Phenology and management of noctuids attacking apple in Central Otago, New Zealand

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ABSTRACT

Noctuids are minor pests of apple crops in New Zealand. Leaf and fruit clusters on apple trees at the Clyde Research Centre were monitored for the presence of eggs and larvae of noctuids and their damage from petal fall to harvest in three growing seasons 1995 to 1998. Over the same period, pheromone traps for the two taxa of *Graphania mutans* 'South' and 'North' were operated in the same apple blocks, and continued for the 'South' taxon until 1999-2000. Eggs could be found on the trees from spring to harvest but not in every season, whereas larval presence and fresh damage was almost confined to the period from petal fall to the end of December and comprised only young larvae. *G. mutans* constituted about 95% of all noctuid eggs and larvae. The time and magnitude of catches of the two taxa in the pheromone traps were extremely similar, with a peak flight over apple flowering, a trough at the end of December, and an extended further flight(s) with peak numbers usually in January/February but catches extending to May. From 1998 to 2000, 21-22 apple blocks in Central Otago commercial orchards were monitored with pheromone traps ('South' taxon) and/or by sampling fruit clusters for noctuid eggs, larvae, and damage over the flowering and fruit set period (Oct-Nov). Harvest sampling in the same blocks demonstrated a strong linear relationship of 'harvest damage to fruit' with 'spring foliage damage to fruit clusters'. An initial action threshold for spring insecticide application was derived from this relationship as >5 out of 200 fruit cluster with leaf damage but further analysis now suggests doubling this threshold. There was only a weak relationship between pheromone trap catches and damage in spring or at harvest. Photographic records of the same damage to apples in spring and at harvest were used to determine unequivocally the separation of noctuid damage from other causes. Two noctuid species, *Graphania plena* and *Agrotis ipsilon aneituma*, were found for the first time to cause occasional damage to apples in spring.

KEYWORDS

Noctuid, *Graphania mutans*, pipfruit, pheromone, phenology, action threshold, integrated pest management

INTRODUCTION

Among the minor pests of apple orchards in New Zealand is a group of noctuid moths of the genus *Graphania* (Lepidoptera: Noctuidae: Hadeninae). Damage from the caterpillars was rarely seen when broad spectrum insecticides were the primary means of insect control, but damage up to 5% of harvested fruit occurred under initial integrated control programmes despite high egg mortality by parasitoids (Collyer and van Geldermalsen 1975). More recently, damage on commercial crops has reached up to 7% at harvest, and eggs, and occasionally first instar larvae, have been intercepted on harvested fruit destined for export (Burnip *et al*. 1995; J. T. S. Walker, personal communication 2009).

Graphania mutans (Walker) is the species reported to be primarily responsible for both the larval damage to apples (Burnip *et al*. 1995) and fruit contamination by eggs (J. T. S. Walker, personal communication 2009). Another species, *Graphania ustistriga* (Walker), has been implicated in spring damage (Burnip *et al*. 1995), and further species attacking apples may yet be identified. These *Graphania* spp. are common in the pastoral environment (e.g. McGregor *et al*. 1987) where they feed on pasture plants (e.g. Lindroth *et al*. 2000) but the adults are highly mobile and fly into orchards from spring to autumn (Suckling *et al*. 1990). Some adult females of the spring flights lay egg batches on apple foliage and the hatching young caterpillars disperse to chew leaves and fruits before descending to the ground cover for continued development. This spring attack occurs at flowering, fruit set and shortly thereafter, when the apples are very small, so that the form of the damage changes as the apples grow. At harvest, the damage to individual apples is characterised by one or more small, russetted marks on the surface. Some other types of harvest damage, such as distortions, have been attributed to *Graphania*, but this has never been closely analysed and the present study sought to investigate this. Routine hand or chemical thinning of the crop by orchardists removes some of the damaged fruits and the chemical thinner carbaryl is insecticidal, but the levels of harvest damage recorded above have occurred despite thinning practices.

The identification of the pheromones of two taxa

(‘Lincoln’ and ‘Auckland’, also referred to as ‘South’ and ‘North’ respectively) within the species *G. mutans* (Frérot and Foster 1991; Frérot *et al*. 1993) provided an opportunity to monitor males of their adult populations in orchards using pheromone traps (Suckling *et al*. 1990; Burnip *et al*. 1995). Both these studies revealed that the phenology of male flight by the two taxa was extremely similar in regions where the species occurred together (Canterbury and Nelson). Moths were caught at any time throughout the growing season, with peak catches in spring and autumn but sometimes in summer. The spring peak preceded the known egg laying and larval damage seen in apple orchards and the autumn peak fitted with the known risk of contamination of harvested fruit by noctuid egg batches. These pheromone trapping programmes (*loc. cit*.) were conducted in apple orchards in Canterbury, Nelson, and Hawke’s Bay.

While damage by noctuids to harvested apples has been recorded routinely for many years (e.g. Collyer and van Geldermalsen, 1975), the ecology of these insects in orchards has been little studied. The present study investigated the species composition of noctuids and their damage to apples, and the phenology of egg and larval incidence on this crop in Central Otago; it also extended pheromone trapping of both *G. mutans* taxa to the Central Otago region (1995 – 2000). In addition, changes to spraying practices in Otago with the introduction of integrated fruit production (IFP) (Walker *et al*. 1997) in the 1990s reduced insecticide usage and, in particular, delayed the application of the first insecticide in spring. This increased the risk of spring noctuid damage, and we describe here a specific research project that targeted analysis of spring flights, crop infestation, and damage leading to a monitoring method and an insecticide action threshold for orchardists.

MATERIALS AND METHODS

Seasonal pheromone trapping at Clyde Research Centre

Pheromone trapping of adult male *G. mutans* followed the procedures of Burnip *et al*. (1995). Standard green funnels traps (International Pheromone Systems Ltd, Wirral, United Kingdom) were operated from 15 September 1995 to 5 June 1996, 23 September 1996 to 23 April 1997, 28 October 1997 to 9 June 1998, 1 October 1998 to 15 June 1999, and 15 October 1999 to 13 June 2000. Three growing systems, biological (BFP), integrated (IFP), and conventional (CFP) fruit production (see Suckling *et al*. 1999) were being compared in three separate areas of the Clyde Research Centre at that time and a single trap for each of the ‘South’ and ‘North’ taxa of *G. mutans* was placed in the centre of each area. The paired traps were at least 8 m apart and hung 1.5 m high on tree support wires; the trapped moths were recorded and removed weekly and the pheromone caps were replaced every six weeks. The very close similarity of catches of the two taxa from 1995 to 1998 resulted in restricting trapping to the ‘South’ taxon for the final two seasons.

The pheromone caps were rubber septa impregnated with the following blends:

(1) ‘South’ – 1000 µg (Z)-9-tetradecenyl aldehyde (Z9-14:ALD), 150 µg (Z)-9-tetradecenol (Z9-14:OH), 350 µg (Z)-9-tetradecenyl acetate (Z9-14:Ac), 140 µg (Z)-7-tetradecenol (Z7-14:OH), and 50 µg (Z)-7-tetradecenyl acetate (Z7-14:Ac)
(2) ‘North’ – 1000 µg Z9-14:OH, 230 µg Z9-14:Ac, 130 µg Z7-14:OH, and 30 µg (Z7-14:Ac).

The weekly trap catches are presented as mean number per trap per day.

Seasonal infestation and damage assessment at Clyde Research Centre

In 1995-96, timed searches for lepidopterous eggs and larvae, and their damage, on leaf and fruit clusters were conducted in the BFP area on 10 occasions from 1 November 1995 to 9 May 1996. On each occasion, trees and their clusters were selected at random within cultivar blocks of ‘Royal Gala’, ‘Braeburn’, ‘Fuji’, ‘Fiesta’, ‘Dayton’, ‘Prima’, ‘Redfree’, ‘Jonafree’, and ‘Liberty’ (one hour per cultivar). On one occasion in each of November, January, February, and April, similar searches were conducted on ‘Royal Gala’, ‘Braeburn’, and ‘Fuji’ in the CFP area, and on ‘Sciros’, ‘Southern Snap’, and ‘mixed selections’ in the IFP area. The numbers of leaf and fruit clusters examined were recorded. The numbers of egg batches and larvae per cluster and the percentage of damaged clusters were calculated for each sampling occasion. A proportion of the unhatched eggs and larvae (n = 129) found were reared through to adult on narrow leaved plantain, *Plantago lanceolata* L., in the laboratory to determine the species present and any parasitism. Similar procedures were carried out in the 1996-97 (13 fortnightly samples from November to May) and 1997-98 (11 fortnightly samples from November to April) seasons, but only in the BFP area, which had the highest incidence of noctuid damage at harvest in 1995-96.

Larval damage to random samples of harvested fruits was recorded in all three seasons and production areas using large numbers of fruits (e.g. 100 fruits per tree on each of 5–20 trees per cultivar block) in the following cultivars: BFP – ‘Dayton’, ‘Braeburn’, ‘Fiesta’, ‘Fuji’, ‘Jonafree’, ‘Liberty, ‘Prima’, ‘Redfree’, ‘Royal Gala’; IFP – ‘Braeburn’, ‘Fuji’, ‘Sciros’, ‘Royal Gala’, ‘Southern Snap’; CFP – ‘Braeburn’, ‘Fuji’, ‘Royal Gala’.

Analysis of spring damage in commercial orchards: Species/damage identification

Beginning on 7 October 1998, timed weekly examinations for noctuids and their damage were carried out on the foliage and fruits of flowering and fruiting clusters of apple trees in 21 commercial blocks in nine orchards of the Ettrick and Dumbarton districts, Central Otago. Sampling continued through flowering, fruit set, and early fruit development until November 18 1998 for eggs and December 10 1998 for larvae and damage. Apple cultivars included were 'Braeburn', 'Cox's Orange Pippin', 'Fuji', 'Golden Delicious', 'Granny Smith' and 'Royal Gala'. One cultivar was sampled at each of the 21 sites.

Over 100 examples of fruit damage by noctuid larvae were photographed and labelled in spring 1998, and growers were asked not to remove them during thinning. Those remaining at harvest (after natural drop) were again photographed to determine the relationship between the appearance of spring and harvest damage.

Samples of the noctuid eggs and larvae found were collected and their survival was monitored in the laboratory. Hatched (2 larvae per egg batch) and surviving larvae were placed on artificial diet in tubes (n = 100) and were reared through to adult to determine the noctuid species and any parasitism.

Analysis of spring damage in commercial orchards: Monitoring and action threshold

In 1998, one pheromone trap for *G. mutans* ('South' taxon) was operated, as described earlier, on each of the 21 monitored blocks from 30 September to 26 November (i.e. throughout the spring flight period). The weekly trap catch data are presented as the mean number of moths per trap per day, and the catches provided guidance to the timing of sampling for eggs, larvae, and damage.

The 1998 weekly examinations for pest species and damage identification described above were also used as a quantitative sampling method based on the flower/fruit cluster as the sampling unit. The numbers of flower/fruit clusters examined and the times spent sampling were recorded, as well as the numbers of noctuid egg batches, larvae, and damage to leaves and fruits. After the first sample at pink stage which took 20-25 person minutes per cultivar block (about 120 flower clusters), sampling time was reduced and was normally 10–15 minutes for a total of 25–110 flower/fruit clusters per cultivar block. Wide variation in the numbers of clusters sampled in the available time reflected the variation in the numbers of insects found and collected (see above), as well as the stage of the crop and size of the clusters. For example, with no fruit to examine during flowering, larger number of clusters could be examined in a given time than was possible after fruit set.

These procedures provided estimates of the density of eggs, larvae and damage each week which could be expressed as numbers per flower/fruit cluster or time interval. Leaf damage per flower/fruit cluster and fruit damage per fruit cluster were also recorded and calculated separately. The time taken in monitoring was recorded to enable this to be costed, and to enable development of a commercial monitoring procedure for use in the IFP programme (Walker *et al.* 1997).

The commercial monitoring method developed from the 1998 research was evaluated on 22 cultivar blocks in spring 1999. On 11 November in each cultivar block, we examined 200 fruit clusters (10 clusters on each of 20 trees) for foliage damage by noctuids (shot-hole damage). The cultivars used were 'Braeburn' (2), 'Cox's Orange Pippin' (5), 'Fuji' (2), 'Golden Delicious' (1), 'Granny Smith' (4), and 'Royal Gala' (8). Growers also carried out their own monitoring to determine their spray requirements. The same IFP monitoring procedure was carried out on six blocks of apples at the Clyde Research Centre, where no corrective spraying action was undertaken regardless of the spring damage levels recorded. The cultivars used were 'Braeburn' (1), 'Fuji' (1), 'Sciros' (1), 'Royal Gala' (2), and 'Southern Snap' (1). At harvest in both 1999 and 2000, 1000-1600 fruits per cultivar block were examined for noctuid damage (normally 200 fruits from each of five harvest bins).

Regression analyses were undertaken to determine the relationship between the following parameters of the noctuid population at each site in 1998-99:

(a) weekly spring fruit cluster damage and weekly spring leaf damage on the same fruit clusters;
(b) peak spring fruit cluster damage and peak spring leaf damage on the same fruit clusters;
(c) peak spring fruit damage on fruit clusters and mean harvest fruit damage;
(d) peak spring leaf damage on fruit clusters and mean harvest fruit damage;
(e) average weekly pheromone trap catches and all the foregoing parameters;
(f) total pheromone trap catch and all the foregoing parameters.

The primary purpose in these analyses was to identify a spring sampling method which could be used to give a reliable and practical estimate of potential damage at harvest. This was then used to derive an action threshold. Regression analysis (d) was conducted with data from 1999-2000 to confirm its efficacy as a predictor of harvest damage and as a generator of the action threshold.

RESULTS

Seasonal pheromone trapping at Clyde Research Centre

The pheromone trap catches of *G. mutans* 'South' and 'North' in 1995 to 1998 were very similar despite the data being the means of only three traps in each taxon (Figs 1a – 1c). The spring flight provided much higher catches of males than later in the season in three of the five years (Figs 1a – 1e) but particularly high catches of males were obtained in the period prior to harvest in 1995-96 and 1999-2000. Conversely, particularly low catches of male *G. mutans* (<10 moths/trap/day) were obtained in the autumns of 1997-98 and 1998-99. A trough in catches occurred in late December/early January in every year.

Seasonal infestation and damage assessment at Clyde Research Centre

Monitoring of noctuid egg batches in 1995-96 on leaf and fruit clusters in the fifteen cultivar blocks of the BFP, IFP and CFP areas showed that egg laying occurred throughout the growing season (see BFP Fig. 2a). Sampling began too late to record egg laying during the flowering period but egg batches were found from petal fall onwards, and peak numbers of egg batches occurred in January/February, at the time of major peaks of pheromone trap catches of males in that season (Fig. 1a). First (1º) and second (2º) instar larvae only were detected on the trees in the BFP area in November and December 1995 but were then found again on only

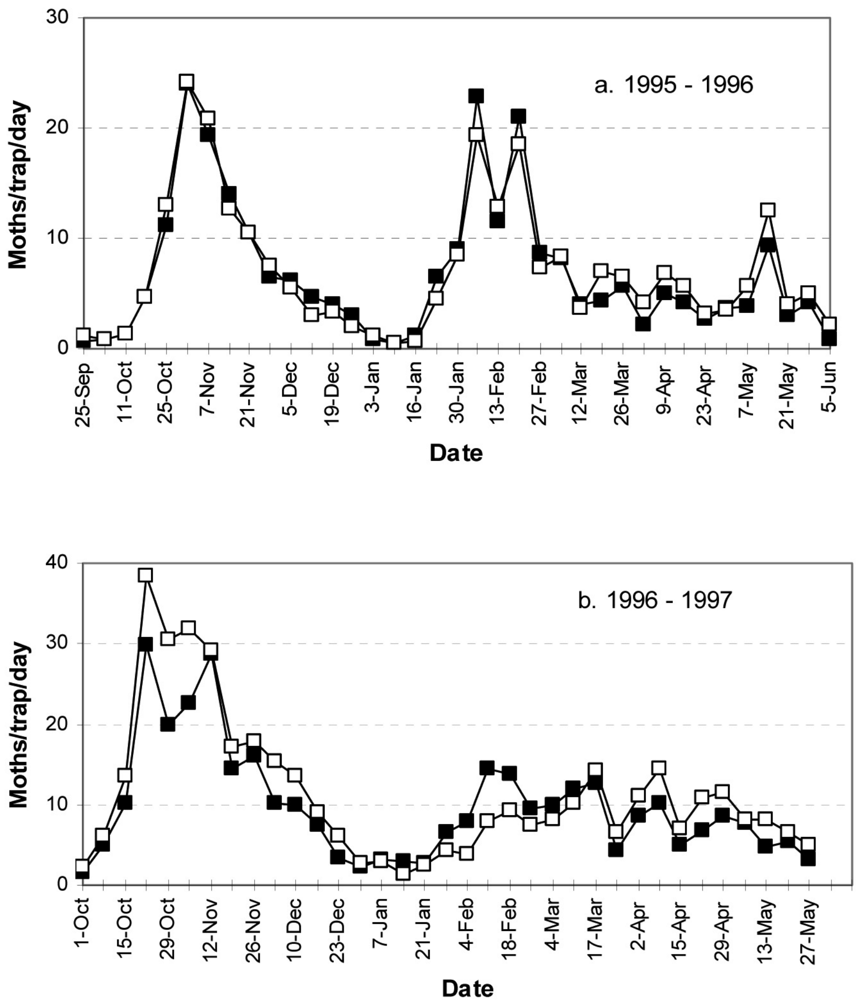
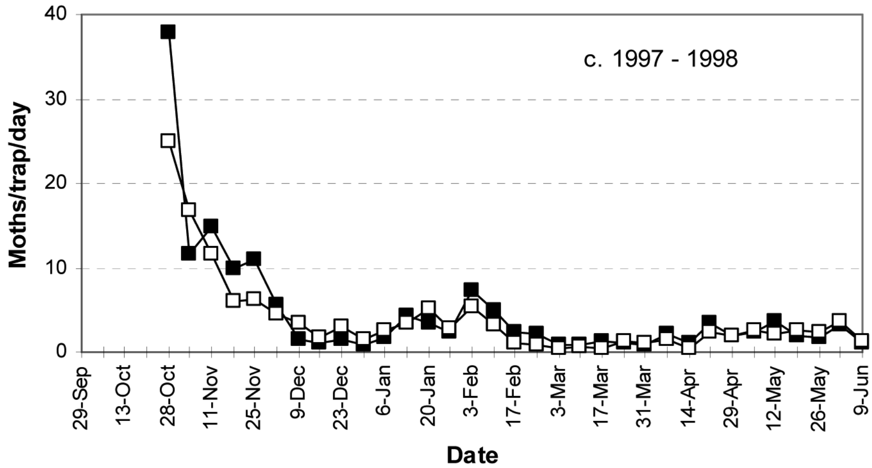
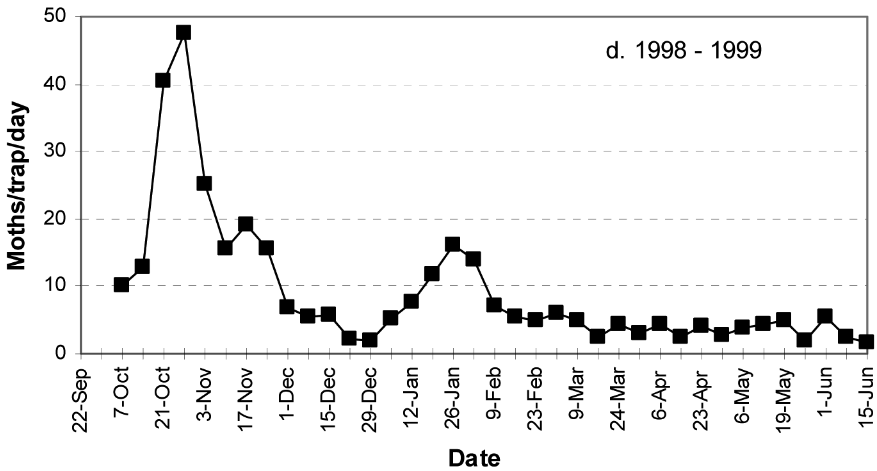
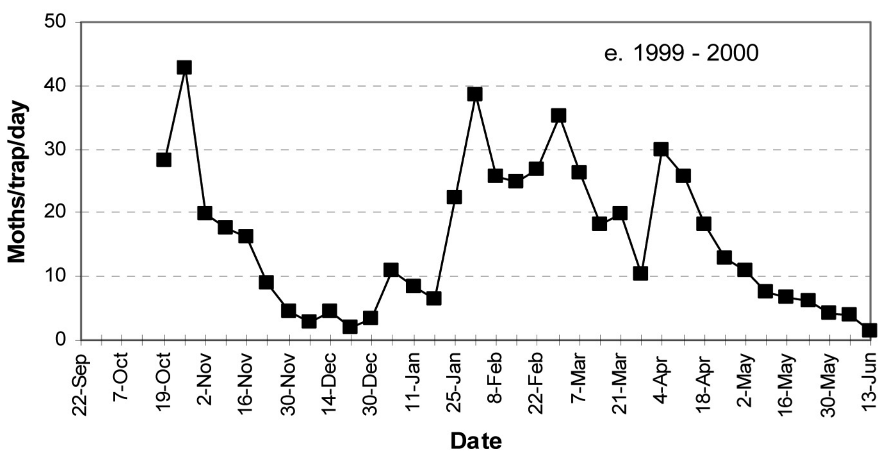


Figure 1a - e. Mean weekly pheromone trap catches of G*raphania mutans* 'South' (■) and 'North' (□) in apple blocks at Clyde Research Centre 1995 to 2000.







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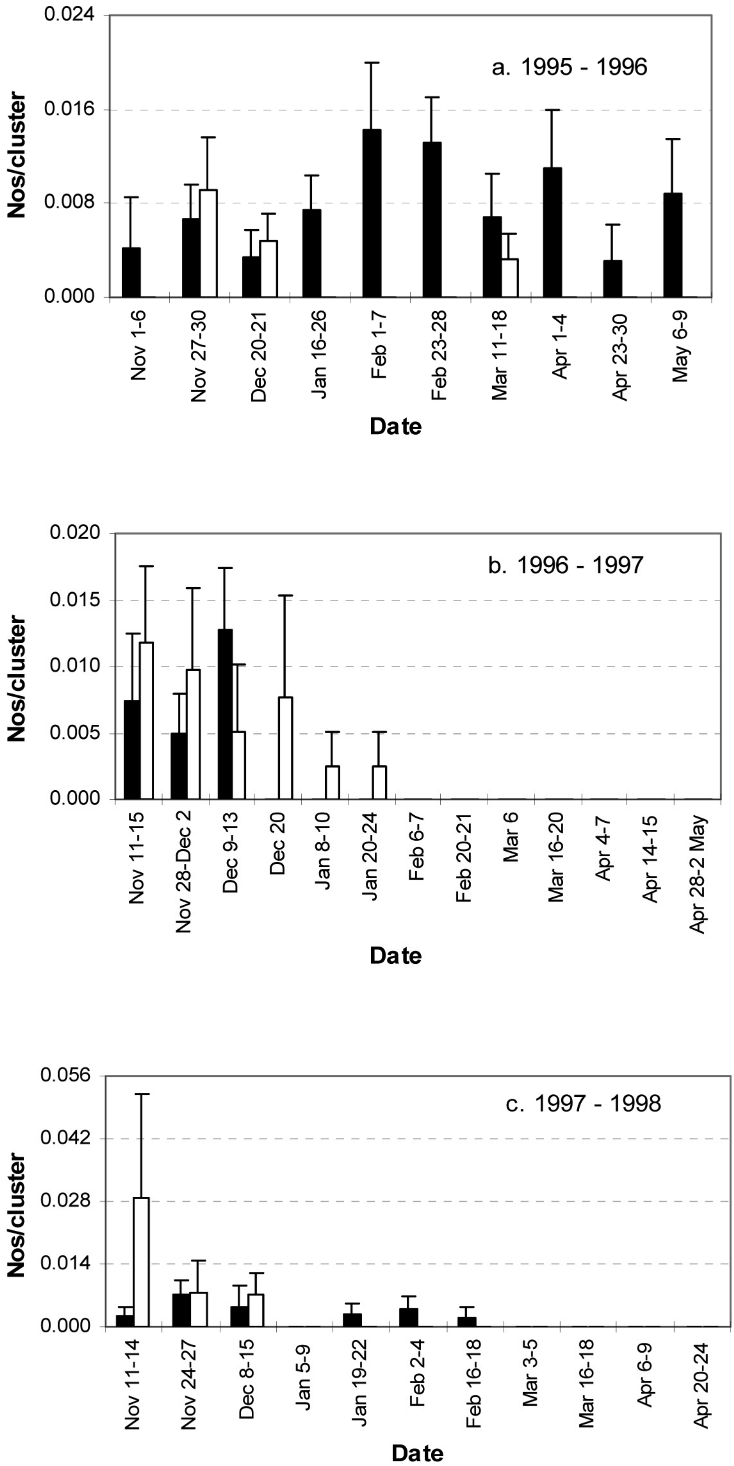

Figure 2. Mean numbers (± SE) of noctuid egg batches (■) and larvae (□) per leaf and fruit cluster on apple trees in the biological fruit production (BFP) area at Clyde Research Centre during the three growing seasons, 1995 to 1998.

one occasion in March, again in the BFP area (Fig. 2a). Densities of egg batches found in the samples from the IFP and CFP areas (not shown) were similar to those from the BFP area at those times. However, no larvae were recorded on the clusters of IFP or CFP trees, which was likely due to the efficacy of their insecticide treatments (e.g. tebufenozide and azinphos-methyl respectively).

High spring numbers of male *G. mutans* in 1996 (Fig. 1b) were associated with egg batches and larvae (1º and 2º) at and after petal fall in the BFP area, higher than in 1995 (Fig. 2b), with larvae present until January 1997. On the other hand, the low pheromone trap catches later in the 1996-97 season (Fig. 1b) were accompanied by an absence of egg batches and larvae in the samples after January.

In 1997-98, spring flights of adult moths were again followed by eggs and larvae (1º and 2º) on the trees in November and December (Fig. 2c). Initial larval density at petal fall was the highest seen over the three years (note the y axis in Fig. 2c), suggesting that peak egg laying occurred prior to the first sample on 11-14 November and very high numbers of moths may have flown over the flowering period (before trap deployment). Following the mid-season trough, a low incidence of egg batches was recorded in January and February but no larvae were found in samples after December.

Noctuid damage to leaf and fruit clusters in the monitored blocks was recorded on every sampling occasion from petal fall onwards in 1996-97 and 1997-98 and from December onwards in 1995-96. Although there was some accumulation of damage over the initial two to three samples, damage fluctuated thereafter at that level (e.g. 1997-98 Fig. 3). This failure of damage to increase over the season was supported by the absence or rarity of larvae in the samples after December each year (Figs 2a – 2c).

The noctuid damage at harvest in the three production areas is summarised in Table 1.

Annual noctuid damage at harvest was not correlated with the numbers of adult moths trapped over the summer (see Fig. 1) and supported the evidence of cluster sampling that larval damage was almost exclusively attributable to the spring populations.

Species composition of eggs and larvae, and the development of fruit damage

Over the three years of egg and larval collections at the Clyde Research Centre, about 95% of the noctuids were *G. mutans*, but in 1995-96 they constituted just 90% and most of the remainder were *Agrotis ipsilon aneituma* (Hufnagel). The latter species was not recorded in later years, whereas a very small number of individuals (1-5) of *G. ustistriga* were found every year, and a similar number of *Graphania plena* (Walker) in 1996-97 and 1997-98. In addition, 1-2 specimens of the geometrid *Declana leptomera* (Walker) were reared. The collections of noctuid eggs and larvae which were reared from the commercial orchards in 1998-99 were entirely *G. mutans*.

Photographs of the same fruit damage in spring 1998 and at harvest 1999 (e.g. Fig. 4) provided the first evidence specifically demonstrating how noctuid damage develops (n ≈ 50). The typical damage in spring

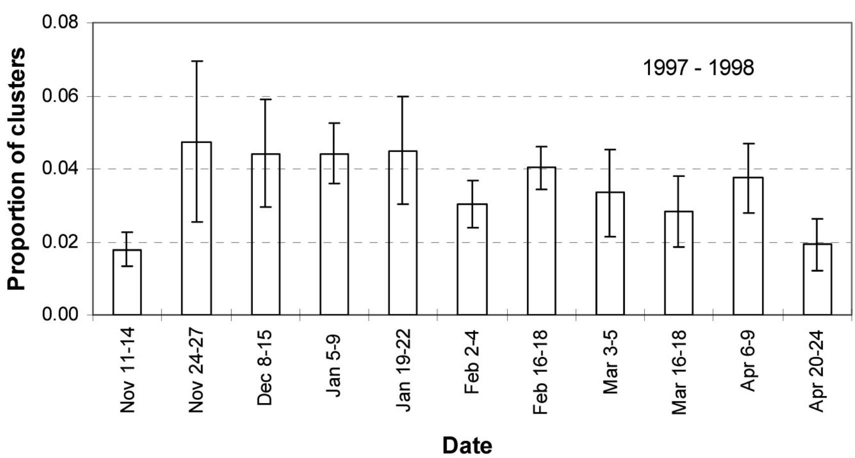

Figure 3. Mean proportions (± SE) of leaf and fruit clusters damaged by noctuid larvae on apple trees in the biological fruit production (BFP) area at Clyde Research Centre in the 1997-98 season.

Table 1. The mean (± SE) and range* of noctuid damage (%) at harvest in three apple production systems at Clyde Research Centre, Central Otago, 1996 –2000.

Year	Production System**		
	BFP	IFP	CFP
1996	2.49 ± 0.31 (1.1 – 4.4)	1.31 ± 0.18 (0.7 – 2.5)	0.58 ± 0.12 (0.3 – 0.8)
1997	2.61 ± 0.19 (1.4 – 3.9)	1.10 ± 0.26 (0.4 – 2.3)	1.28 ± 0.21 (0.9 – 1.9)
1998	3.36 ± 0.26 (2.1 – 6.1)	2.96 ± 0.29 (1.8 – 4.0)	2.51 ± 0.34 (2.3 – 2.7)
1999	0.79 ± 0.22 (0.4 – 1.8)	0.79 ± 0.13 (0.0 – 1.3)	0.28 ± 0.09 (0.1 – 0.5)
2000	1.08 ± 0.25 (0.4 – 2.7)	1.15 ± 0.14 (0.3 – 1.7)	1.52 ± 0.27 (1.2 – 2.3)

***Range of mean damage in cultivar blocks **biological (BFP), integrated (IFP), and conventional (CFP) fruit production**

Figure 4. Noctuid damage to apples in spring (top) and to the same apples at harvest.

was several small feeding areas on the surface of a fruit, the vast majority of which became small russetted subcircular scars at harvest, usually protruding slightly from the apple surface. Near the calyx, the fruit growth resulted in many of the scars being tear-drop shapes. Contrary to expectations, other forms of anecdotal noctuid damage, such as those resulting in infolds, distortions, or holes, were extremely rare and uncertain. The greatest confusion with identification of noctuid damage was caused by spring hail, which had extremely variable impacts on the fruit surface, sometimes resembling noctuid damage, but usually accompanied by distinct indentation of the apple surface. Grazing of the apple surface by grass grub beetles, *Costelytra zealandica* (White), was readily distinguished by the shape and greater size of the feeding scars.

Analysis of spring damage in commercial orchards: Monitoring and action threshold

The relationship between the timing of male trap catches and subsequent egg laying, larvae, and damage in 1998-1999 is shown in Figure 5. Although the flight of males peaked during flowering and the laying of egg batches began at this time, the first hatching of eggs and presence of larvae were detected at petal fall (week ending November 4). Damage to the foliage also began at that time and occurred primarily over the next 3-4 weeks. Damage to the foliage preceded damage to the young fruitlets which was first detected on 18 November.

The regression of peak damage to the fruit on peak damage to the foliage of the same fruit clusters in spring was highly significant (Fig. 6).

The outlier on the x-axis (Fig. 6) was from ‘Granny Smith’ trees with a very light crop which was almost

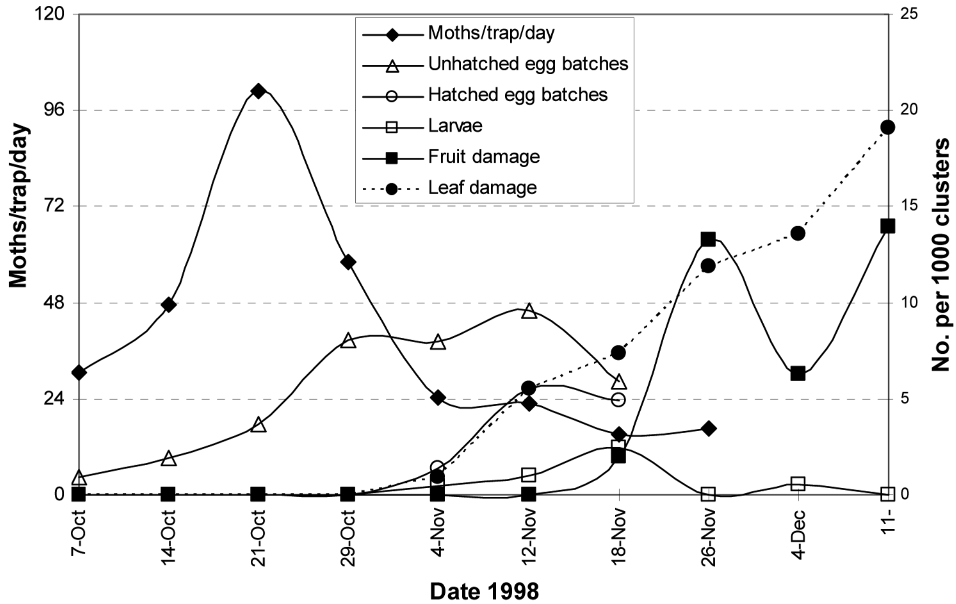

Figure 5. Mean weekly pheromone trap catches of *Graphania mutans* 'South' in spring in relation to mean noctuid phenology and damage on the flower/fruit clusters of apple trees in 21 commercial apple blocks, Central Otago, 1998.

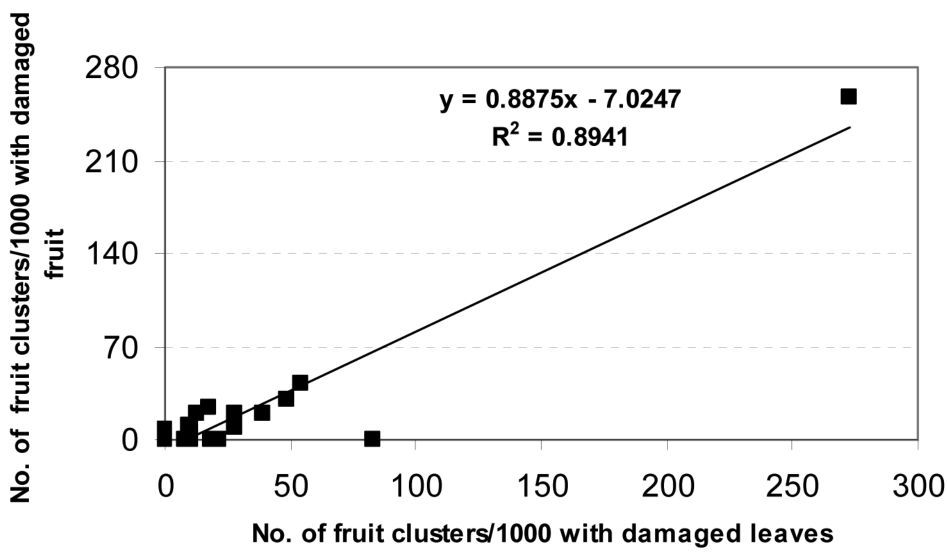

Figure 6. Regression of peak noctuid damage to fruit on peak noctuid damage to leaves on fruit clusters in spring 1998 in 21 commercial apple blocks, Central Otago.

entirely single fruits with dense foliage. Damage to the leaves in this instance was not matched by damage to the fruits. Nevertheless, the results showed that sampling of fruit clusters for foliage damage in spring, which is shot-hole feeding and highly visible, might be used to estimate the risk of damage to the fruit at that time, thereby avoiding the need to examine individual small fruitlets when monitoring.

Some of the other regression analyses are summarised in Table 2.

The analyses showed that there was a highly significant relationship between spring damage (to either leaves or fruits of fruit clusters) and fruit damage

Table 2. Results of selected regression analyses of the relationships between spring damage, harvest damage, and pheromone trap catches of noctuids in apple cultivar blocks (n = 21) of Central Otago orchards in 1998-1999.

Independent variable (x)	Dependent variable (y)	Equation	R^2
Peak spring fruit damage to fruit clusters/1000	Harvest damage (%)	y = 0.0003x - 0.0013	0.9528***
Peak spring leaf damage to fruit clusters/1000	Harvest damage (%)	y = 0.0003x - 0.0037	0.8765***
Average weekly trap catch	Harvest damage (%)	$y = 6x10^{-5}x - 0.0103$	$0.1789^{n.s.}$
Average weekly trap catch	Peak spring fruit damage to fruit clusters/1000	y = 0.1823x - 25.506	$0.1725^{n.s.}$
Average weekly trap catch	Peak spring leaf damage to fruit clusters/1000	y = 0.1689x - 11.146	$0.1304^{n.s.}$
Excluding two blocks sprayed with an organophosphate insecticide at petal fall*			
Peak spring fruit damage to fruit clusters/1000	Harvest damage (%)	y = 0.0003x - 0.0006	0.9678***
Peak spring leaf damage to fruit clusters/1000	Harvest damage (%)	y = 0.0003x - 0.0024	0.9743***

*** this treatment is no longer used in commercial orchards *** P<0.001$^{n.s.}$ not significant**

at harvest. This was improved even further when two blocks which had been sprayed with an organophosphate insecticide at petal fall were excluded from the analyses (Table 2). This practice, which is no longer used, was highly toxic to the eggs and larvae, thereby preventing damage, grossly affecting the relationship under study, and confirming that economic damage by noctuids was confined to the spring period. Carbaryl was widely used for thinning and the effects of these sprays (see Discussion) have not been removed from any of the analyses. The regressions were strongly influenced by the results from one orchard which was very heavily attacked (see Figs 6 and 7) and the grower collaborated exceptionally by not intervening with sprays. Because there were not more orchards with similar high damage levels, the regression results were considered preliminary in providing a basis for developing an action threshold (see below), pending the results for 1999-2000.

There were poor relationships between male moth catches in spring and the levels of damage in spring or at harvest (Table 2). Although significant regressions were obtained when organophosphate-sprayed blocks were excluded ($R^2 = 0.55$, $P<0.05$), the correlation was insufficient to be used with confidence.

The regressions of harvest fruit damage on spring leaf or fruit damage to fruit clusters in 1998-99 provided a means of calculating a preliminary action threshold for noctuids for use in 1999-2000. Using the last two equations in Table 2, the relationships between a specified tolerance of damage at harvest and the damage which would have occurred in spring are summarised in Table 3; these are compared with the results for 1999-2000 using only leaf damage as the predictor (see equation of Fig. 7). A sample size of 200 fruit clusters was chosen in these calculations and was used in the 1999-2000 sampling programme. Table 4 summarises the relationships between a specified level of spring damage and the damage predicted at harvest (using the same equations as for Table 3).

The results of 1998-99 were confirmed by the 1999-2000 monitoring (Fig. 7).

Although the regression lines for the two seasons differed slightly, this was not statistically significant and the relationship between spring foliage damage and harvest fruit damage was similar in the critical range up to 2% (Tables 3 and 4). A conservative spring action threshold for noctuids of >5 out of 200 **fruit clusters** with damaged **leaves** in spring was proposed and proved satisfactory in 1999-2000. This is a conservative threshold because a proportion of the damage is minor and would not result in downgrading of the fruit. On the other hand, carbaryl thinning sprays are assumed to be applied on those varieties which require it, and if this practice was reduced, the threshold may be expected to decrease (see Discussion). Sampling for threshold assessment in spring 1999 took 20-25 minutes for 200 fruit clusters per cultivar block.

The action threshold was exceeded in only two

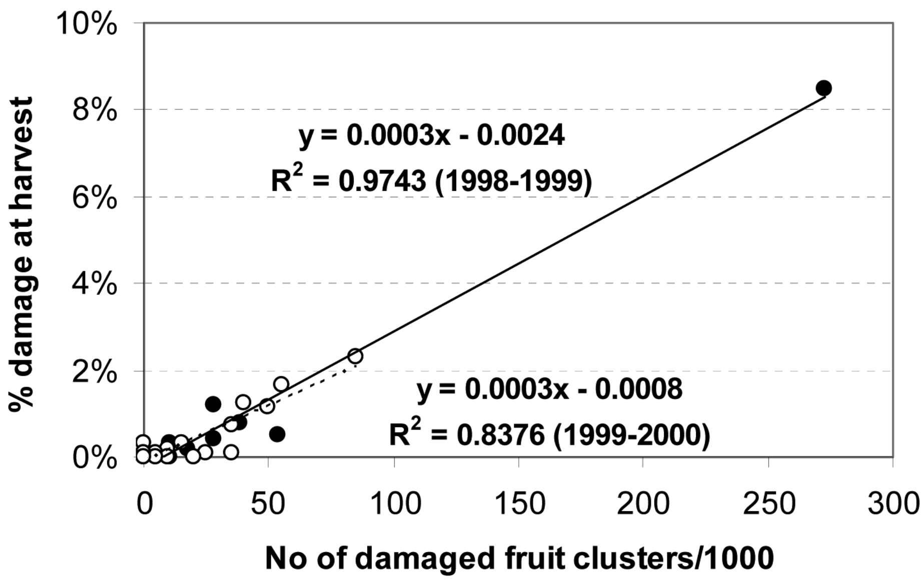

Figure 7. Regression of mean noctuid damage to fruit at harvest on leaf damage to fruit clusters in spring, for Central Otago apple blocks, 1998-99 (●) and 1999-2000 (○).

Table 3. Relationship between tolerance of noctuid damage at harvest and the numbers of fruit clusters with damaged fruit or leaves per 200 fruit clusters in spring 1998 and 1999.

Damage tolerance at harvest (%)	Fruit clusters with damaged fruit in spring 1998	Fruit clusters with damaged leaves in spring 1998	Fruit clusters with damaged leaves in spring 1999
0	0.4	1.5	0.6
0.5	3.4	4.7	4.6
2.0	12.6	14.3	16.4
5.0	31.0	33.4	40.0

Table 4. Relationship between noctuid damage to fruit or leaves of fruit clusters per 200 in spring and the expected fruit damage at harvest 1999 and 2000.

Fruit clusters with damaged fruit in spring 1998	Damage expected at harvest 1999 (%)	Fruit clusters with damaged leaves in spring 1998 or 1999	Damage expected at harvest 1999 (%)	Damage expected at harvest 2000 (%)
1	0.1	2	0.1	0.2
4	0.6	5	0.6	0.6
12	1.9	14	2.0	1.7
30	4.8	33	4.9	4.1

cultivar blocks in the commercial orchards in spring 1999, with six damaged fruit clusters/200 and seven damaged fruit clusters/200. Both blocks were sprayed with carbaryl for thinning and harvest noctuid damage was only 0.1%. In the six cultivar blocks at the Clyde Research Centre where no sprays were applied for noctuid control, spring samples of 200 fruit clusters yielded 17, 11, 10, 8, 7, and 3 with damaged leaves which resulted in 2.3%, 1.7%, 1.2%, 1.2%, 0.8%, and 0.3% fruit damage respectively at harvest.

DISCUSSION

This research has shown that, as in other regions of New Zealand (Burnip *et al*. 1995), the noctuid primarily responsible for damage to apples in Central Otago is *G. mutans*, accompanied by occasional damage by *G. ustistriga*. In addition, two new species, *G. plena* and *A. ipsilon aneituma*, contributed a minor part of the spring damage in Central Otago. Samples from Clyde Research Centre showed that the most common parasitoids attacking noctuid larvae on the apple trees were the tachinid *Pales cf. nyctemeriana* (Hudson) (det. J. S. Dugdale, Landcare Research) and the braconid *Meteorus pulchricornis* (Wesmael) (det. J. Berry, Landcare Research, see Berry and Walker 2003). Apple damage by geometrid caterpillars was rare, as recorded in Nelson (Collyer and van Geldermalsen 1975).

The photographic study of damage revealed that noctuid feeding caused a very consistent form of surface damage to apples, as described earlier. The ability of the developing apples to recover from this damage is remarkable, as illustrated by the calyx damage in Figure 4. The occurrence of apple distortion, in-folds, and healed holes into the surface, which have sometimes been attributed to noctuids, require an alternative explanation. Such damage was reported in Central Otago in the spring of 1997, with up to 25% of apples affected on commercial orchards in the Ettrick and Miller's Flat districts. This rare and extreme case stimulated the research which began in 1998 but the damage did not recur and its cause remains unknown.

Pheromone trapping of male *G. mutans* in Central Otago revealed a phenology very similar to that in Canterbury (Burnip *et al*. 1995), and with like in-season and annual variation in the relative size of catches between the spring, summer, and autumn flights. The most consistent features in Otago were the timing and magnitude of spring flights and a trough in catches at the end of December, similar to that in Canterbury (Burnip *et al*. 1995). The close similarity of the catches of the 'South' and 'North' taxa of *G. mutans* was also a strong characteristic of trapping in Otago and Canterbury (Burnip *et al*. 1995), and justified monitoring for only one taxon as suggested by Suckling *et al*. (1990).

Suckling *et al*. (1990) also suggested a link between the numbers of male *G. mutans* caught in pheromone traps and the surrounding land use. This was supported by Burnip *et al*. (1995) who noted higher catches in orchards which had a higher proportion of pasture in their environs compared to those in more urban locations. The vast majority of apple orchards in Central Otago, including Clyde Research Centre, are located in areas where areas of pasture are close by. The spring trapping data from the commercial orchards in this region in 1998-99 were characterised by high catches of males in almost all locations. The mean numbers of male moths per trap per day (in spring) ranged from 18.3 to 68.1, with mean peak daily catches per week of 43 and 240 respectively. The two lowest mean catches (18-27 males per trap per day) were in cultivar blocks surrounded by large areas of sprayed orchards; the highest mean catch (68 males per trap per day) was in an orchard on the fringe of the fruit growing area adjacent to vast areas of pasture.

Mean pheromone trap catches of male *G. mutans* in spring proved a poor predictor of spring or harvest damage. The consistency of the timing of noctuid attack on apples in spring in Otago makes trapping to obtain that information unnecessary and, as a monitoring method, the cost of trap operation would be greater than that of simply searching fruit clusters on one well-timed occasion, as described in this paper. Similarly, the frequency of noctuid eggs on harvested apples is extremely low and currently would not justify the further development of pheromone trapping as a means of monitoring this risk.

The phenology of egg laying and larval feeding of noctuids on apples has not been previously studied. While the evidence showed that eggs could be laid on the trees throughout the growing season in some years, it was also clear that larvae and fresh leaf or fruit damage were very rare or absent after December even on unsprayed trees, suggesting that the larvae at that time rapidly descended to ground cover plants to feed. Larvae found at any time were either 1º or 2º, confirming that larvae either died or dispersed to feed on ground cover plants. All data confirmed that the only noctuid feeding damage of potential economic significance was caused in November and December by young larvae arising from the spring flight of adults. Peak spring fruit damage always exceeded harvest damage. Contamination of harvested apples by noctuid egg batches was too rare to be investigated in the present study.

The insecticide action threshold of >5 out of 200 fruit clusters with noctuid-damaged leaves in spring was made deliberately conservative, partly because of the use of a single application of carbaryl for thinning in most of the study orchards (a practice which is in decline). Mortality records of the eggs and larvae in the field, and among those collected from the orchards and reared in the laboratory, showed that carbaryl usually caused 100% mortality for one week. In the following two weeks, egg mortality ranged widely from 0 to 98% and the mortality of surviving larvae ranged from 50 to 100%. It is probable, therefore, that carbaryl prevented some fruit damage and also caused some larval mortality after damage by the insects. It was reasoned that if carbaryl were to be removed as a thinning option, larval fruit damage at harvest may be increased for a given level of spring foliage damage. However, further analysis suggests that this effect is minor because the results from the Clyde Research Orchard on unsprayed blocks were included in generating the regression of harvest fruit damage on spring foliage damage in 1999-2000 (Fig. 7). Moreover, the alternative of hand thinning could also preferentially remove noctuid-damaged apples. Consideration should be given to revising the noctuid action threshold for a specific spring insecticide application upwards to >10 out of 200 fruit clusters with damaged leaves. This should ensure harvest damage well within the tolerance of damage being shown by fruit growers.

In integrated fruit production for pipfruit, the timing of the first post-bloom insecticide application against lepidopterous pests is increasingly based on pheromone trapping for codling moth and spring temperatures. Compared with past spraying practices in Central Otago, this results in a delay of the first spray to late November or early December; carbaryl use for thinning is also declining. In these circumstances, an action threshold for insecticidal control of noctuids in southern orchards in spring may become more important and more widely used, particularly in those surrounded by extensive pasture.

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