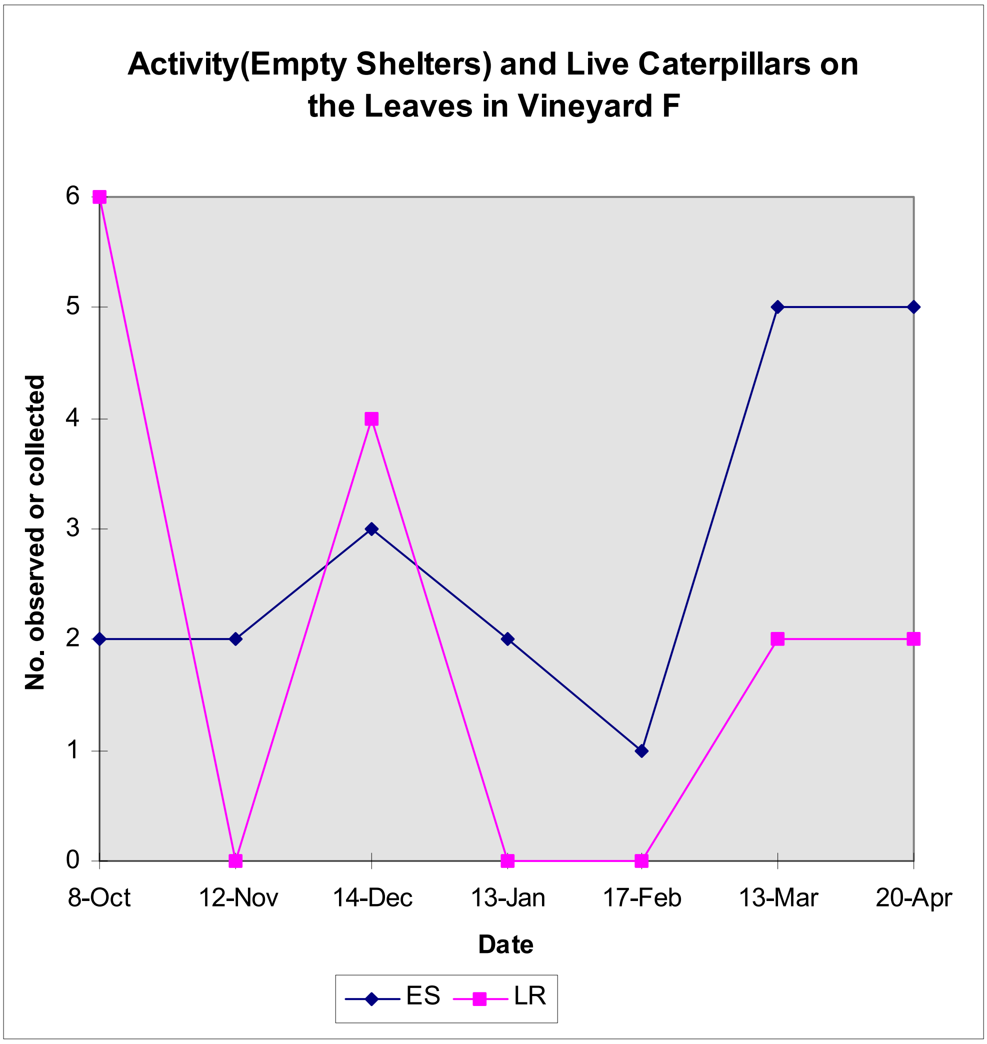

Fig. 12 Activity and caterpillar numbers on the leaves in Vineyard F. Field collected data. Most caterpillars were collected on the first sample. The whole of thirty Chardonnay Vines from ten rows were sampled.

Four more caterpillars were taken two months later, one died, one produced an adult and two produced parasitoids (fig.12). The two caterpillars collected on the 13th March both produced adult *E. postvittana* moths showing that there was sufficient leaf material without active Mimic deposit on it. The deposit applied in December may have degraded or the caterpillars may have fed on new grown leaves.

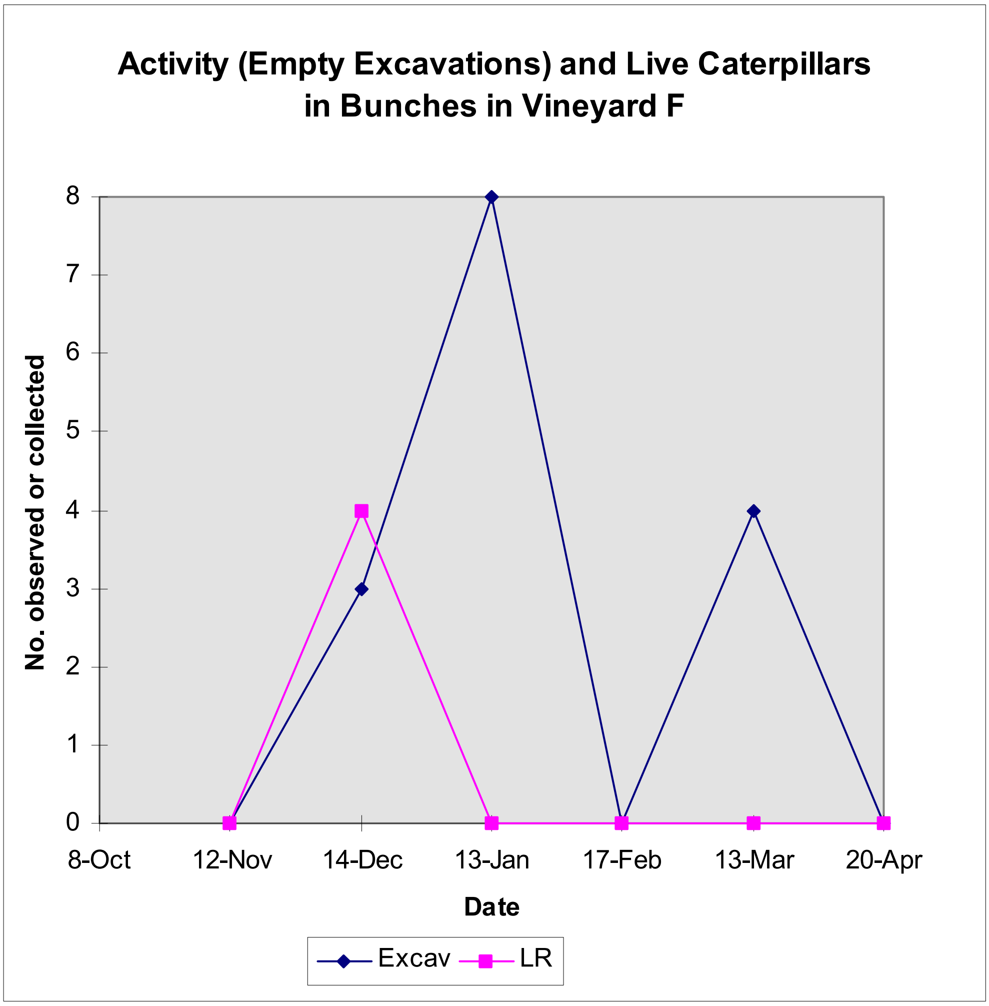

Fig. 13 Activity (empty excavations) and leafrollers in the bunches in vineyard H. Field collected data. The whole of thirty Chardonnay Vines from ten rows were sampled.

The only leafroller collected from the grape bunches were taken on the 14th December. All four successfully produced adult moths, three *E. postvittana* and one native *Ctenopseustis* sp. A "shadow" peak of activity followed and some activity (but no live caterpillars) was seen in March.

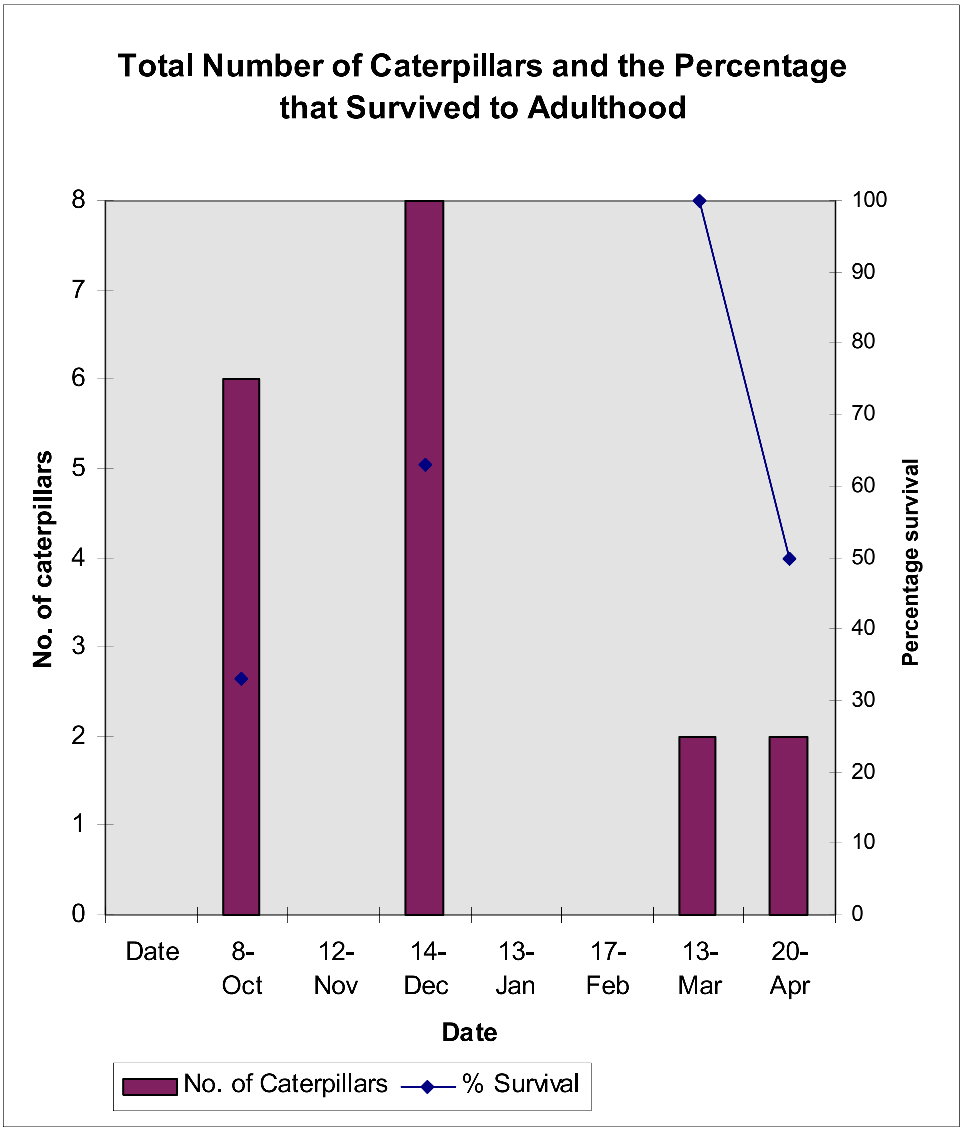

Fig. 14 All of the caterpillars collected and their survival to adult moths in vineyard F. The whole of thirty Chardonnay Vines from ten rows were sampled.

One of the two caterpillars collected on the 20th April had a long white egg attached to the pronotum behind the egg. This caterpillar produced a *D. tasmanica* wasp as expected. The second caterpillar was neither an introduced or native leafroller as was still feeding sluggishly on the diet at the time of writing this report (3rd August 2001 last check…..4 months as a caterpillar!!). This suggests that it was not a leafroller as it clearly was not happy with the provided food.

Only 19 individuals from the beneficial species were collected from vineyard F. (table2). All three wasp species were present.

<u>Table 2</u> Total beneficial insects, both collected as empty and full cocoons and reared from caterpillars. *D. tasmanica* is solitary, with one new wasp produced from every caterpillar taken. *G. jacintae* and *Gl. demeter* produce more than one new wasp. Numbers of new wasps in brackets, numbers of caterpillars un-bracketed.

	Dolichogenida tasmanica		*Goniozus jacintae*		*Glyptapanteles demeter*	
Date	Leaf	Bunch	Leaf	Bunch	Leaf	Bunch
8-Oct	0	0	0	0	2(23)	0
12-Nov	0	0	0	0	1(18)	0
14-Dec	1	0	0	0	1(4)	0
13-Jan	0	1	0	0	0	0
17-Feb	0	2	0	0	0	0
13-Mar	1	0	2(3)	0	0	0
20-Apr	6	0	2(3)	0	0	0

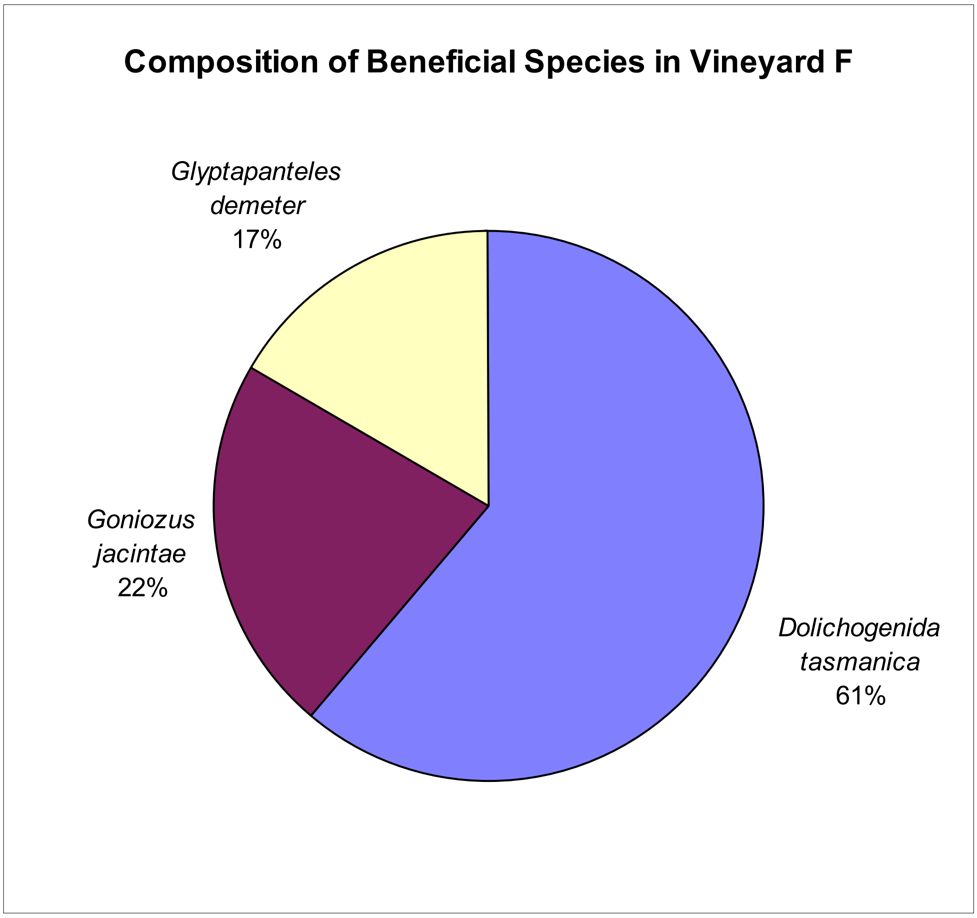

Fig. 15 Proportions of the beneficial species present in the Vineyard F Total of 19 insects.

Most (61%) of the beneficial wasps found were the solitary parasitoid *D. tasmanica,* with 22% *G. jacintae* and 17% *Gl. demeter.*

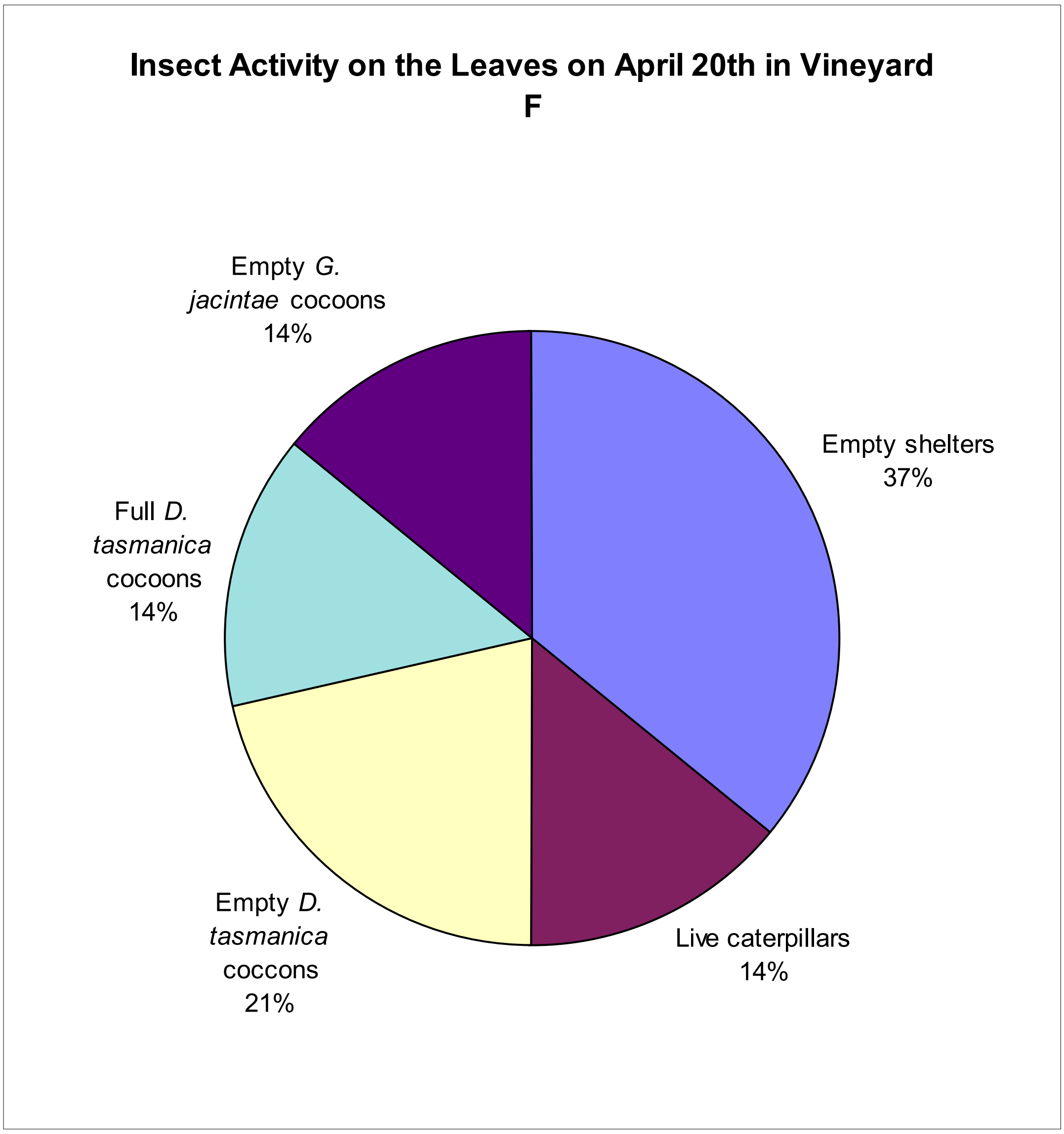

Fig.16 The only live insect material available during the April 20th sample was taken from the leaves. (see above for the fate of the caterpillars).

The presence of full *D. tasmanica* cocoons that later produced live wasps (in culture) is particularly significant as it shows that activity of beneficials is possible after a Mimic spray. No live leafrollers were produced by vines from this sample….the beneficials got them all apart from one caterpillar that was clearly not a leafroller.

(C) Vineyard G, the late spray of Mimic.

This vineyard received a single spray of Mimic on the 5th January, shortly before bunch closure. Signs of activity on the leaves were present, but no live leafrollers were collected (fig.17).

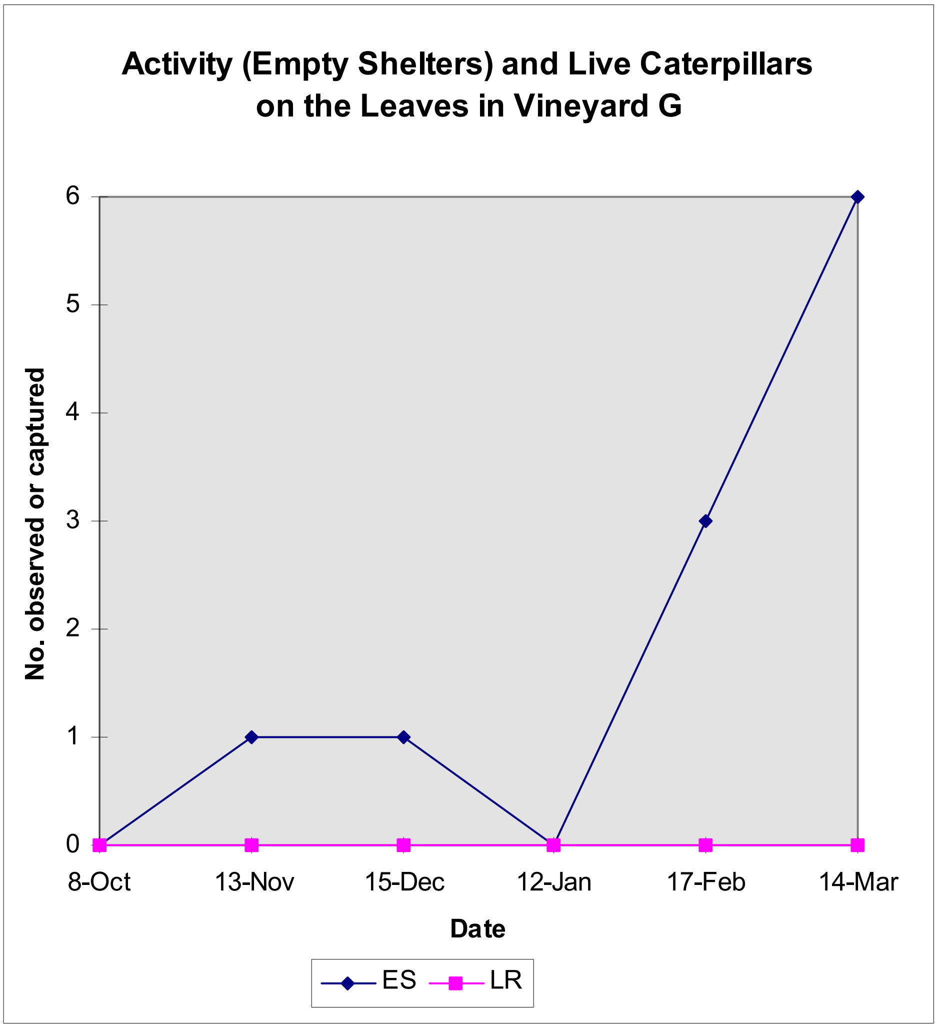

Fig. 17 Activity and caterpillar numbers on the leaves in Vineyard G. Field collected data. The whole of thirty Pinot Noir Vines from six long rows were sampled.

The only indication of the presence of leafroller in the leaves in this vineyard were abandoned shelters. No live leafrollers were found.

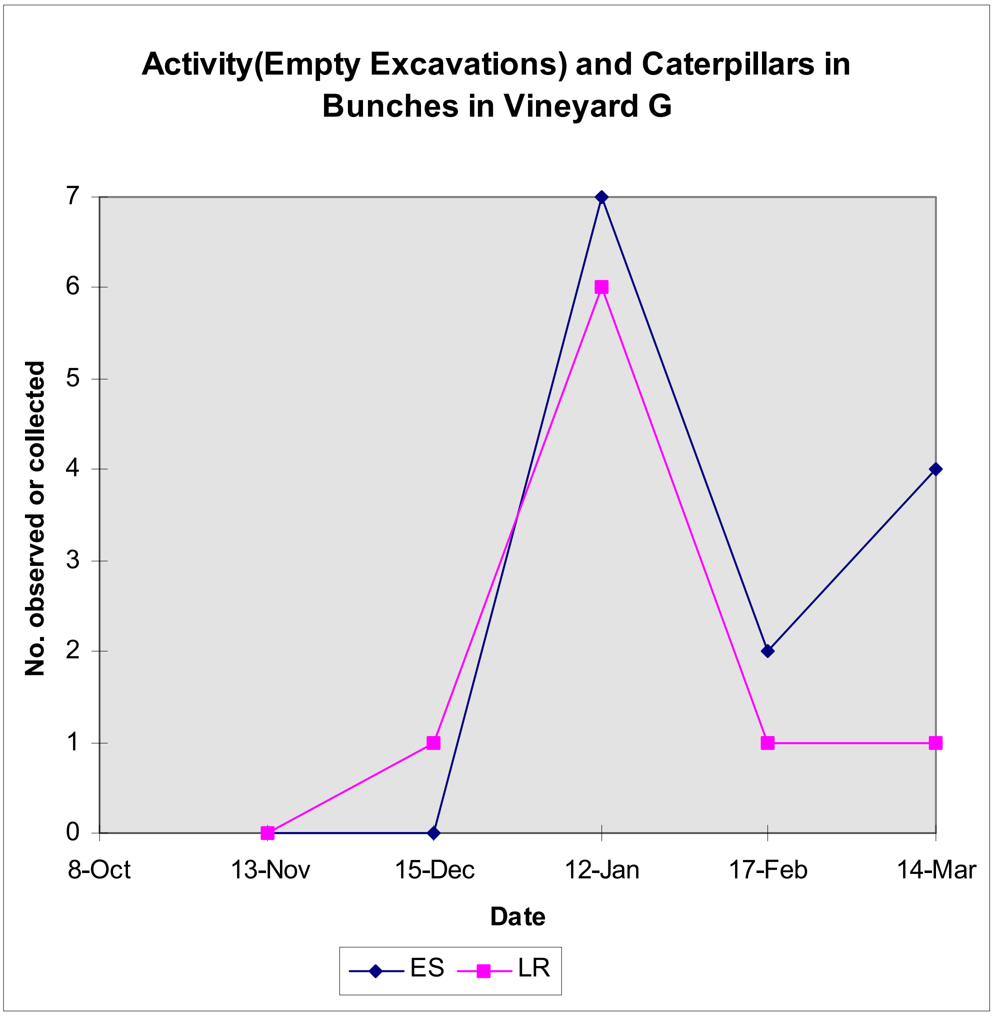

Fig. 18 Activity (empty excavations) and leafrollers in the bunches in vineyard G. Field collected data. The whole of thirty Pinot Noir Vines from six long rows were sampled.

Few beneficial species were observed in vineyard G. An empty cocoon of *D. tasmanica* was found in a bunch on 12th January and an adult of this species was observed hunting on leaves on 14th March. The caterpillar collected in a bunch on the 15th December 2000 produced an adult Australasian leafroller (*E. postvittana*). The six caterpillars collected on the 12th January a week after the Mimic spray produced no adults. Four became brown, hunched corpses with a half-shed transparent head capsule typical of Mimic intoxication and two produced live *D. tasmanica* wasps. The two caterpillars that produced wasps had been in the presence of Mimic spray for a week (5-12th January) without obvious harm to the wasp grubs inside. A live pupae was collected which produced a male *E. postvittana*. Two live adult moths were collected, one a male and the other a fresh, unmated female. An exuviae was also collected. The two caterpillars found, one each recorded on the 17th February and 14th March were dead when collected, again with the symptoms of Mimic poisoning.

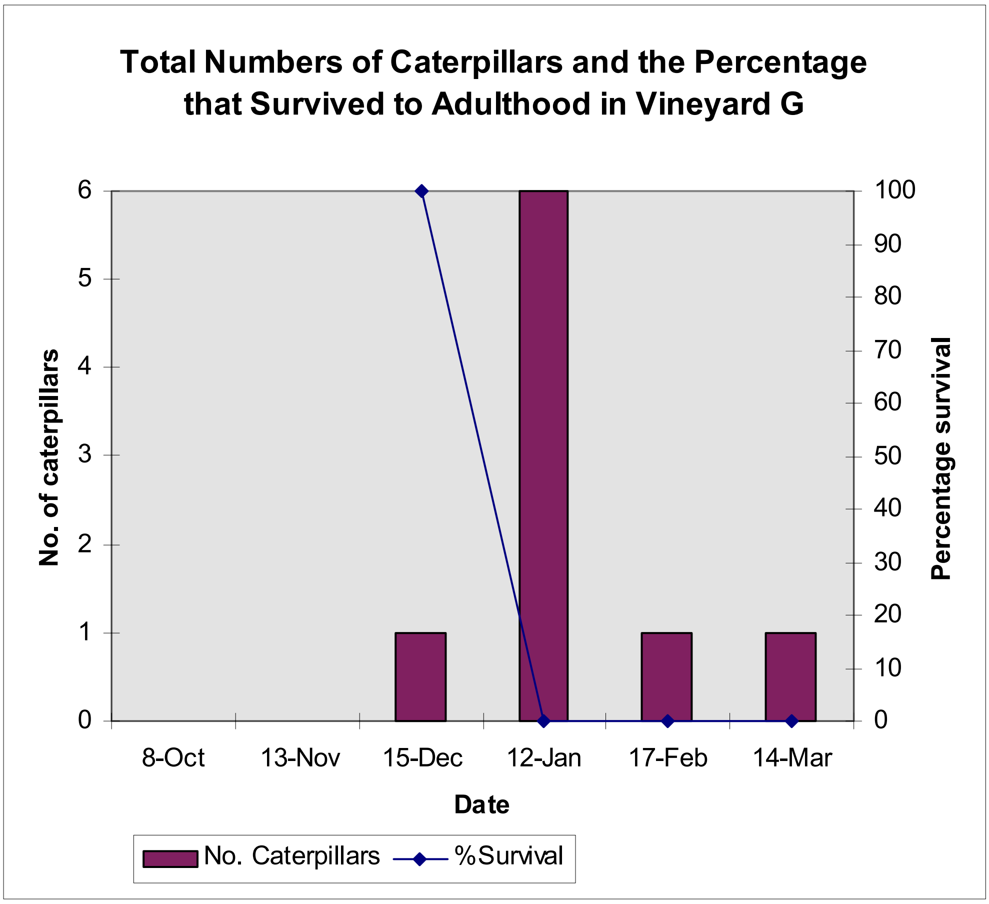

Fig.19 All of the caterpillars collected and their survival to adult moths in vineyard G The whole of thirty Pinot Noir Vines from six long rows were sampled.

The leafroller population shows no survival at all over the critical months of January through to March.

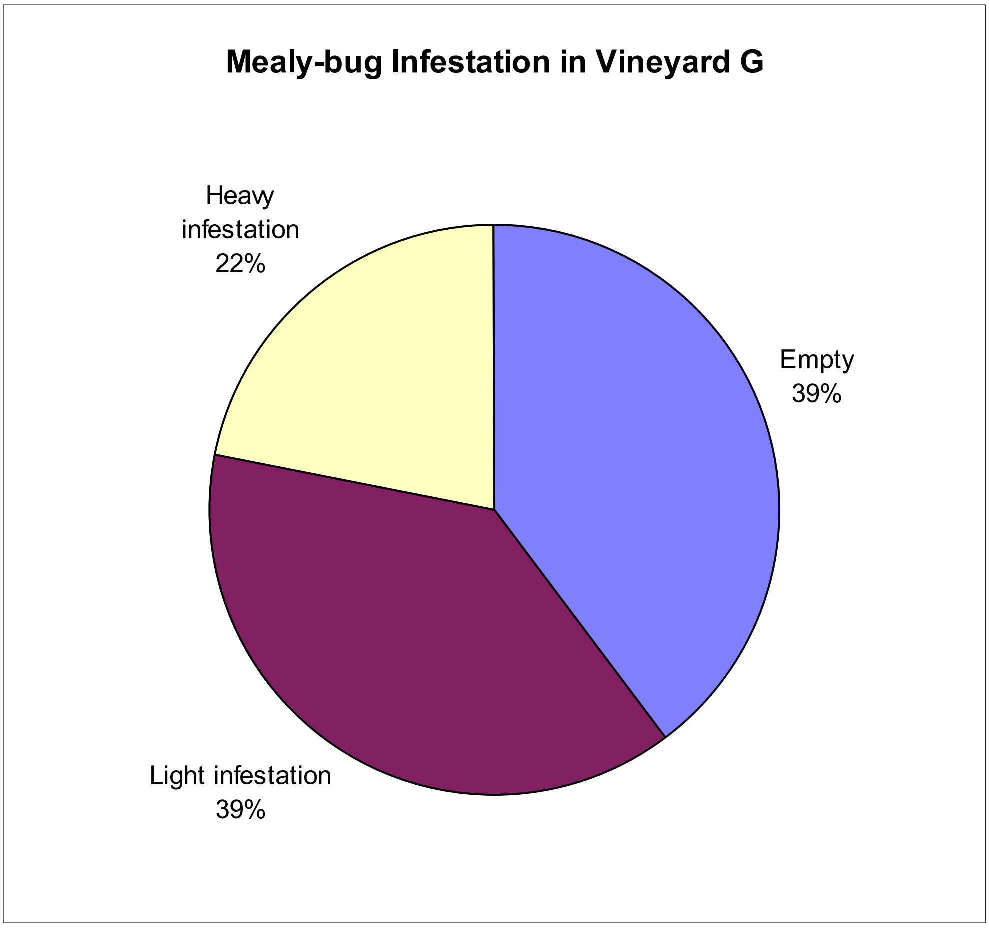

Fig 20 The proportion of bunches with light (1-4 MB) and heavy (>4 MB) infestations of mealybug (*Pseudococcus calceolariae*). Sample of 96 bunches randomly picked and cool-stored. Analysed on 20th April 2001

This was the only vineyard to use a single spray of Mimic for both the 1999/2000 (29/12/2000) and 2000/01 seasons. It was also the only vineyard with a significant mealybug problem.

(D) Vineyard H, two sprays of *Bacillus thuringiensis.*

Vineyard H used two sprays of Bt. to control leafrollers.

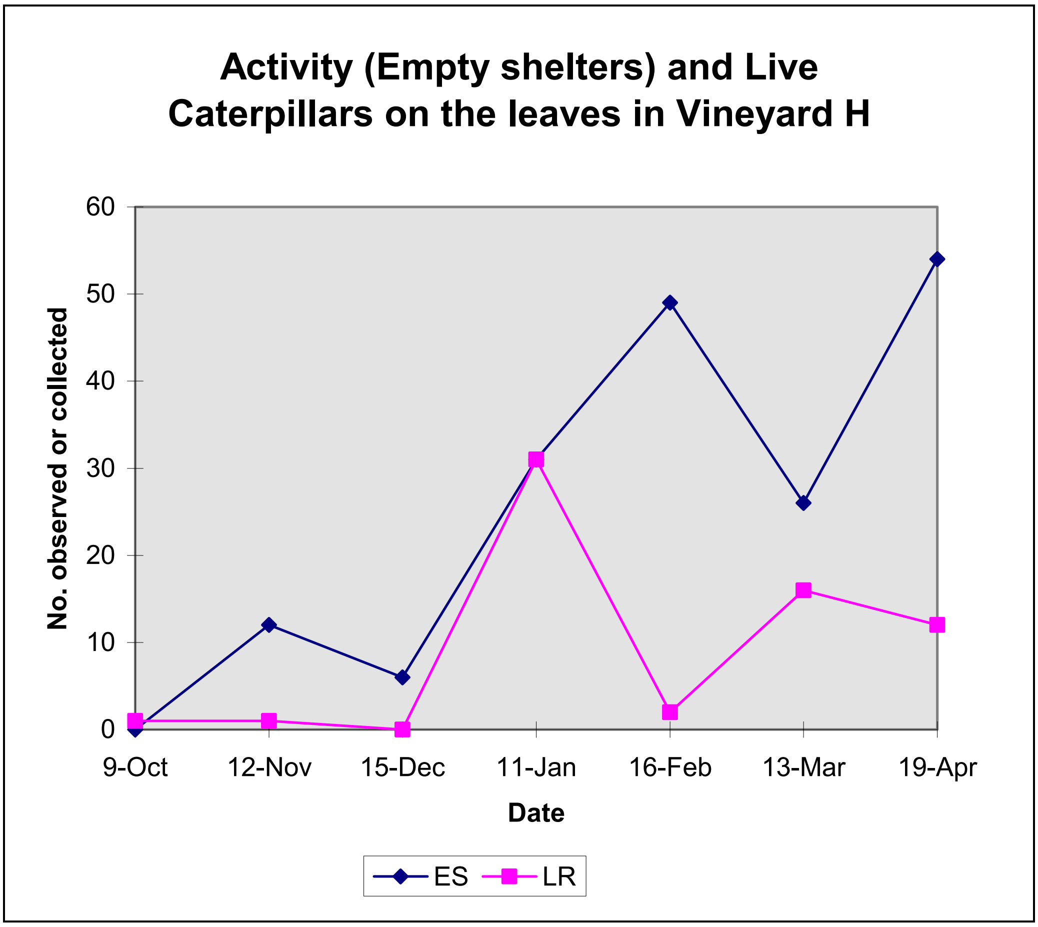

Fig. 21 Activity and caterpillar numbers on the leaves in Vineyard H. Field collected data. Most caterpillar activity is seen in January with a smaller peak in March. The January peak is “shadowed” by an activity peak in February The whole of thirty vines from ten rows were sampled, eighteen Riesling and twelve Cabernet Sauvignon.

The activity peak in November (fig. 21) shows the presence of a first generation in October. The second generation is represented by a caterpillar peak in January and an activity peak in February and the third by respective peaks in March and April.

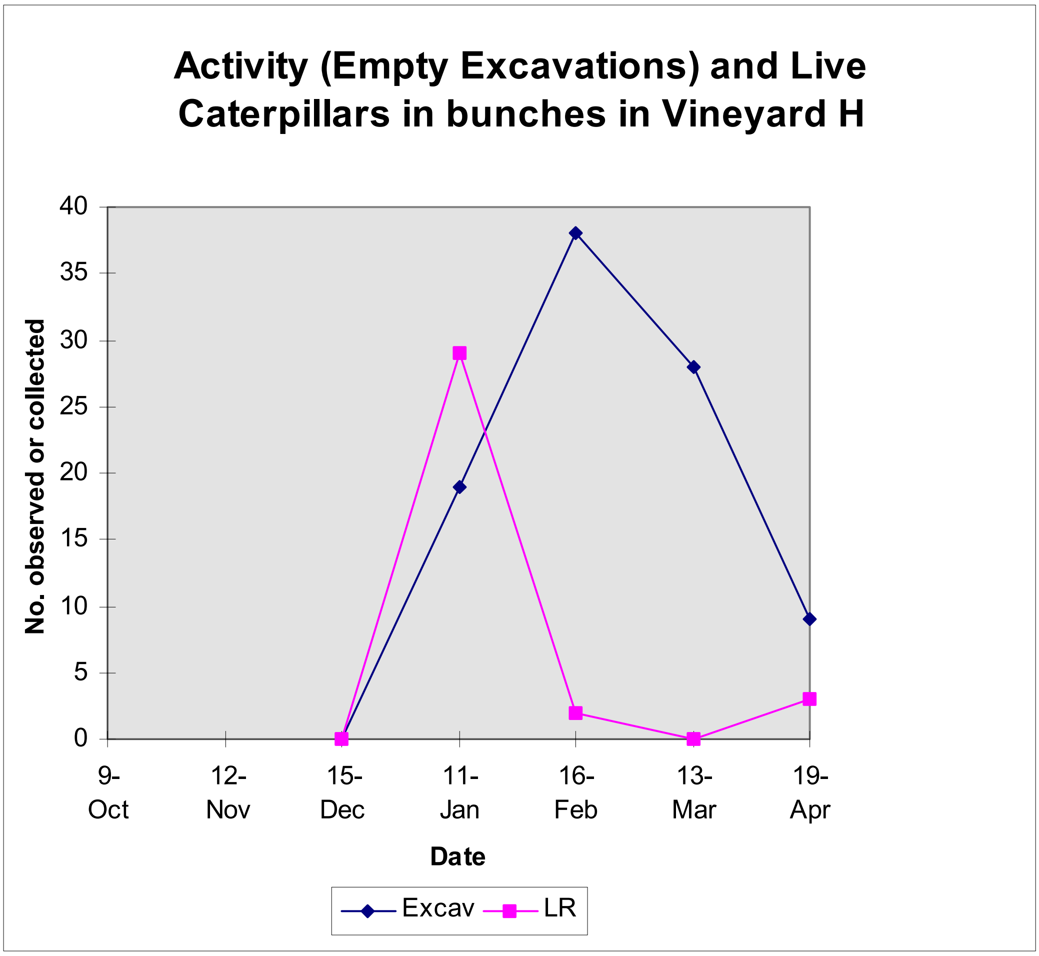

Fig. 22 Activity (empty excavations) and leafrollers in the bunches in vineyard H. Field collected data. The whole of thirty vines from ten rows were sampled, eighteen Riesling and twelve Cabernet Sauvignon.

A single peak of leafroller caterpillars with a larger, shadow activity peak is observed in the bunches. Note that the slopes of the peaks are roughly parallel in this fig and the preceding fig.. Very few live caterpillars were collected from bunches in February to April.

The structure of the leafroller excavation in the looser Cabernet Sauvignon bunches was very different from the structure in the tight Riesling bunches. The tunnel was a single silken tubular structure heavily covered with brown plant debris running along the central rachis in Cabernet Sauvignon bunches. Berries were not included. Silken strands were attached to many Riesling berries. There were multiple pathways running through the tightly packed berries of this variety and stalks and berries were chewed.

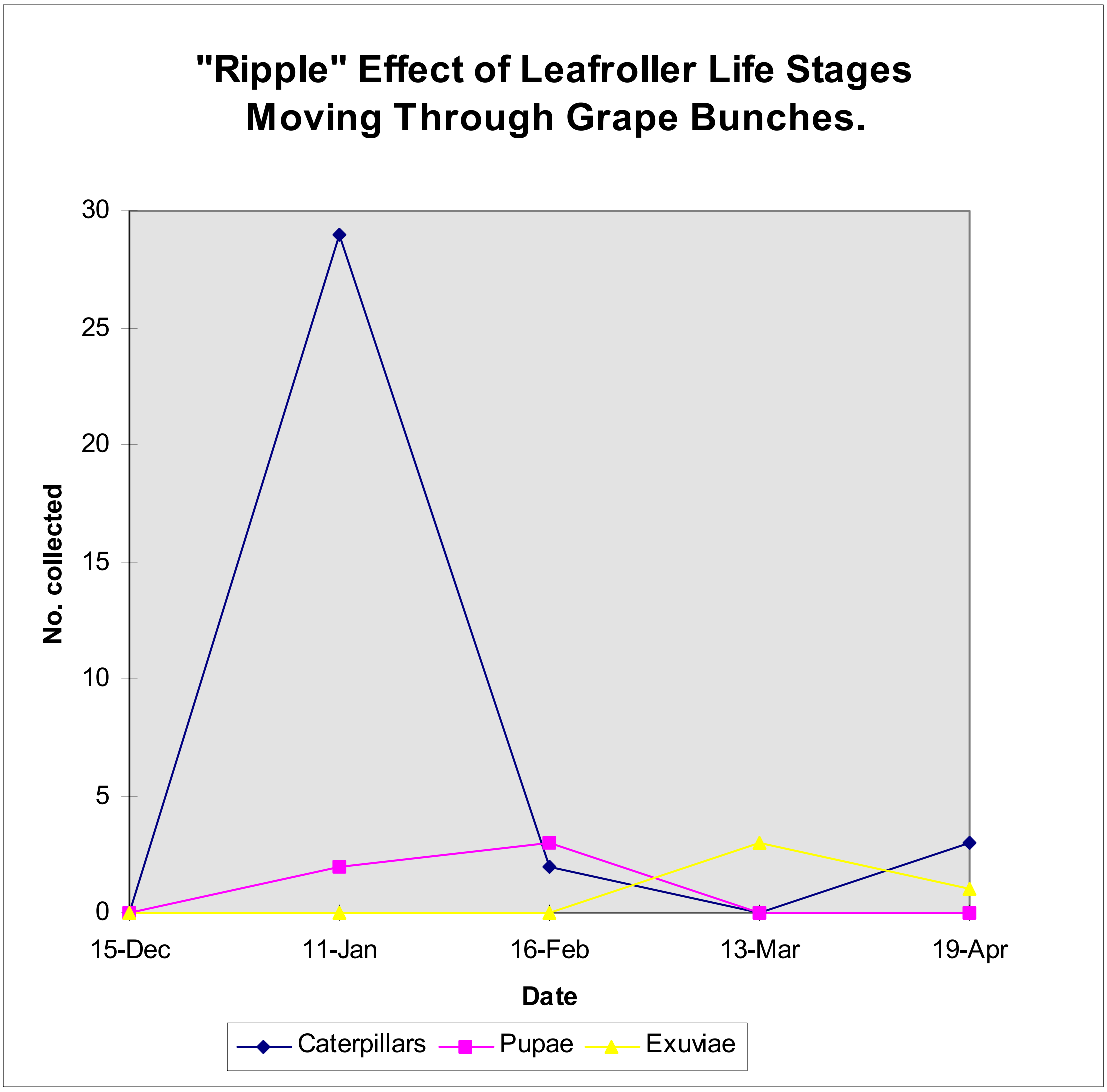

Fig. 23 The ripple of succeeding life stages through the bunches in vineyard H. Field collection. The whole of thirty vines from ten rows were sampled, eighteen Riesling and twelve Cabernet Sauvignon.

The fingerprint of this population (fig. 23) is characteristic of one where few individuals survive till adulthood. Large collections of caterpillars are followed by small numbers of pupae and pupal exuviae. This fingerprint is typical of orchards where biological control is taking many of the caterpillars

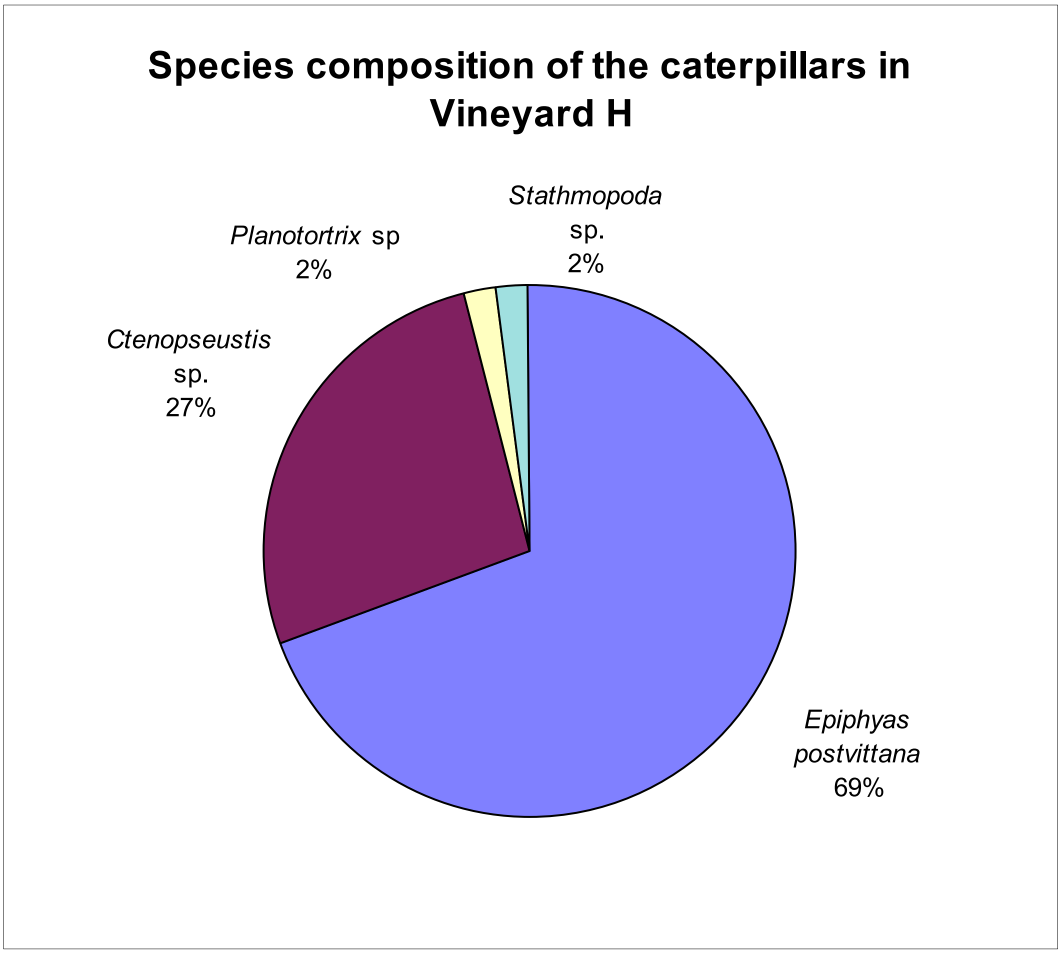

Fig. 24 Proportions of different species of caterpillar from Vineyard H Reared insect data.

Four species of moth were reared from the caterpillars collected from this vineyard. All most all were leafrollers (Tortricidae). The light Brown apple Moth *Epiphyas postvittana* was much the most common(69%) species (fig. 24). Two native leafrollers were present. *Ctenopseustis* sp. made up 27% of the collection. It is not possible to distinguish *C. obliquana* from *C. herana* by colour pattern or morphology. A single *Planotortrix* sp. was collected. The species identity can be determined in both cases by trapping with the specific pheromone lures.

Table 3 Numbers of different species of caterpillar from Vineyard H Reared insect data.

	Epiphyas postvittana		*Ctenopseustis* sp	
Date	Leaf	Bunch	Leaf	Bunch
9-Oct	0		0	
12-Nov	0		1	
15-Dec	0	0	1	0
11-Jan	6	18	6	3
16-Feb	2	3	0	0
13-Mar	6	0	0	0
19-Apr	1	0	3	0

The early activity (October-November) may be due to the native *Ctenopseustis* sp. It is the only species present in the reared group (table 3) during these months. More data is needed to confirm this. There is an indication in this data that *Ctenopseustis* sp. prefers the leaves and *E. postvittana* prefers bunches.

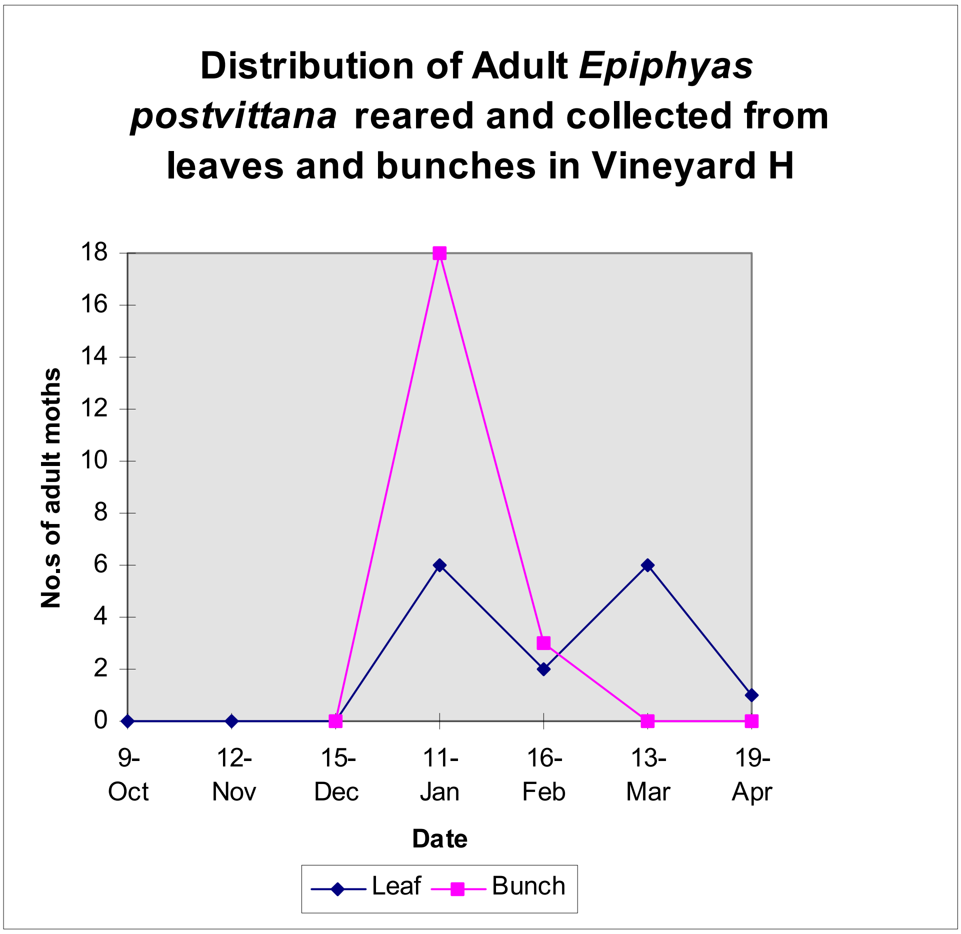

Fig. 25 Reared *E. postvittana*. From leaves and bunches from Vineyard H. The whole of thirty vines from ten rows were sampled, eighteen Riesling and twelve Cabernet Sauvignon.

A single peak of adult *E. postvittana* moths was observed from bunch collected caterpillars and two from the samples from leaves. This species is much the most common and the data therefore matches the distributions seen for the whole caterpillar collection (compare fig's 21,22 and 25)

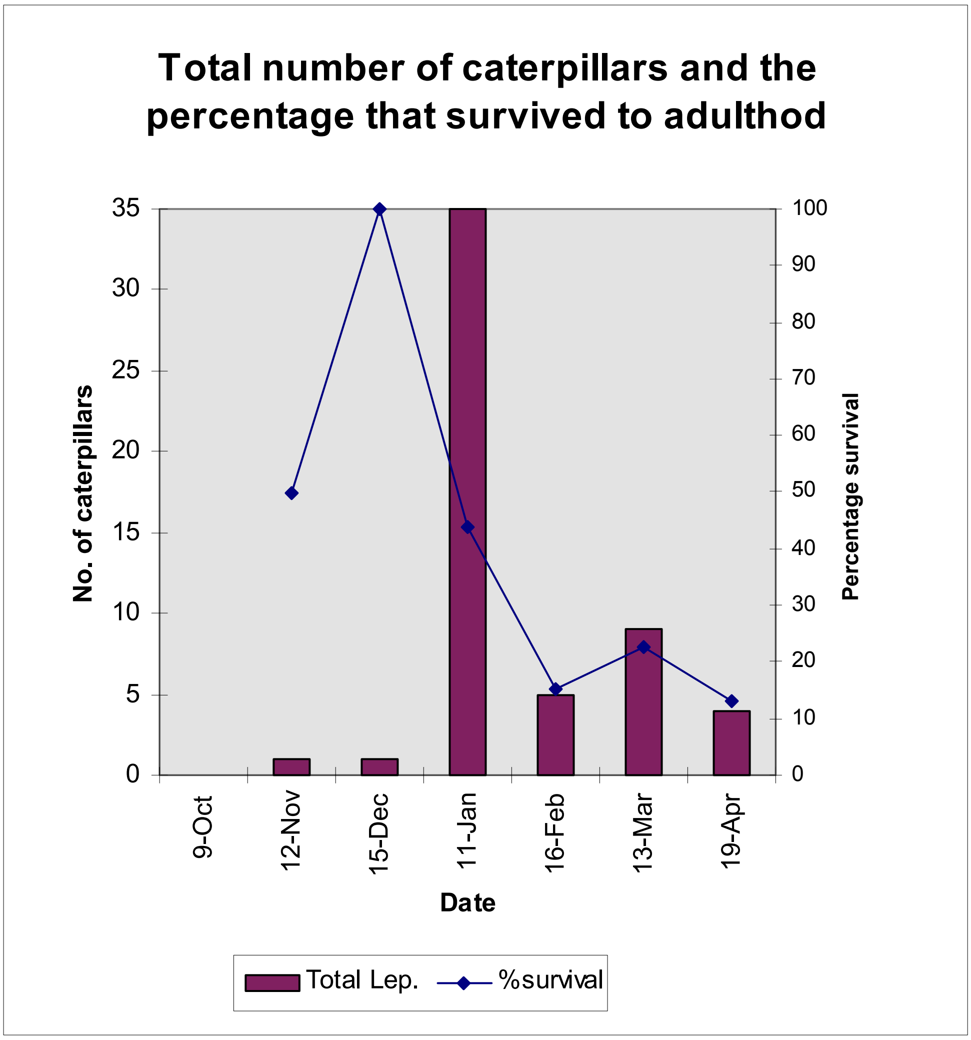

Fig 26 Summary of the fate of the caterpillars. Less than half of the very large number found in January survive to become adults. The reduced number of adults produce fewer caterpillars and they in turn suffer even heavier losses, numbers remaining low for the rest of the season. The whole of thirty vines from ten rows were sampled, eighteen Riesling and twelve Cabernet Sauvignon.

Only 15.2% on the caterpillars collected on the 16th February survived to become adults, followed by 22.5% on the 13th March and 12.9% on the 19th April. This a consistent, low survival (average = 16.9%).

There were two known causes of mortality of caterpillars. The orchardist applied two sprays of Bt. and the naturally occurring beneficial species consume caterpillars. Four identified parasitoids were collected. Much the most common beneficial species is *Dolichogenida tasmanica*. This solitary species takes an 86% share of the caterpillars (fig. 27). The related *Gl. demeter* takes only 5% and the Bullet wasp *G. jacintae* another 8%. A single tachinid fly (*T. breviefacies*) was collected.

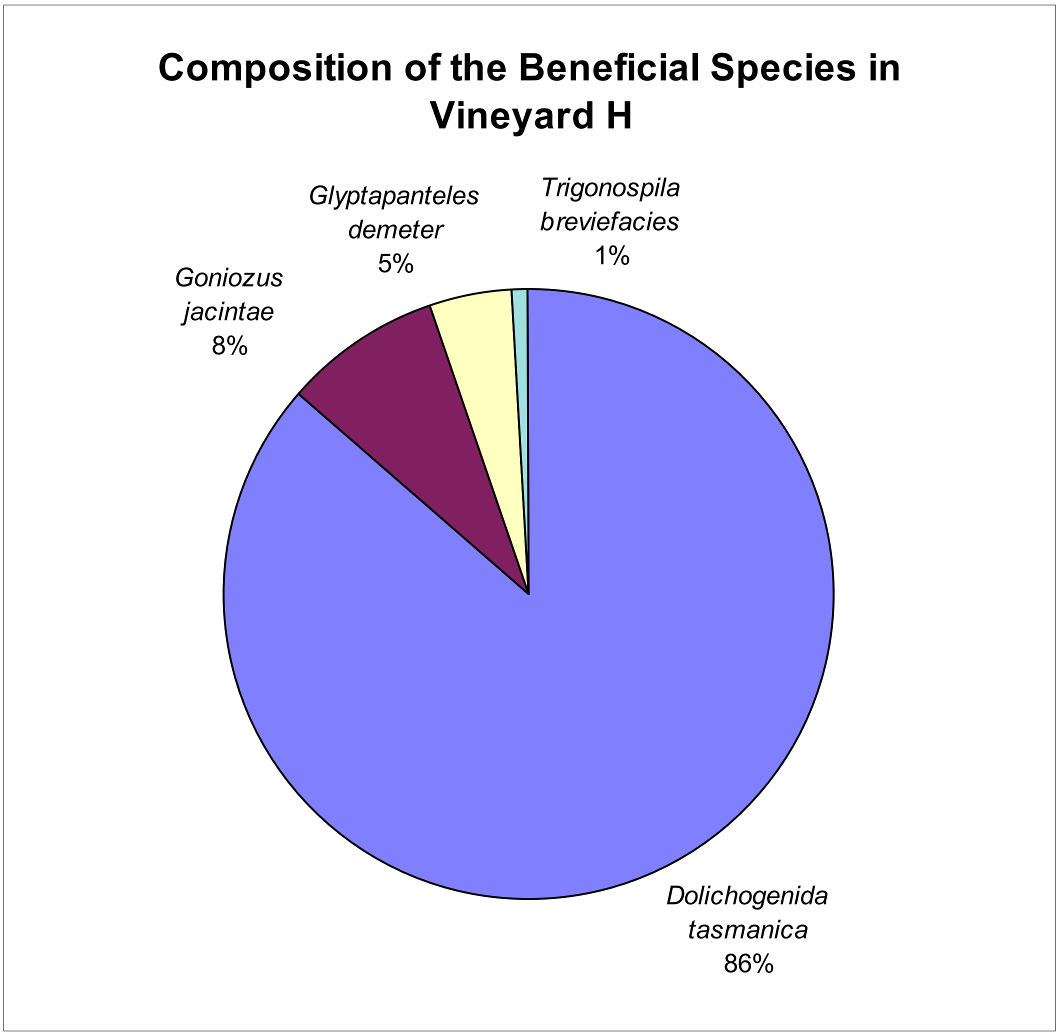

Fig 27 Composition of the beneficial species in Vineyard H. All collected and reared specimens from leaves and bunches. Total of 133 leafrollers consumed and 194 new beneficials produced.

Table 4 Numbers of beneficial species collected. Solitary species (*D. tasmanica* and *T. breviefacies*) are represented by a single number that represents both the number of leafrollers consumed and the number of new wasps or fly's produced. Gregarious species (*G. jacintae* and *Gl. demeter*) are represented by the number of leafrollers consumed and (in brackets) the number of new wasps produced

	Dolichogenida tasmanica		*Goniozus jacintae*		*Glyptapanteles demeter*		*Trigonospila breviefacies*	
Date	Leaf	Bunch	Leaf	Bunch	Leaf	Bunch	Leaf	Bunch
9-Oct	0		0		0		0	
12-Nov	1		0		0		0	
15-Dec	0	0	0	0	0	0	0	0
11-Jan	23	20	0	1(3)	1(4)	0	0	0
16-Feb	8	16	0	2(5)	2(17)	0	0	1
13-Mar	16	8	0	4(11)	1(4)	2(23)	0	0
19-Apr	16	7	3 (8)	1(3)	0	0	0	0

Gl. demeter wasp pupa were also found in the pine shelter.

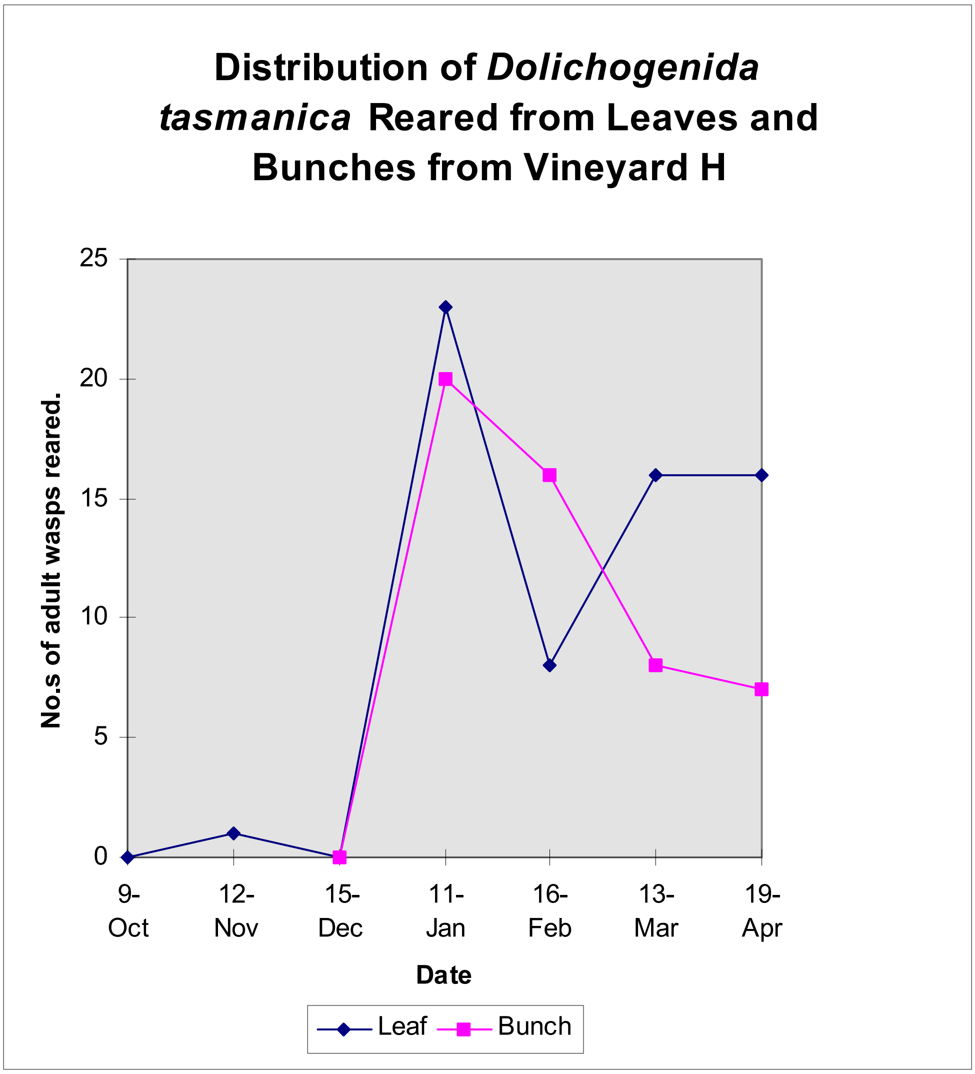

Fig. 28 *D. tasmanica* reared from caterpillars collected from leaves and bunches in vineyard H The whole of thirty vines from ten rows were sampled, eighteen Riesling and twelve Cabernet Sauvignon.

The pattern of *D. tasmanica* closely matches the pattern of available caterpillars (compare fig's 21,22 and 28). Two peaks are seen on the leaves (Jan and March-April) and a single peak in the bunches (Jan). The biggest difference is in the much slower way the numbers of wasp in the bunches drop in Feb to April compared with the drop in *E. postvittana.* The numbers of caterpillars collapse completely (fig. 22), while the number of wasps only halves. This suggests that the wasps are able to capture almost all of the caterpillars present in the bunches from February onwards.

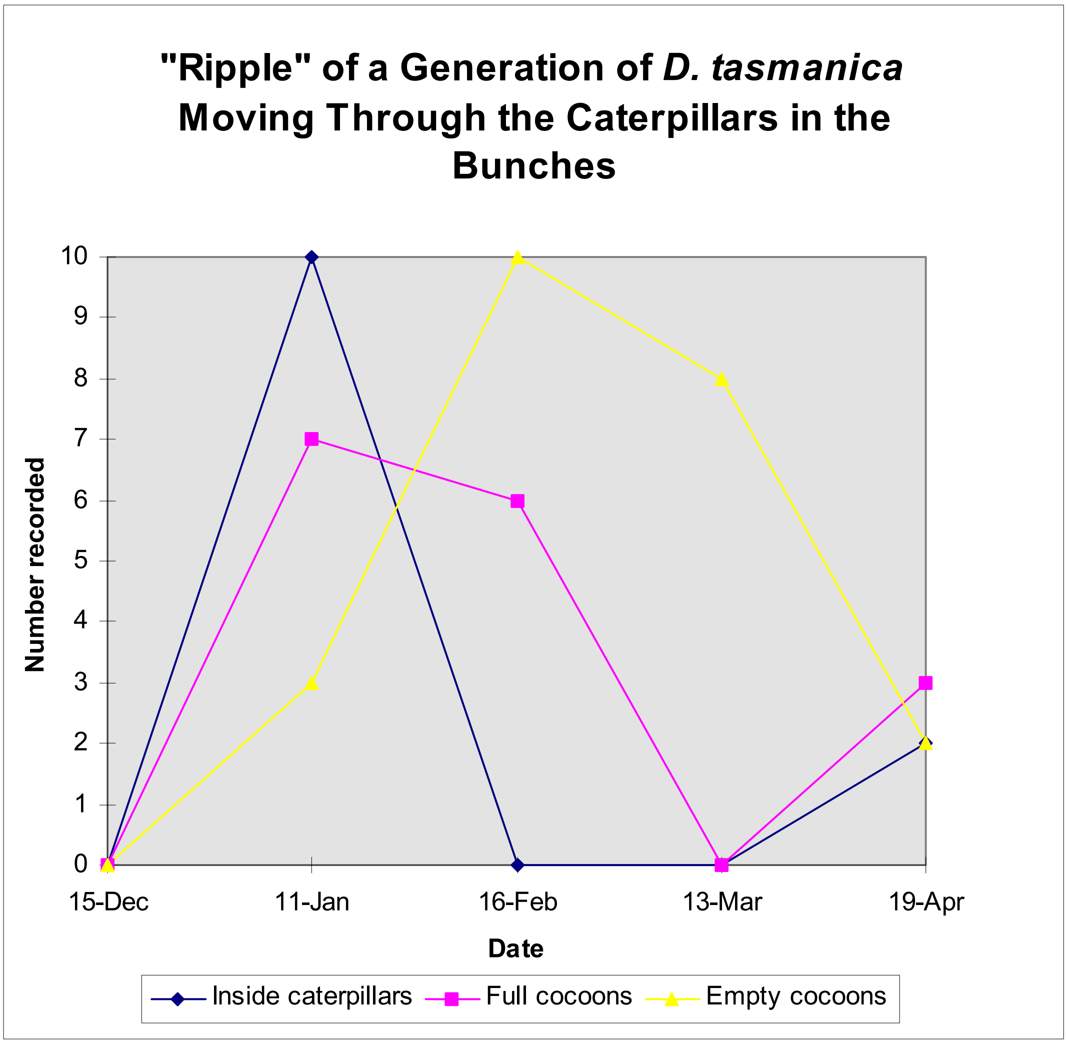

Fig 29 The succeeding life stages of *D. tasmanica* from the bunches in vineyard H. The number inside caterpillars is determined by counting the number of cocoons that appear later in the diet tubes. Full cocoons and empty cocoons are collected in the field. The whole of thirty vines from ten rows were sampled, eighteen Riesling and twelve Cabernet Sauvignon.

This graph shows a life pattern radically different from the caterpillars (fig. 23). The number of wasp grubs inside caterpillars is similar (same area under the curve) to the number of full cocoons. The area under the curve for empty cocoons is larger suggesting that the cocoons persist in the field for longer and are thus available to be collected. Losses are imperceptible for *D. tasmanica* as the wasp moves through its life cycle but are drastic for caterpillars(compare fig.s 23 and 29).

Large numbers of 11-spot and 2-spot ladybirds were seen in this vineyard. The 2-spot *Adalia bipunctata* was found inside the silken leafroller shelters on 11th January. The leafroller feeding scars were fresh but the leafrollers were absent. This species of ladybird is known as an aphid feeder (Thomas 1989) but should be investigated to see whether it is also able to eat leafroller caterpillars.

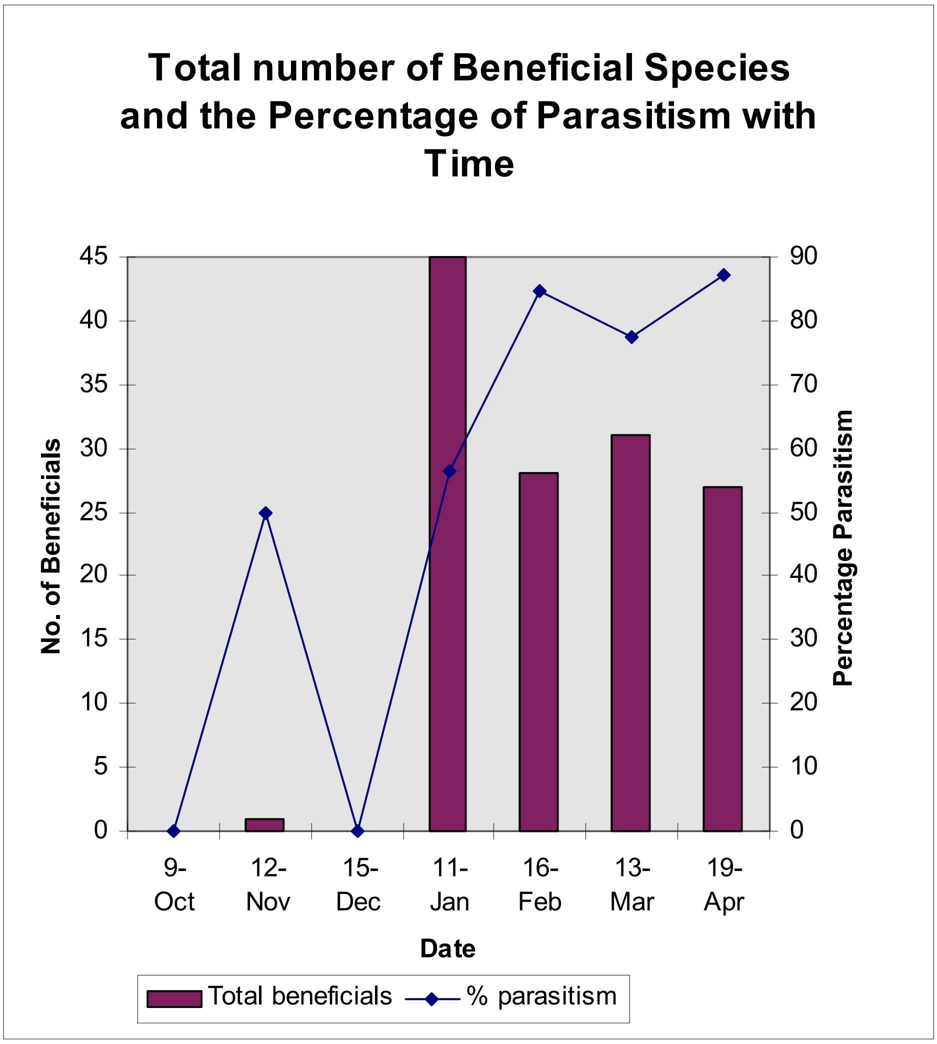

Fig. 30 The sum totals of all collected and reared beneficials (bar graph) and the percentage of the leafrollers parasitised (line) from bunches and leaves. Roughly equal numbers of reared and field collected insects in this figure. The whole of thirty vines from ten rows were sampled, eighteen Riesling and twelve Cabernet Sauvignon.

There are many interesting features in this graph. The largest number of beneficials were collected in January and at this time have taken 56% of the available caterpillars. Numbers of beneficials drop during February to April, but the percentage of caterpillars taken increases from January to February, then remains constant (February 84.8%, March 77.5%, April 87.1%) at an average of 83.1%.

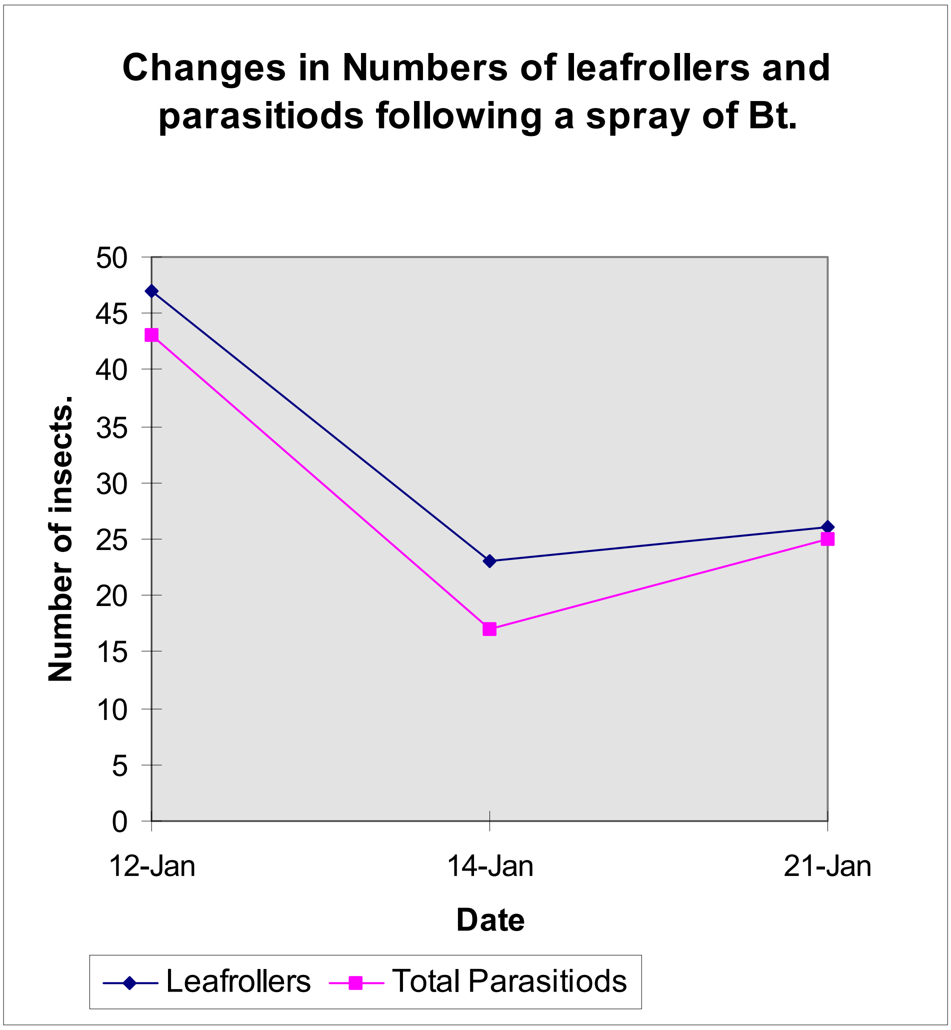

Fig. 31 The reference sample was made on the 12th January and the Bt spray was applied the same evening. The first post-spray sample was made two days later (14th Jan) and a second collection a week later(21st Jan). Because of the risk of sampling the same vine within the few days of these measurements, each of the two post spray samples were made from rows one and two places past the standard sample rows. The whole of thirty vines from ten rows were sampled, eighteen Riesling and twelve Cabernet Sauvignon on each date.

The spray of Bt. applied in January reduced the number of caterpillars and of beneficials by half(fig. 31) two days after the spray. No further reduction was seen a week later.
This data strongly suggests that there is no selectivity from a spray of Bt. The caterpillars that are host to a beneficial wasp grub feeding inside are as likely to succumb to Bt as a caterpillar free of the wasp. In each case approximately half of both populations of insects are dead, two days after a spray of Bt. The parasitoids take a consistent slice of the caterpillars, 48% (12th), 43% (14th) and 49% (21st).

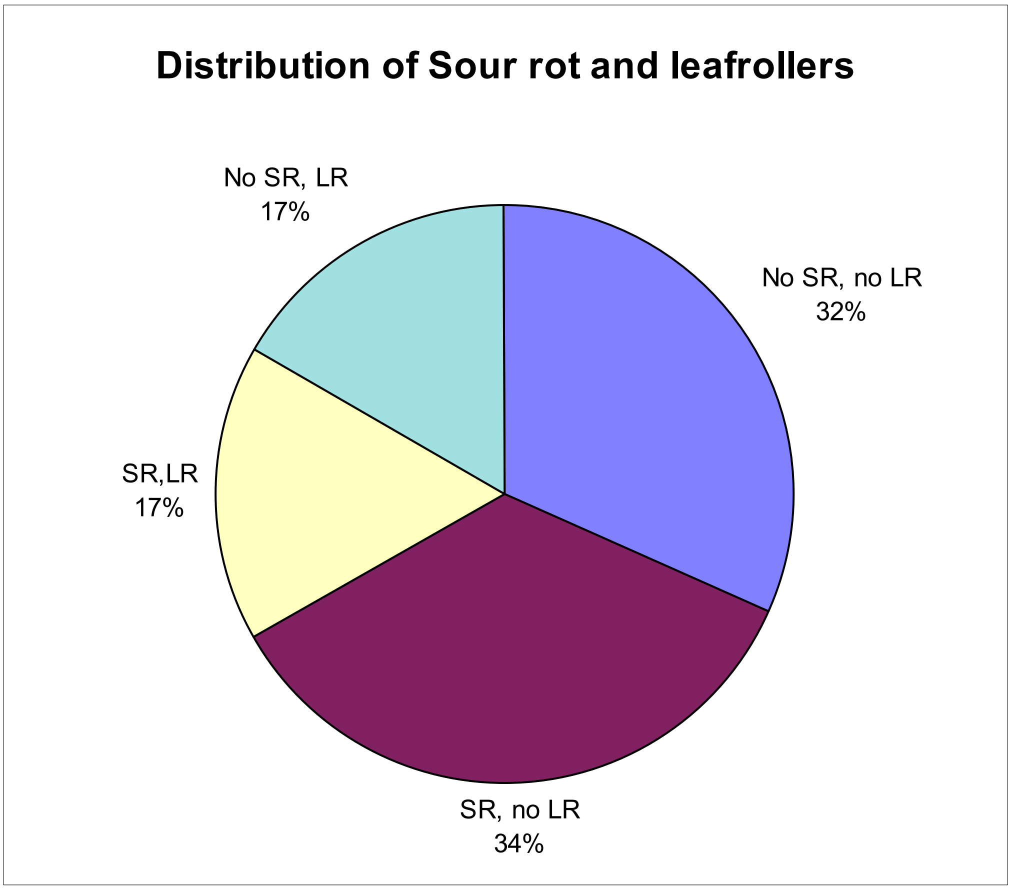

Fig 32 The distribution of Sour rot berries in the Riesling Bunches. There was no sour rot in the Cabernet Sauvignon Grapes Sample of 60 bunches from six vines (Row 54 - 79)

Half of the Riesling bunches are free of sour rot. Some (32%) also lack leafrollers. The half of bunches that have some rotted berries are not always infested with leafrollers…only 17% of bunches have both rotted berries and signs of leafroller activity. These bunches contained 4 live leafroller, 2 *D. tasmanica* cocoons and 5 empty excavations where a leafroller caterpillar had been feeding but was no longer present. A similar sized group with leafroller but no sour rot contained 5 *D. tasmanica* cocoons and 5 empty excavations. No live leafroller were present. The average number of rotted berries in a bunch without leafroller was the same (18.6 berries/bunch) as the number of rotted berries when leafroller were present (18.7)

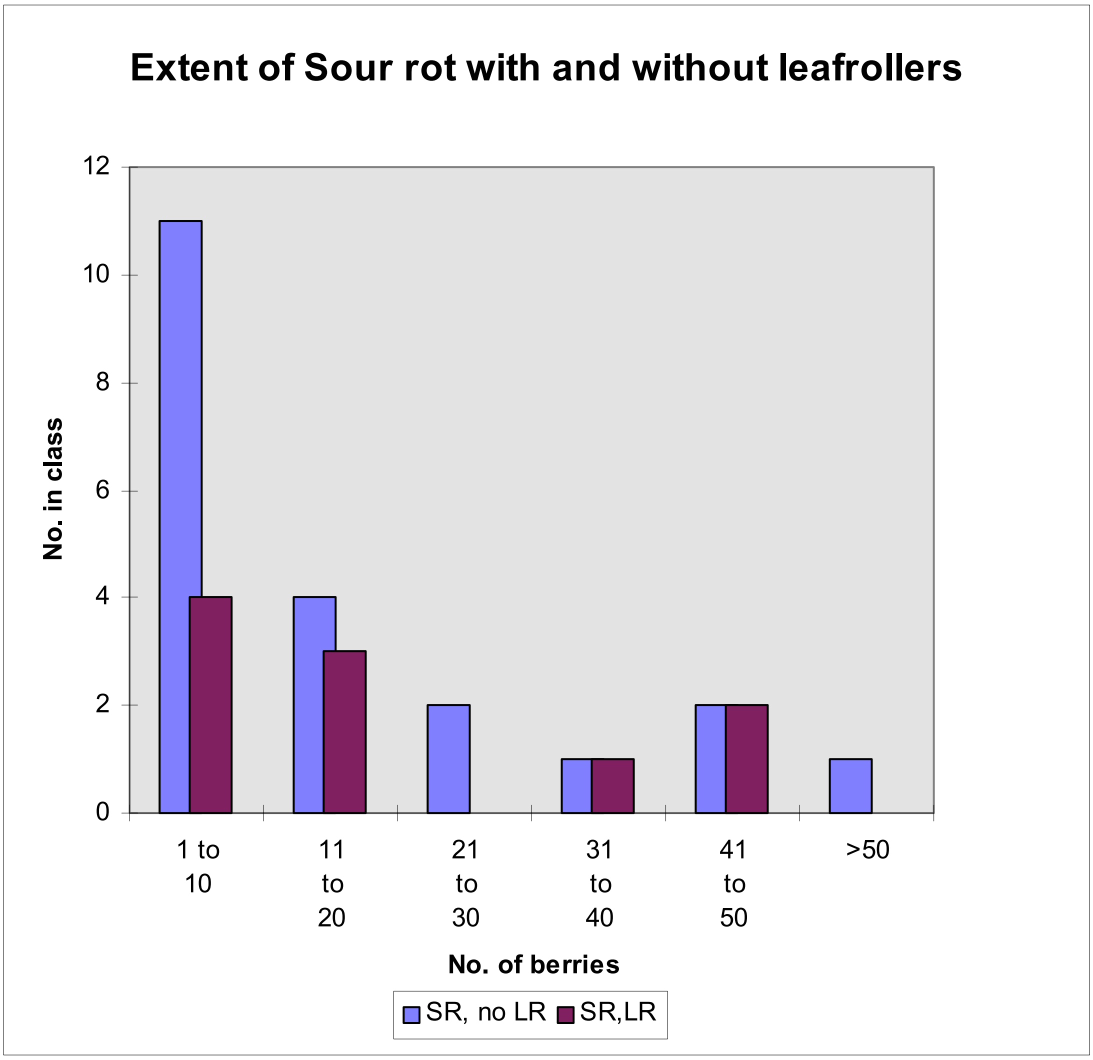

Fig.33 The numbers of sour rotted berries in Riesling bunches with and without leafroller (class size = 10) Data from vines as in Fig.32.

Fewer bunches with 1-10 rotted berries contained evidence of leafrollers (fig. 33) More heavily rotted bunches were as likely to not have a leafroller present as to have a leafroller.

There was a small incidence of mealybug infestation (3.3%). The predator *Cryptolaemus montrouzieri* was observed feeding on mealybug on the 16th February.

Leafroller and the Disposition of the Vine

The vineyards in this study varied greatly in the manner in which the vines were arranged on the supporting wires. The Chardonnay vines in vineyard F were arranged so that the bunches of grapes formed a distinct and continuous band with a band of evenly distributed leaves above them. Dense patches of leaves were only found where two branches from neighbouring vines met and overlapped. Vineyard G used a Scot Henry training system. The vines and leaves were re-arranged in the middle of the December leaf growth flush. This re-arrangement formed dense patches of leaves that provide ideal habitat for the leafrollers that arrive in large numbers at just the time when this ideal habitat is provided for them. The large flush of leaves also coincided with the arrival of leafroller in vineyard H. Delays in plucking the leaves may have allowed more leafroller feeding activity than necessary. There is a certain amount of "chicken or the egg" argument about this situation…..would the leafrollers have arrived any way or was the impact greatly increased by the ideal habitat provided?

Discussion

It is very difficult to arrive at sound conclusions with data that consists of sets of small numbers. The substantial leafroller populations available from the Wairarapa region have allowed the clear identification of generations, provided the first measures of the levels of parasitism and leafroller survival that lead to an expanding pest population compared with a population under control. Measures of age classes were developed in Gisborne as an indicator of a population under control with few individuals reaching adulthood compared with populations with large numbers of older life stages indicating high rates of completion of life cycles. These measures have received further support from the Wairarapa data.

The vineyards involved provided a most interesting set of comparisons. Vineyard E illustrated the untrammelled activities of a natural leafroller population with its associated beneficial species and H a large population subject to an additional mortality factor (Bt.). Vineyards E and H contain similar proportions of beneficial species, but H is unusual in the significant native leafroller present. Vineyards F and G largely eliminate leafroller with Mimic and the beneficial species are relegated to a "final clean-up crew" role. This role may be very important in the prevention of pesticide resistance as any mutant able to escape the effect of the Mimic is likely to be taken out by a wasp looking for a prey to lay an egg on.

The technique of graphing the sequence of life stages can effectively delimit the generations. The depiction is at its most convincing when a single large peak is present (eg. Fig.22,29)……..however establishing the principle in this way validates its use for the smaller earlier generations.

A checked leafroller population, either severely checked with a Mimic spray or moderately checked with Bt sprays never seems to recover its momentum.
The Bt. sprays applied in Vineyard H clearly caused losses to the beneficial wasps as well as to the leafroller caterpillars. Despite this the caterpillars have clearly been "ankle-tapped" as they raced to build a high population. The percentage of parasitism climbs from high fifties to between eighty and ninety and remains high. All the leafrollers in bunches from February onwards are taken by wasps. The mechanism by which the beneficials "catch up" following a spray of Bt. is unknown. Sub-lethally affected caterpillars may be sluggish and more easily tackled by ovipositing beneficials. The interaction between a caterpillar and an ovipositing female wasp or fly is usually very vigorous …I have watched a large leafroller caterpillar and a female *T. breviefacies* play hide and seek among the apple leaves for over 10 minutes. The caterpillar escaped from its pursuer.

Now that a grower contribution to leafroller control has been shown to be necessary in the Wairarapa region, we should consider how best to time that contribution. The timing of Mimic sprays is constrained by maximum residue limits (MRL). Most market requirements require a Mimic spray no later than 80% cap-fall. Later timing (bunch closure = mid-January) permitted by some markets provides no better leaf roller control. These sprays are applied when there is little leafroller activity and effectively provides a far-reaching protection when the leafrollers begin to invade.

Sprays of the biological insecticide *B. thuringiensis* are much shorter lived and must be applied when small caterpillars (most susceptible stage) are seen. The synchronised appearance of many small caterpillars in mid-February in vineyard E would be an excellent time to apply this spray. There is no substitute for careful monitoring of the vines for caterpillars. Neither egg batch searches (Australian wine-grape program) nor pheromone traps (as used in apples with the ENZA IFP-P program) provide an accurate measure of leafroller numbers (report in progress).

The data from this study suggests that there is little re-invasion of the bunches in vineyard H following the large influx in Dec-Jan. The following generations of leafrollers appear to target the leaves and this is true of vineyards treated with Bt and with Mimic.

Further improvement of this program may be effected by restricting the Mimic spray to the bunch-line. The Chardonnay vines in vineyard F were arranged so that the bunches of grapes formed a distinct and continuous band with a band of evenly distributed leaves above them. This vine layout is perfectly suited to a bunch-line spray of Mimic and should be considered as a future research project.

Two observations support claims for the selective effect of Mimic, killing caterpillars but not beneficials. The Mimic spray applied to Vineyard F largely eliminated leafroller. The leaves (but not the bunches) were re-invaded later in the season but were met by sufficient beneficials to effect the complete removal of all LBAM caterpillars from the leaves on April 20th (fig.16). Two caterpillars from Vineyard G produced active adult wasps (*D. tasmanica*) despite seven days exposure to fresh Mimic deposits (fig.18). The presence of large numbers of mealy bugs on the only vineyard to have used Mimic for two consecutive seasons is a concern. This is far from sufficient data to suggest any linkage between Mimic use and out of control mealybug populations but it would be useful to investigate the impact of Mimic sprays on *Cryptolaemus montrouzieri,* the predator observed feeding on the small populations of mealybug in the other vineyards.

There are two key differences between the bunches and the leaves. New leaves appear throughout the growing season albeit at a much slower rate after the mid season leaf flush. There is only one major period when new bunches appear (a small number of bunches are formed during a later secondary bunch set). A leaf lamina is exposed to moving air currents, washed by rain and all surfaces are exposed to sunlight as each day progresses. After bunch closure, any Mimic (or Bt.) deposited inside the bunch by a pre-bunch closure spray would be protected from air movement or sunlight and in very tight bunches like Riesling protected from rain as well. Bunches appear to have retained protection well beyond the 32 to 52 day half life claimed by the manufacturers.

There are major differences between this study and the report of Hamblin *et al* 1998. In the Australian study, freshly hatched LBAM caterpillars migrate to the shoot tips where they feed for a while before moving to the bunches. The numbers in the leaves decrease as the numbers in the bunches climb. A single spray of Mimic has very little effect (87% bunch damage dropping to 69% NSD) a second spray dropping damage to 9%. The sprays are applied mid and either late November or early December

In these two data sets (see below)from Hamblin *et al* 1998, the change in leafroller numbers changes in concert with the changes in *Botrytis* infection. The implication is that all or most of the disease is associated with the leafrollers.

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Treatment	%bunches with LBAM	%bunches with *Botrytis*
Untreated	87	37.5
Mimic x 2	8.6	10.5
LSD	1.3	0.26
Treatment	%bunches with LBAM	%bunches with *Botrytis*
Untreated	50.8	7.2
Mimic x 2	1.6	2
LSD	1.02	0.11

If the data from fig. 32 in the Wairarapa study had been plotted similarly, the 34% of leafroller presence in the bunch would seem to “fit” well with the 51% of sour rot…..reference to fig. 32 shows clearly that there are fewer (17%) bunches with leafroller and without sour rot, as bunches with sour rot and no leafroller (34%). The apparent correlation apparent from a casual glance at the data disappears as the data is closely examined.

The sudden appearance of large caterpillars on new buds in October that was seen in Vineyard F (fig. 12) is uncommon in NZ. Smith *et al* (1996) searched the understorey of vines in Victoria, Australia in July and August for populations of large caterpillars (5th and 6th instars, 1-2 cm long) that will climb up the vine trunks to feed on the fresh spring leaf growth.

To what extent should leafrollers be tolerated on grape vines? Much may depend on when and where the leafroller is active. A leafroller feeding on leaves is consuming a tiny fraction of the photosynthetic capability of the vine…at most, the caterpillar is making a modest contribution to the leaf-plucking. These caterpillars provide food for the beneficial species that will take out bunch feeding caterpillars. If Hamblin *et al* 1998 are correct in stating that leaf feeding caterpillars transfer to bunches they may make a contribution to damage……….this theory needs careful testing. In the Wairarapa study, leafroller caterpillars infested the new bunches in parallel with leaves rather than appearing to transfer from leaves to bunches.

Caterpillars in the bunches are another matter. Bailey *et al* (1997) demonstrated experimentally that one or two second instar caterpillars placed on grape flowers will consume a large part of the new bunch. The bunch does not compensate for the lost berries. Similar measurements should be considered for future NZ studies.

	% weight loss with	
	1 larvae /bunch	2 larvae/bunch
early inflorescence	23	40
2 weeks pre-flowering	23	35
flowering	23	43
berries half mature size	10	15

Ferguson *et al* (1996) were dissatisfied with accepting that a correlation between the presence of leafrollers and the presence of *Botrytis* actually meant that the leafrollers actually caused the disease. Caterpillars can carry spores on mouthparts and skin. They ingest spores when feeding on infected grapes and these spores remain viable as they pass through the gut. Contaminated faeces are unlikely to cause disease as LBAM have clean toilet habits and propel their droppings away from its feeding area and they usually drop on the ground. Ferguson *et al* (1996) experimentally infected caterpillars with *Botrytis* spores and added them to grape bunches at bunch closure. In the lab, these caterpillars cause 33% disease, but produced much less of a problem in the field. Four LBAM larvae with spores resulted in 3.25% infection of bunches, two larvae 1.75%, in a field experiment at Lenswood Australia. Clean larvae (and the untreated control) caused zero disease. Caterpillars move from leaves to bunches but rarely from bunch to bunch. Their paper is entitled "Lightbrown apple moth increases the incidence of *Botrytis* rots in maturing grapes" but the evidence that they present suggest strongly that the caterpillars are minor contributors.

The low level of disease (sour rot and *Botrytis*) on the Pinot Noir and Chardonnay bunches from vineyards F and G comes as no surprise given the excellent control of leafroller achieved. Most of the bunches of Pinot Noir from Vineyard E contained live leafroller or the evidences of their presence during the season. Despite this, only a single diseased berry was recovered from a large harvest sample. The two varieties from Vineyard H produced completely different results. The Cabernet Sauvignon had as many evidences of leafroller activity as the Riesling but was free of disease. Half of the Riesling bunches had sour rot but the diseased berries were distributed in a fashion (fig.32) that made it unlikely that the leafrollers had produced more than a minority of disease hits.

This region received consistently dry weather over the final stages of maturation , effectively removing one factor (wet weather) from the equation that drives disease. Any person working on a jigsaw puzzle is aware of the moment when enough of the pieces are in place to reveal the nature of the picture. Each new jigsaw puzzle piece added at this stage increases the information content (appearance of the picture) and does so in a way that is more than additive. The larger the number of accurately placed pieces, the more pieces each new piece has to interact with allows it to make a greater contribution than a piece placed in the early stages where much careful work is necessary before any picture emerges at all. Enough of the leafroller activity on grapes in NZ is now known to provide a framework for future work to fill in the remaining details.

Acknowledgments
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