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Revised thresholds for cabbage stem flea beetle on oilseed rape

by

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CONTENTS

ABSTRACT

The aim of the study was to investigate a field-based method using water traps to provide information in early autumn on the need for control of cabbage stem flea beetle. At each of 71 sites (27, 25 and 19 sites in autumn 2004, 2005 and 2006 respectively) in central, eastern and northern England, four yellow water traps 25 cm in diameter were placed on the soil surface in winter oilseed rape crops soon after drilling or at early crop emergence. Two traps were sited on the crop headland with two traps within the field; 12 and 24 metres from the crop headland. Weekly and total catches of cabbage stem flea beetles in traps were recorded between crop emergence and late October or early November. Peaks of adult activity were recorded in late September or early October with higher totals of beetles recorded in each year of the study in central and northern England than in eastern England. Plant samples were collected in December to determine the number of larvae per plant and seventeen from the total of 71 sites subsequently developed infestations averaging two or more larvae per plant.

Regression analysis using data from all 71 sites showed that mean numbers of larvae per plant were significantly related to mean number of adults per water trap ($P < 0.001$). An infestation averaging two larvae per plant was likely to be attained from an average of 36 (SE 3.2) adults per trap with 69.3% of the variance explained. Regressions testing the relationships between adult numbers and larval infestations for each of the three study years were also significant (P = or < 0.001). Regressions were tested for headland or field-sited traps with two larvae per plant likely to be attained from means of 33 and 40 beetles per trap respectively.

The use of water traps enabled successful decisions to be made whether to spray or not at 87% of sites using a mean of 36 beetles per water trap. Overall predictive success was improved to 89% if the lower or upper 95% confidence limit values of 30 and 43 respectively per trap were used. Similar predictive successes were also obtained from headland or field-sited traps with correct treatment decisions made at 86% and 90% of sites respectively.

At sites where infestations averaging two or more larvae per plant were recorded, predictions of the need for control using the lower 95% confidence limit value of 30 cabbage stem flea beetle adults per water trap enabled 82% correct treatment decisions to be made, compared with 65% of correct treatment decisions using the median and upper 95% confidence limit values of 36 and 43 adults per water trap. A threshold value for water trap catches averaging 30-35 per trap was shown to be an action threshold above which an autumn pyrethroid spray treatment would be justified, irrespective of whether an earlier seed treatment had been applied.

In autumn 2004, four yellow sticky traps were compared with water traps as predictive methods at 27 sites. Sticky traps caught fewer cabbage stem flea beetles than water traps with a mean of 1.3 per sticky trap compared with a mean of 8.0 per water trap. A significant regression was obtained ($P < 0.001$) with 51.0% of variance explained with two larvae per plant likely to be attained from a mean of 5.7 beetles per sticky trap. The use of sticky traps provided a poor predictive method compared with water traps and the method tested did not predict the two sites in 2004 where above threshold numbers of larvae developed.

Regressions between larval numbers and plant, cotyledon and first true leaf damage were also tested at 52 sites in the first two years of the study during harvest years 2005 and 2006. Although larval numbers were significantly correlated with plant and cotyledon damage, only 14.0% and 10.8% of variance was explained and these methods were overall poor predictors of larval damage with only 20% of sites that developed larval infestations greater than two per plant being correctly predicted for treatment.

SUMMARY

Oilseed rape is attacked by a complex of pests and in recent years, cabbage stem flea beetle (*Psylliodes chrysocephala*) has become one of the most important insect pests during the establishment phase of autumn-sown crops. Its range has expanded into north-eastern England and Scotland, from initial infestation strongholds in southern and eastern England. Adult cabbage stem flea beetles emerge from aestivation from mid to late-August onwards and lay eggs in the soil after a period of feeding on the cotyledons and leaves of newly-emerged crops. The resulting larvae burrow into the plants and feed within the leaf petioles or stems during the autumn and winter period.

The larvae of cabbage stem flea beetle are normally considered to be more damaging than the adults. A control threshold for control of larvae that was previously used in the UK was an average of five larvae per plant providing an average 0.34 t/ha yield response from an effective, autumn-applied insecticide treatment. This threshold was updated in 2006 to reflect the favourable economics of control using pyrethroid sprays and is currently an average of two larvae per plant providing an average response to spraying of 0.16 t/ha worth around £40/ha at the present oilseed rape average price of £250/t. Treatment with a pyrethroid insecticide, if well-timed to coincide with the early stages of larval invasion, provides control of 70-80% or more and provides an option for cost-effective control where required.

Control of cabbage stem flea beetle relies heavily on the use of autumn-applied pyrethroid insecticides and, since 2002, on imidacloprid + beta-cyfluthrin applied as an insecticidal seed treatment. Large numbers of adult beetles feeding in crops from establishment can kill plants, but normally the larvae are more important economically with feeding damage occurring in leaf stalks and plant stems, typically from mid-late October and continuing overwinter. An economic-action threshold for control in autumn can be determined by plant dissection or assessment of leaf scarring. However, these methods provided a result that was often too late for autumn-applied insecticide sprays to be applied where necessary; usually as convenient tank mixes with autumn-applied herbicides and/or fungicides.

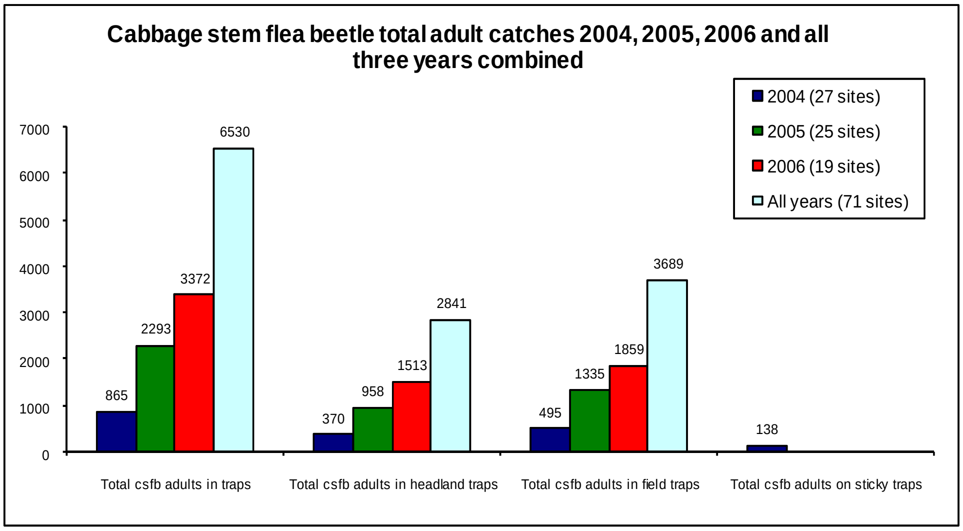
The three-year HGCA-funded study titled ‘Revised thresholds for cabbage stem flea beetle’ started in July 2005. The field-based study was conducted in a total of 71 commercial winter oilseed rape crops in central, eastern and northern England. The overall aims were to determine whether the number of cabbage stem flea beetle adults caught in ground-placed water traps or on vertically-mounted sticky traps could be used to predict the subsequent larval infestation and therefore the need for autumn control with pyrethroid sprays. A secondary objective was to determine whether larval infestations could be predicted from cabbage stem flea beetle adult damage to plants, cotyledons and first true leaves. A longer-term objective was to determine whether the method could be reliably used to update Decision Support System models currently being developed and tested for use on winter oilseed rape.

At each site, four yellow water traps 25 cm in diameter were placed on the soil surface in winter oilseed rape crops at early crop emergence, with two traps on the crop headland and two traps within the field at distances of 12 and 24 metres from the crop headland. Traps were left in place until late October or early November. Each week, the traps were reset with fresh water plus a few drop of detergent to reduce surface tension and the number of cabbage stem flea beetles in each trap was recorded to enable the total autumn catch to be determined.

Figure 1 summarises the incidence of adult cabbage stem flea beetle adult activity for each of the three study years. Mean numbers of beetles were 8.0, 22.9 and 44.4 per water trap in autumn 2004, 2005 and 2006 respectively. Combined trap catches for the three study years totalled 3,689 and 2,841 cabbage stem flea beetle adults in field-sited and headland-sited water traps respectively. In autumn 2004, catches on sticky traps were compared with catches in water traps at

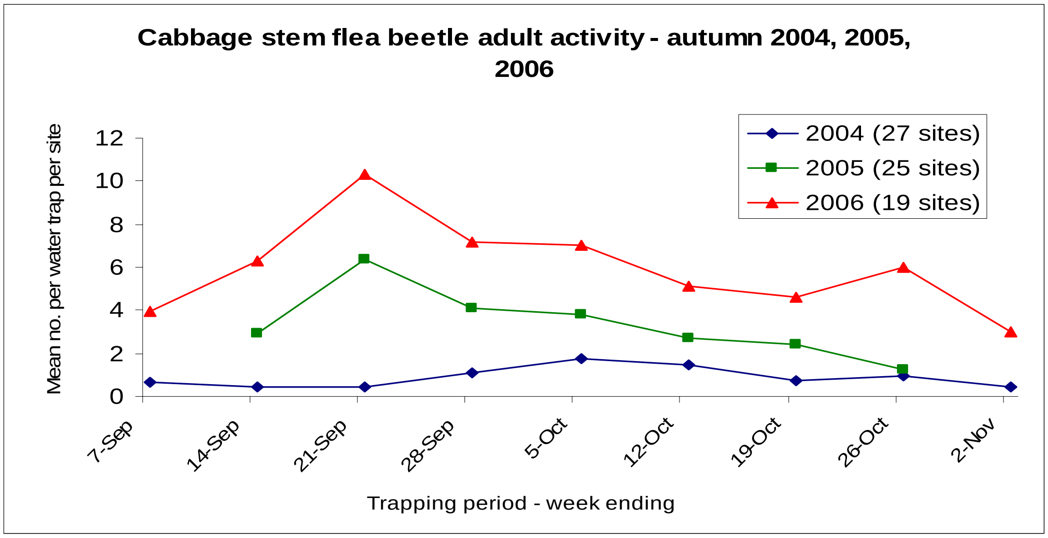
27 sites. The total catch of 865 in water traps in autumn 2004 was 6.3 times as high as the total catch of 138 on sticky traps.

Figure 1. Summary plot showing total number of cabbage stem flea beetle adults caught in four water traps at 71 sites; totals in two headland or two field-sited traps at 71 sites and total number on four sticky traps at 27 sites in autumn 2004.



Peaks of adult activity were recorded in late September or early October (Figure 2). Higher totals of beetles were recorded in each year of the study in central and northern England than in eastern England.

Figure 2. Summary plot for mean number of cabbage stem flea beetle adults per site for each weekly trapping period in autumn 2004, 2005 and 2006.



In the first study year, first catches were recorded in the first week of September 2004 during the early stages of crop emergence. A peak of adult activity was recorded in early October, followed by decreasing activity until mid October and a short-term increase in activity in late October before trap catches declined in early November. Peaks of autumn activity were recorded in late September 2005 and 2006 (Figure 2). The pattern of adult activity in each of the three years of the study was similar to that described by Alford (1979) who noted that the number of adults peaked in late September or early October and then declined.

Sampling of plants for larvae was undertaken, usually in early-mid December, to determine the number of larvae per plant and the number of plants and leaves infested. Totals of 25 plants (year 1) and 20 plants (years 2 and 3) were randomly sampled from unsprayed crop areas at each of the study sites. Plant samples were returned to the laboratory for damage assessment to record larval number and size; and percentages of plants and leaves infested by larvae (Tables 1 and 2).

Table 1. Mean number of cabbage stem flea beetle larvae per plant by survey region and for all sites in harvest years 2005, 2006 and 2007 (number of sites in brackets).

Harvest year	Survey region			
	Central England (32 sites)	Eastern England (23 sites)	Northern England (16 sites)	All sites (71 in total)
2005	0.70 (12)	0.00 (9)	0.05 (6)	0.32 (27)
2006	2.55 (11)	1.03 (8)	1.57 (6)	1.75 (25)
2007	3.08 (9)	0.46 (6)	3.00 (4)	2.24 (19)

Following the increased incidence of adult cabbage stem flea beetles between autumn 2004 and 2006 (Figure 1), larval infestations also increased with means of 0.32, 1.75 and 2.24 larvae per plant in harvest years 2005, 2006 and 2007 respectively (Table 1). Seventeen from the total of 71 sites subsequently developed larval infestations greater than a control threshold of two larvae per plant. The incidence of mean adult beetle damage to plants, cotyledons and first true leaves also increased during the three year study period (Table 2).

During each of the three years of the study, most of the heaviest larval infestations were recorded at sites in the Midlands. A total of 32 sites were monitored in the Midlands and 14 sites (44% of total) developed infestations greater than a mean of two larvae per plant. In this region, the heaviest larval infestation of 10.3 larvae per plant was recorded in Shropshire in harvest year 2006. Infestations were low at the majority of sites in eastern England, although an exception was one site in Norfolk in harvest year 2006 where a mean of 4.85 larvae per plant was recorded. In northern England, low infestations were recorded at the majority of sites although, in North Yorkshire, a mean of 10.6 larvae per plant was recorded at one site in autumn 2006. This was the heaviest infestation recorded at any of the 71 monitoring sites during the three-year study.

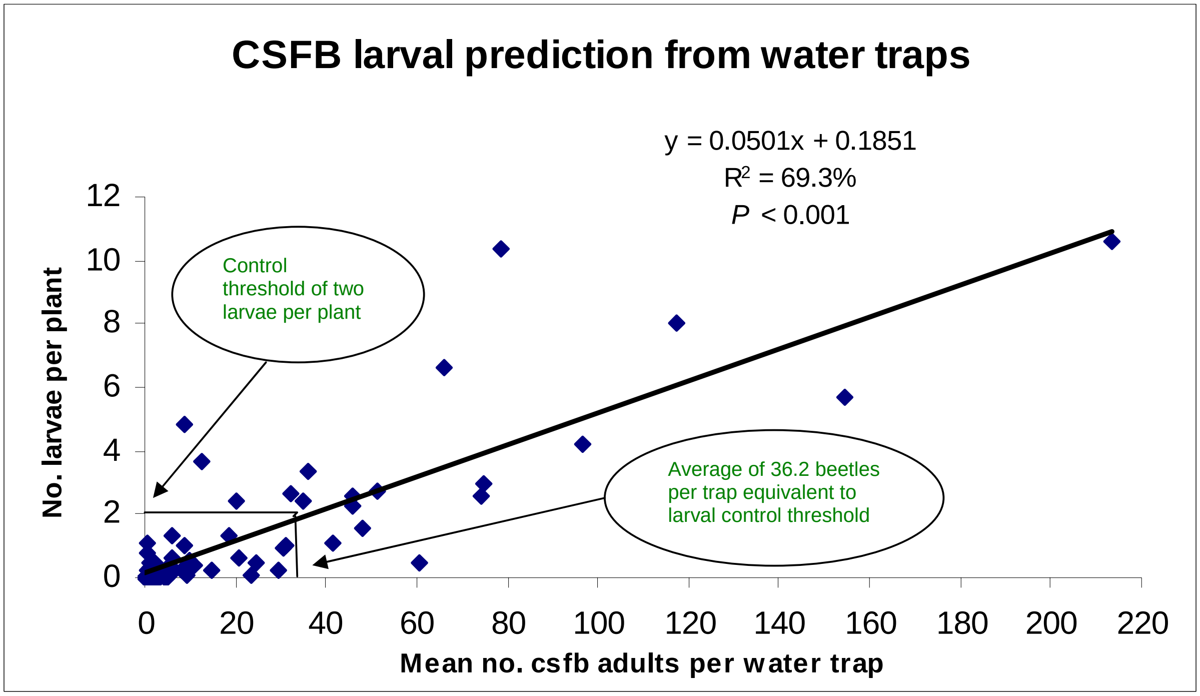
Table 2. Mean percentage of plants and leaves infested by cabbage stem flea beetle larvae in harvest years 2005, 2006 and 2007.

Harvest year	Mean percentage of plants infested	Mean percentage of leaves infested
2005	11.9	5.5
2006	44.2	18.5
2007	54.7	24.8

Regression analyses enabled the relationship to be tested between mean number of larvae per plant and mean number of adults in traps to determine whether it was possible to predict the number of larvae per plant from the number of cabbage stem flea beetle adults in traps. Regressions were also tested for larval number against mean numbers of plants, cotyledon and first true leaves damaged by the adult beetles.

Mean numbers of larvae per plant at 71 sites were significantly related to mean number of adult beetles per water trap ($P < 0.001$). A mean of two larvae per plant was likely to be attained from an average of 36.2 (SE 3.20) beetles per water trap with 69.3% of the variance explained (Figure 3) providing lower and upper 95% confidence limits between 29.8 to 42.6 beetles per trap. For predictive purposes, these values were subsequently tested in relation to correct or incorrect recommendations to treat or not to treat.

Figure 3. Cabbage stem flea beetle larval predictions from water trap catches at a total of 71 sites in harvest years 2005, 2006 and 2007.



Regressions of larval numbers were tested against mean number of beetles per water trap for each of the three years of the study. Two larvae per plant were predicted from means of 40.7 (SE 13.60. $P < 0.001$) beetles per water trap in harvest year 2005; 27.3 beetles per trap (SE 4.40, $P < 0.001$) per trap in 2006 and 39.3 (SE 6.21. $P = 0.001$) per trap in 2007. Regressions were also tested for headland-sited or field-sited traps with two larvae per plant likely from means of 32.9 (SE 3.49, $P < 0.001$) and 40.1 (SE 3.19. $P < 0.001$) beetles per trap respectively.

Larval infestations greater than a control threshold of two larvae per plant developed at a total of 17 from 71 sites (24% of total). Five sites developed infestations greater than five larvae per plant; two sites developed more than ten larvae per plant. Table 3 summarises the number and percentage successes for use of water trap catches for the prediction of larval infestations at the 17 sites where a control threshold of two larvae per plant was reached. An assumption is made that sites would have been recommended for spray treatment where larval numbers developed to two or more per plant.

If the median value derived from regression analysis of 36.2 adults per trap (Figure 3) was used to predict the need for treatment, correct treatment decisions were made at 11 from 17 sites (65% predictive success) where infestations developed to two or more larvae per plant. Using the lower 95% confidence limit of 29.8 (rounded to 30) beetles per trap, 14 from 17 predictions for the need to treat above threshold infestations were correct and use of this value enabled the predictive success to be improved to 82% (Table 3). Use of the upper 95% confidence limit of 42.6 9rounded to 43) per trap provided the same result in terms of predictive success as 36.2 beetles per trap with 11 correct ‘to spray’ decisions made for the 17 sites with two or more larvae per plant.

Infestations of less than two larvae per plant were recorded at 54 sites and the predictive success for these sites is next considered with the assumption that a usable predictive method will not advise treatment unnecessarily at an unacceptably high number of sites. Table 3 shows that if the median value of 36.2 beetles per water trap was used as a predictor, a total of 51 correct 'no treatment' decisions were made at the 54 sites with fewer than two larvae per plant (94% correct decisions not to treat). At the lower (more risk averse) 95% confidence interval value of 29.8 per trap, a total of 49 correct 'no treatment' decisions were made providing a predictive success of 91%. At the upper 95% confidence interval value of 42.6 per trap, a total of 52 correct 'no treatment' decisions were made at 63 sites monitored providing a predictive success of 96% (as summarised in column 4 of Table 3).

Table 3. Summary of prediction accuracy of 'to spray' and 'no spray required' decisions. Percentage of correct decisions made from mean water trap catches in brackets.

Water trap threshold tested (mean no. beetles per water trap)	Total no. sites above water trap catch shown in column 1	Correct decision to spray (% of sites in brackets).	Correct decision not to spray (% of sites in brackets)	Total number of correct decisions	Total number of incorrect decisions	Overall % success of predictive method tested
>36.2 (median value)	14	11 (65%)	51 (94%)	62	9	87%
>29.8 (lower 95% confidence limit value)	19	14 (82%)	49 (91%)	63	8	89%
>42.6 (upper 95% confidence limit value)	13	11 (65%)	52 (96%)	63	8	89%

Table 3 assumes that a decision to treat would be taken at the 17 from 71 sites that developed larval infestations of two or more per plant and that no treatment would be recommended at 54 from 71 sites with fewer than two larvae per plant.

Taking all decisions into account, the percentages of correct decisions to spray or not to spray were similar for the three categories tested for catches averaging 29.8, 36.2 or 42.6 beetles per water trap. Predictive-success rates ranged from 87% for the median value of 36.2 per trap to 89% for means at the lower and upper 95% confidence limits of 29.8 and 42.6 cabbage stem flea beetle adults respectively per water trap as summarised in the final column of Table 3.

The lower 95% confidence limit value of 29.8 per trap gave the highest success rate (82%) at predicting sites where economic damage (larval number greater than two per plant) was likely and where treatment would have been justified. Although the predictive value of 65% for 36.2 per trap is clearly lower than the result obtained for 29.8 per trap, the result should be put into context. Two sites recorded only marginally lower water trap catches of 35 and 36 beetles per trap with a water trap catch averaging 32 per trap at one further site. Inclusion of these sites would then have provided the same 'to spray' result as that obtained from 29.8 per trap. Use of the 29.8 per trap threshold indicated that three more sites were correctly identified for treatment compared with the use of 36.2 per trap, although two more sites (5 and 32) with water trap catches marginally above 29.8 per trap (see also Table 17) would have been recommended for treatment unnecessarily.

The upper 95% confidence limit value of 42.6 per trap enabled 11 from 17 correct decisions (65%) to be made for treatment where the larval infestation was greater than two larvae per plant. This value provided the greatest percentage (96%) of successful predictions for sites where treatment would not have been recommended (52 correct decisions at 54 sites). However, as it was a relatively poor predictor of sites where treatment would have been justified, this might be expected to prejudice the use of this value as a predictive threshold on economic grounds.

In summary, it was concluded that a prediction on the need for larval control based on means of 29.8-36.2 (rounded to 30-35 beetles per trap) should be considered for adoption as an advisory threshold for water trap catches of cabbage stem flea beetles.

Predictive successes were also tested from cabbage stem flea beetle adult catches in headland or field-sited traps. If successful predictions could be made using two traps rather than four, this might be expected to make the method more attractive to agronomists and farmers with a requirement to monitor infestation levels of cabbage stem flea beetles in winter oilseed rape crops.

For headland-sited traps, regression analysis indicated two larvae per plant from a mean of 32.9 beetles per trap with 62.2% of the variance explained and a standard error of 3.49 providing 95% confidence limits of 32.9 +/- 7.0 and values between 25.9 and 39.9 beetles per headland-sited trap. For field-sited traps, regression analysis indicated that two larvae per plant were likely to be attained from a mean of 40.1 beetles per trap with 73.2% of the variance explained and a standard error of 3.19 providing 95% confidence limits of 40.1 +/- 6.32 and values between 33.8 and 46.4 beetles per field-sited trap. Overall for headland and field-sited traps, correct predictive decisions were made at 86% and 90% of sites respectively (as summarised in more detail in Tables 19 & 20) providing similar levels of accuracy to those obtained from the use of four water traps per site. With wider confidence interval values for larval predictions made from beetle catches in two headland or two field-sited traps compared with four traps in total, the accuracy of predictions made from two traps only will often be lower than using four traps per site. A trap catch at the lower, more risk-averse lower 95% confidence limit value of 33.8 beetles per field-sited water trap is recommended for adoption as an alternative method of monitoring should time preclude the use of four traps per site. This value enabled the same number (14 from 17) of correct predictions of the need to treat where larval infestations developed to two or more per plant as the prediction made using the lower 95% confidence interval value obtained from the use of four traps per site.

In autumn 2004 (year 1 of the study only), four vertically-mounted, yellow sticky traps of dimensions 20 x 10 cm were compared with water traps at 27 sites for use as a predictive method to determine larval infestation. Sticky traps caught fewer cabbage stem flea beetles than water traps with means of only 1.3 adults per trap compared with 8.0 per water trap. A significant regression was obtained ($P < 0.001$) with 51.0% of variance explained with two larvae per plant likely to be attained from a mean of 5.7 beetles per sticky trap. Cabbage stem flea beetle larval numbers were low in the first year of the study and infestations greater than two larvae per plant were recorded at two sites only; neither of which were successfully predicted from sticky trap catches. The use of sticky traps provided a poor predictive method compared with water traps, although greater predictive success might have been obtained if higher infestations of cabbage stem flea beetle larvae had been recorded.

Assessments of adult cabbage stem flea beetle feeding damage on plants, cotyledons and first true leaves were made in harvest years 2005 and 2006. During this period, ten sites from a total of 52 developed infestations of two or more larvae per plant. Regression analysis showed that a mean of two larvae per plant was likely to be attained if a mean of 0.65 plants (65%) was damaged by cabbage stem flea beetle adults. Although the regression between larval number and plant damage was significant ($P = 0.006$), it was overall a poor predictor of larval damage with only 14.0% variance explained. Only two sites (sites 35, 45) from ten with infestations greater than two larvae per plant were correctly predicted for treatment from plant damage assessments, providing an overall predictive success of only 20%. A number of sites also showed an obvious incidence of slug damage, notably in autumn 2005, which complicated the damage assessments for cabbage stem flea beetle. Unless obvious slime was present, leaf grazing damage due to slugs could be difficult to separate from the effects of plant damage caused by cabbage stem flea beetle adults.

Regression analysis of larval number against cotyledon damage showed that an infestation of two larvae per plant was likely if a mean of 0.51 cotyledons (51%) was damaged by cabbage stem flea beetle adults. Although a significant ($P = 0.017$) regression was obtained, only 10.8% of the variance was explained and a predictive method based on cotyledon damage proved to be of poor predictive value with only two sites (sites 35, 45) that justified treatment being predicted accurately from the ten sites that developed a control threshold averaging two larvae per plant.

Damage to the first true leaf was also tested as a predictor of larval damage. As a non significant ($P = 0.334$) regression was obtained with only 1.5% of variance explained, this method had no value as a predictive method in this study with none of the sites that developed infestations greater than two larvae per plant being successfully identified for treatment.

In autumn 2006, rectangular traps of dimensions 40 x 30 cm and a water surface area of 1,200 cm^2 were compared with 25 cm diameter round traps with a water surface area of 491 cm^2 at three sites in the Midlands. At two sites, total catches during September and October in 'large' and 'small' traps were similar, indicating that the method was insensitive to trap size. However, in a vigorously-established oilseed rape crop at a third site, the total catch in the large traps was greater than in the round traps possibly because the smaller traps became partially overgrown by crop foliage. As the results were inconclusive for trap size comparisons, more sites would have been required to investigate this aspect more thoroughly. It was, however, determined that round traps 25 cm in diameter were effective at catching cabbage stem flea beetle adults and that mean numbers of larvae per plant were significantly correlated with mean number beetles per water trap.

Thus, the key objective of this HGCA-funded study was met in terms of ability to predict the need for control of cabbage stem flea beetle larvae from catches of adult beetles in water traps. As only 1.5 litres of water were required per 25 cm diameter trap compared with six litres per large rectangular trap, the smaller traps were found to be much more convenient to use in the field than the larger traps. It is therefore recommended that the use of round, yellow water traps of 25 cm in diameter offered a convenient and easily used method of recording adult cabbage stem flea beetle activity for predictive purposes. As the effect of trap size was lower than expected, small variations of trap size would be unlikely to jeopardise the predictive method using yellow water traps.

The effects of plant population on larval numbers were tested at two sites, one in Shropshire and the second in North Yorkshire, in harvest year 2007. At the first site, infestation levels for cabbage stem flea beetle larvae in normally-established crop areas (mean of 36.4 plants/m^2) were compared with infestation levels in crop areas where a low plant population had established naturally (mean of 17.2 plants/m^2). Mean number of larvae per plant averaged 8.1 per plant in the normally-established plant population area compared with a mean of 4.3 larvae per plant in the low plant population area. It is possible that the low plant population areas proved less attractive to adult beetles in the autumn with the result that fewer eggs were laid in sparse crop areas.

At the second site in North Yorkshire being used in the plant population study, infestation levels for cabbage stem flea beetle larvae in normally-established crop areas (mean 49.4 plants/m^2) were compared with infestation levels in crop areas where a low plant population (mean of 21.2 plants/m^2) was achieved by artificial removal of 50% of plants by hoeing at an average four leaf stage. Mean number of larvae per plant averaged 14.9 per plant in the normally-established plant population area compared with 21.9 larvae per plant in the low plant population area. Assuming that similar numbers of eggs had been laid in the normal and artificially-reduced plant population areas, fewer plants were available for larval invasion in the reduced-population area with the result that larval infestation per plant was nearly 50% greater where plants had been removed.

The contrasting results from a preliminary investigation of the effect of plant population on cabbage stem flea beetle larval infestations indicated that more detailed studies would be required to clarify the effects of plant density on infestation incidence.

TECHNICAL REPORT

INTRODUCTION

Cabbage stem flea beetle (*Psylliodes chrysocephala)* has become one of the most important and damaging establishment pests of winter oilseed rape. Adult beetles (Figure 1 are 3-5 mm in length, metallic blue-green, or sometimes light brown in colour. Cabbage stem flea beetle has continued to spread across the country from its original infestation strongholds in brassica seed and mustard-growing areas of southern and eastern England (Graham & Alford (1981), Winfield (1992), Oakley, (2003)). The distribution range has since continued to increase northwards and into Scotland (Evans (2001, 2007), Green *et. al.* (2001), Walters *et. al.* (2001)). Cabbage stem flea beetle is economically important as the adult beetles can kill plants in the autumn resulting in poorer than planned crop establishment. Larvae feed in leaves and stems resulting in reduction of crop vigour and stunted plants in spring with impaired stem elongation. Earlier-sown (late August or early September drilled crops) often attract most beetles.

Following a summer period of aestivation, adult *P. chrysocephala* move into winter oilseed rape crops soon after crop emergence (Alford, 1979) and lay eggs in the soil after a period of feeding on the cotyledons and leaves of newly-emerged crops. Mature eggs were laid around 12-14 days after beetles began to feed on oilseed rape foliage. The timing of first larval invasion of plants occurred typically in early November commencing when 240 day degrees above a threshold temperature for development of 3.2 ºC was recorded. On hatching from eggs in the soil, larvae burrow into leaf petioles where they feed during the autumn and winter period (Saringer (1984), Alford *et. al.* (1991)). Larvae (Figure 2) are whitish in colour with three pairs of legs with a black head and abdominal ‘tail’. Larvae may continue to hatch overwinter if the weather is mild. Later, the larvae move into the main stem to feed below the growing point.

	
Figure 1. Adult cabbage stem flea beetle (*Psylliodes chrysocephala).*	Figure 2. Cabbage stem flea beetle larvae feeding within leaf stalk of oilseed rape plant.

The main targets for insecticide spray usage on oilseed rape are considered to be cabbage stem flea beetle and aphid virus vectors in the autumn and pollen beetle in the spring. Cabbage stem flea beetle was the reason cited for treatment of 37% and 28% of the insecticide-treated area in 2002 and 2004 respectively, increasing to 37% in 2006, which with an average of 1.5, 1.8 and 1.9 spray rounds per crop equated to 55%, 50% and 70% of crop area respectively. Imidacloprid+beta-cyfluthrin (Chinook) received approval for use as an insecticidal seed treatment on winter oilseed rape in 2002 when 36% of the crop area was treated, increasing to 63% of crop area in 2004 and 68% of crop area in 2006 (Garthwaite *et. al.* (2003, 2005, 2007). Although, the use of beta-cyfluthrin + imidacloprid seed treatment (Chinook) on winter oilseed rape has provided a check to cabbage stem flea beetle damage at early stages of establishment, studies in England and Scotland have shown that economically-damaging attacks by larvae can occur in crops grown from treated seed.

The high level of insecticide usage results in part from the convenience of tank mixing pyrethroid insecticides with post-emergence herbicide or fungicide applications which minimises the number of spray passes required through the crop. In relation to the financial return from the oilseed rape crop, the cost of pyrethroids, for example cypermethrin, is low costing around £5 per ha or less, The cost of pest assessment can therefore appear high in relation to treatment cost and cheap, effective assessment methods are essential if prophylactic spraying is to be avoided. There is also, a relative timing insensitivity to autumn-applied sprays for cabbage stem flea beetle control with the main difficulty arising if egg laying, prolonged by warm autumn weather leads to a winter-hatch of larvae. Effective control is likely to be obtained from pyrethroid treatments applied in the autumn at adult or larval control timings, as demonstrated by Reed & Nicholls (1984) who reported on field-based studies using alpha-cypermethrin; Smith & Hewson (1984) using deltamethrin and by Northwood & Verrier (1986) using lambda-cyhalothrin.

Pyrethroid insecticides control adult beetles and larvae on hatching as they burrow into leaf stalks. Larvae exit and re-enter leaf petioles thereby coming into contact with treated surfaces, as treatments are lipophilic, strongly adsorbed onto cuticular wax and persist well through the autumn thereby providing a lengthy period of control. Usually one spray is sufficient to provide effective larval control; an exception might occur in a year in which egg hatch and larval invasion is delayed or protracted by cold weather. Larval numbers vary for a number of reasons from year to year, as confirmed for example by Turner *et.al.* (2002) who reported variable numbers of larvae at about 95 sites per year in pest and disease monitoring studies in winter oilseed rape during the period 1997-2001. An upward trend in infestation incidence was noted in the late 1990s that was similar to that recorded in the present study.

There are no firm thresholds for decision-making on the control of adults (Alford *et. al.* (1991). The size of the attacked plants and their ability to grow away from initial damage is important. Control is normally recommended if the rate of adult feeding damage exceeds the rate of new leaf production during the establishment period. Oakley (2003) indicated that a treatment was advisable if 25% or more leaf area loss occurred at the 1-2 leaf stage (GS 1,1-1,2) or if significant plant loss was occurring.

Decision making for control of cabbage stem flea beetle larvae has usually been based on plant dissections to determine larval numbers within stems in autumn. Treatment was recommended if larval number exceeded the then accepted control threshold of five larvae per plant (Purvis, 1986). Published action thresholds are sometimes considered difficult to use, requiring detailed crop examination or plant dissection. Although the latter provides an unequivocal result of the need to spray or not, a treatment may need to be applied in November or December when there are few spray opportunities and after autumn-spraying with herbicides or fungicides has mainly been completed. The threshold for cabbage stem flea beetle control, based on plant dissection, was complemented by one which was easier to use involving observation of symptoms of damage caused by larvae feeding in leaf petioles (Walters *et. al.,* 2001). An action threshold of 71% leaves scarred was calculated for the then larval control threshold of five larvae per plant. This threshold was lowered to 50% of leaves scarred to provide a safety margin for control. However, as this method cannot be used until the time that infestation levels are known, it also involves delaying a treatment decision until November or December.

In practice a decision to apply an insecticide is usually based on previous experience of damage, the observation of obvious adult feeding damage or the first signs of larval invasion. A further complication is the need to sometimes apply a treatment to control aphid virus vectors. The principal preventable virus spread occurs in October, so that any action taken will pre-date an assessment of cabbage stem flea beetle larval damage. However, sprays applied in early October to control virus vectors are as or more effective against cabbage stem flea beetle larvae as those applied in November. Consequently, a precautionary insecticide application that could control either pest, if present, tends to be made to the majority of crops. Indirect crop losses can also occur; for example, infection by canker (*Leptosphaeria maculans)* which causes crop lodging is associated with damage by cabbage stem flea beetle larvae (Newman, 1984).

The chemical control of cabbage stem flea beetle now relies heavily on the use of autumn-applied pyrethroid insecticides and, since 2002 on imidacloprid + beta-cyfluthrin applied as an insecticidal seed treatment; in some cases followed with an autumn-applied spray treatment. Generally, treatment with a pyrethroid insecticide, if well-timed to coincide with the early stages of larval invasion, provides control of 70-80% or more. Delaying treatment until late winter reduced numbers by about 50% (Lane & Cooper, 1989; Purvis, 1986). An average reduction of 78% was obtained from pyrethroid sprays applied in autumn at an early larval invasion timing with a reduction in larval numbers of 86% obtained where imidacloprid + beta-cyfluthrin seed treatment was followed by a pyrethroid spray (Green, 2002). At an infestation level of five larvae per plant, a yield response averaging 0.34 t/ha can be expected from an effective, autumn-applied treatment (Purvis, 1986). A lower threshold of under one larva per plant was proposed in Sweden (Nilsson, 1990) for a spray treatment and under 0.5 larvae per plant for an insecticidal seed treatment. The latter halved the numbers of larvae in trials and increased yield by an average of 0.1 t/ha.

Oakley & Green (2006) re-assessed control thresholds to reflect the low cost of pyrethroid sprays, particularly if treatments were applied as tank mixes. Current crop economics indicated that a threshold of two larvae per plant was more appropriate than the previously-applied five larvae per plant providing an average 0.16 t/ha yield response to an autumn-applied pyrethroid insecticide spray. Treatment was calculated to provide an increased seed yield valued at £40/ha, using an average seed price of £250 per tonne.

In HGCA-funded studies in 1999-2000, imidacloprid + beta-cyfluthrin (100 + 100 g/l) applied as a seed treatment at a rate of 2.0 litres of product (Chinook) per 100 kg seed reduced adult feeding damage at cotyledon and first true leaf stages of oilseed rape. Reductions in larval number averaged 23% from the then, industry-standard lindane and 42% from imidacloprid seed treatment (Green, 2001). A reduction in larval numbers of 86% was obtained where imidacloprid + beta-cyfluthrin (100+100 g/l) seed treatment applied at a rate of 2.0 litres of product per 100 kg of seed was followed by a pyrethroid spray (Green, 2002). The manufacturer of Chinook states that protection is obtained between drilling and the 2-4 leaf stage and that usage reduces the occasional need to re-drill because of cabbage stem flea beetle adult feeding damage. A useful effect against larvae is described in the product literature, but larvae from subsequent hatches can still give rise to economically-important larval infestations following insecticidal seed treatment and a follow-up spray treatment may then be required.

Various types of trap have been used to monitor for cabbage stem flea beetle adults, including ground-placed white sticky traps (Alford, 1979), yellow water traps (Hossfeld (1993), Johnen & Meier (2000)) with sticky delta and funnel traps being tested in Hungary (Csonka *et. al.* (2004). Yellow sticky traps have also been used for field-based crop monitoring for flea beetles (*Phyllotreta* spp.), for example in canola crops in North America (Knodel & Olson, 2002). Yellow, circular water traps have been used to monitor for cabbage stem flea beetle adult activity in previous ADAS monitoring and insecticidal seed treatment efficacy studies (Green, 2002) and preliminary testing of data from six sites in harvest years 2000 and 2001 indicated that a control threshold might be predictable from water trap catches. As a result, it was proposed that this method should be tested at a greater number of sites to determine whether the results obtained could be used to update Decision Support System models being developed and tested for use on winter oilseed rape.

Monitoring for cabbage stem flea beetle using water traps has been tested in Germany with the aim of developing threshold values for timely decisions on the need to treat. For the Schleswig-Holstein area of northern Germany, a threshold value of 50 adults per yellow dish, caught within three weeks of the main migration period was proposed. Numbers below this value did not result in a critical population of larvae defined as over 3-5 larvae per plant (Hossfeld, 1993). A constant correlation between yellow dish catches and subsequent larval numbers could not be determined due to variations in plant cultivation and climate.

Johnen & Meier (2000) described a Decision Support System (DSS) for oilseed rape pests, including cabbage stem flea beetle control in the autumn. It was emphasised that a predictive DSS programme being used as the basis for treatment should take account of not only the number of beetles in water traps but also weather-based forecasts for flight, egg-laying period and larval development. Monitoring of adults provided a basis of the likely need for treatment but if spraying was not possible, perhaps due to adverse weather conditions preventing the application of a planned treatment, subsequent checks for damage would be required.

The subject of insect pest management in Europe was reviewed by Evans & Scarisbrick (1984) who described the use of monitoring for oilseed rape pests using water or sticky traps, unbaited or baited with glucosinolates isolated from oilseed rape. It was noted that action thresholds had been defined for several oilseed rape pests, including cabbage stem flea beetle and that the concept of an economic threshold is a mobile concept determined in part by the changing economics of the oilseed rape crop. A weather-based decision support system developed in Germany covers cabbage stem flea beetle in autumn (Johnen & Meier, 2000). The study noted that if few adult beetles were recorded in water traps, that even under ideal conditions for egg laying there would not be economically-damaging numbers of larvae. If moderate numbers of beetles, defined as 10-30 adults per yellow trap, were recorded, a treatment decision might need to be made also taking account of conditions for egg laying and larval development. If very large but undefined numbers of beetles were trapped, treatment was advised as even under unfavourable conditions for egg laying, significant numbers of larvae were likely to occur.

Johnen & Meier (2000) described a Decision Support System for oilseed rape pests covering cabbage stem flea beetle in autumn and various spring and summer pests,, for example by taking into account the numbers of adults in traps and considering weather-based forecasts of egg-laying period and larval development. It was proposed that monitoring for adults would form the basis for treatment, but if this was delayed, perhaps due to adverse weather conditions for spraying, subsequent crop checks for larval damage were required. Oakley & Green (2006) indicated that once an alternative monitoring system based on water trapping was validated, that the system, if reliable, could be absorbed into the oilseed rape pest Decision Support System forming part of the PASSWORD package, the principles of which were described by Morgan *et. al.* (1998).

Interim results from the current study were presented by Green (2007) in the form of a HGCA Topic Sheet which described adult cabbage stem flea beetle activity during the duration of the study and which considered the prediction of larval number from beetle catches in water traps. This full summary report now goes on to consider the accuracy of predictions made from water and sticky trap results; from headland and field-sited water traps and describes risk analysis for predictions of sites requiring treatment and for sites where control would not have been recommended.

Aims and objectives:

- Improved decision making for cabbage stem flea beetle control with the aim of incorporating water trapping data as a predictive method to update Decision Support Systems for winter oilseed rape. A high priority for further work to improve forecasts of cabbage stem flea beetle attack was recommended by Alford *et. al.* (1991) in a HGCA-commissioned review of oilseed rape pests

- Validate relationships between trap catches and larval numbers.

- Determine whether water trap or sticky trap catches can be reliably used to decide on need for autumn pyrethroid treatment.

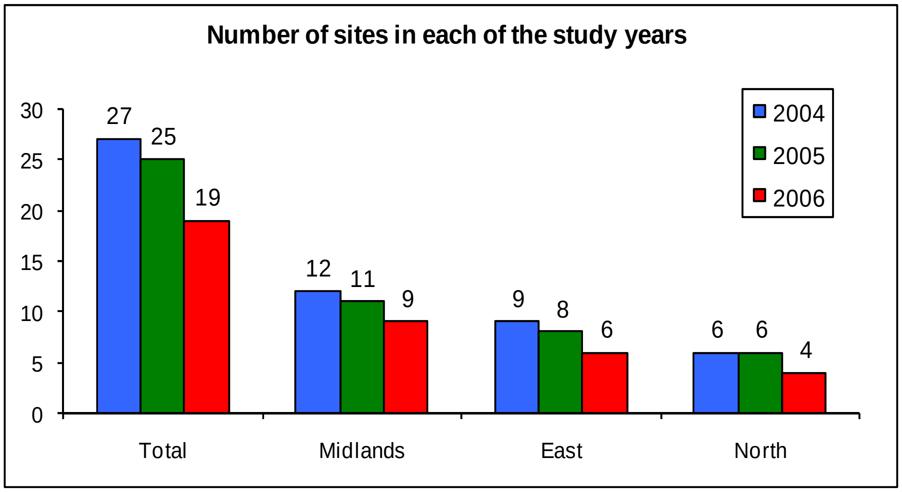
- Determine whether plant damage assessments can be used to predict subsequent damage from cabbage stem flea beetle larvae.

Methods and technical detail

1. Site selection

During the three-year study, a total of 71 fields were monitored, comprising 27 fields in year 1 (cropping year 2004/2005); 25 fields in year 2 (cropping year 2005/2006) and 19 fields in year 3 (cropping year 2006/2007). Late August or early September drilled crops of winter oilseed rape were selected. Sites were located in the main oilseed rape growing areas in the Midlands, eastern England and northern England. Distribution of sites by region and year is shown in Figure 3. Monitoring sites were primarily selected in areas where observations had indicated the likelihood of substantial cabbage stem flea beetle adult activity and subsequent larval damage.

Figure 3. Number of sites.



2. Water trapping

In each of the three study years, four yellow water traps (‘Plantpak 30 cm.’) with an internal diameter of 25 cm and a trap area of 491 cm²) were set out as soon as possible after drilling so that traps were in place during the early stages of crop emergence. Each trap, termed a ‘standard’ trap, was coloured yellow (‘Berger yellow’) and filled with 1.5 litres of water to a depth of approximately 3 cm. A small (1-2 ml) amount of detergent was added to reduce surface tension of the water. Traps were checked weekly between crop emergence in early September until cabbage stem flea beetle activity declined to a low incidence in late October or early November. Crops sown in the third week of August had usually emerged in late August or early September. The majority of crops had emerged by 7 September, although in autumn 2005, germination was delayed by dry seedbeds in eastern England and the East Midlands where some crops did not emerge until mid September.

3. Siting of water traps:

For preference, the water traps were sited at the side of the field adjacent to or nearest to a field cropped with an oilseed rape crop in the previous cropping year. Two water traps were placed on the soil surface on the crop headland, 6 metres from the edge of the crop, with traps 50 metres apart and parallel to the field boundary. Two water traps were placed 12 and 24 metres into the crop (Figure 4). The within-field traps were sited along a transect running at a right angle to the field boundary. Wherever possible, traps were positioned along and adjacent to a convenient wheeling. Weekly visits were made to each site when each water trap was examined to record the number of adult cabbage stem flea beetles*.* Although cabbage stem flea beetles could usually be easily counted in the field, if catches were high or where large catches of other insects were caught e.g. turnip sawfly *(Athalia rosae)* adults during warm weather in September 2006, trap catches were sieved into containers for accurate counting on a later occasion. The traps were reset by rinsing with fresh water and then refilled with clean water plus detergent.

Figure 4. Schematic field plan showing positions of 25 cm diameter, yellow water traps and illustration of trap sited in winter oilseed rape crop.

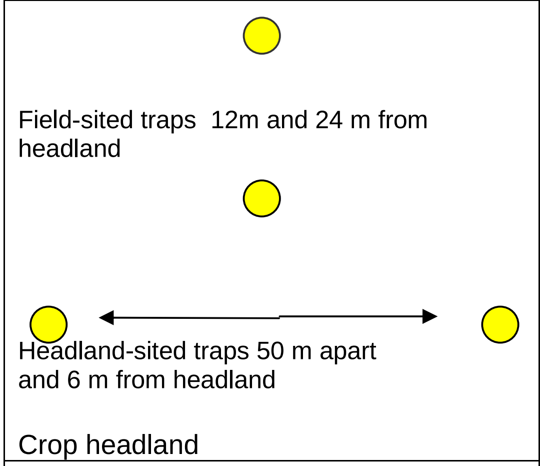


Diagram showing positions of four water traps in oilseed rape crop	Yellow water trap (25 cm diameter) in oilseed rape crop showing cabbage stem flea beetle adults in trap.

4. Sticky traps:

In the first year of the study (harvest year 2005) four, yellow sticky traps (20x10 cm), available from Oecos, were placed vertically on 50 cm stakes to monitor for cabbage stem flea beetle activity. Traps were set out as soon as possible after drilling so that traps were in place during the early stages of crop emergence. Positioning of the traps was similar to that for the water traps. Two of the sticky traps were sited on the crop headland with traps 50 metres apart and parallel to the field boundary. Two sticky traps were set out within the crop 12 m and 24 m from the crop headland as shown in Figure 5.

Figure 5. Schematic field plan showing positions of rectangular 20 x 10 cm, yellow sticky traps and illustration of trap sited in winter oilseed rape crop.

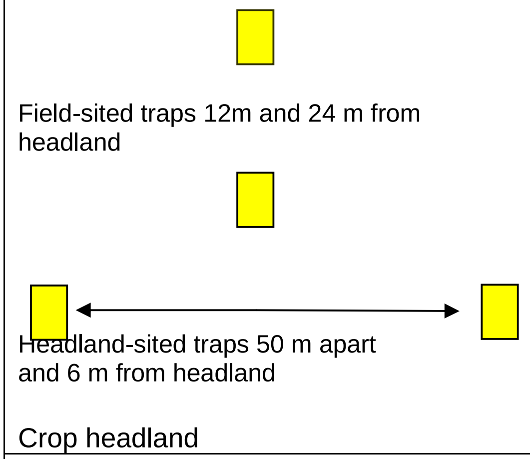


Diagram showing positions of four sticky traps in oilseed rape crop	Yellow sticky trap (20x10 cm) in oilseed rape crop showing cabbage stem flea beetle adults on trap.

5. Comparison of trap size

In the third year of the study at three sites in the Midlands (sites 54, 57, 59), four yellow, rectangular 'large' water traps of dimensions 40 x 30 cm were set out in addition to the round, yellow 'standard' water traps 25 cm in diameter. Six litres of water (plus a small quantity of detergent to reduce surface tension) was required to fill each trap to a depth of 5 cm. The rectangular traps were positioned in equivalent positions to the circular traps with two traps on the headland and two in the field (Figure 6). The rectangular traps were separated from the circular water traps by a minimum distance of 12 metres. Weekly visits were made to each site when each water trap was examined to record the number of adult cabbage stem flea beetles. The traps were reset by rinsing with fresh water and then refilled with clean water plus detergent.

Figure 6. Schematic field plan showing positions of 40 x 30 cm, yellow water traps and illustration of trap sited in winter oilseed rape crop.

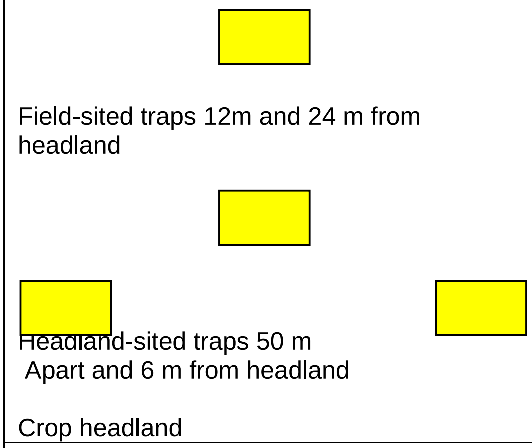


Diagram showing positions of four yellow, rectangular water traps in oilseed rape crop	'Large' yellow water trap (40 x 30 cm) in oilseed rape crop. Showing csfb adults (and turnip sawfly adults) in trap.

6. Assessment of crop damage

At an average two true leaf stage (GS 1,2), 50 randomly-selected plants per study site were collected in year 1 of the study and assessed fro incidence of leaf damage such as shotholing caused by cabbage stem flea beetle adults (Figure 7). In year 2, 25 plant samples were collected. The following damage parameters were recorded:

(i) number of plants damaged.
(ii) number of cotyledons and first true leaves damaged.
(iii) percentage area of cotyledon leaf area holed, notched or windowed.
(iv) percentage area of the first true leaf damaged.
(v) incidence of slug damage was also recorded

Figure 7. Cabbage stem flea beetle adult feeding damage on oilseed rape at two leaf stage.

Cabbage stem flea beetle adult feeding damage

7. Assessment of larval damage

Typically during in early-mid December, random samples of 25 plants (year 1) and 20 plants (years 2 and 3) were collected from unsprayed crop areas at each of the study sites. Plant samples were returned to the laboratory for damage assessment.

The following were recorded from visual observation and plant dissection:
(i). Number of leaves >2 cm in length
(ii). Number of leaves with larval damage (indicated by holing, scarring, discoloration, presence of larvae).
(iii). Total number of larvae and number of larvae within the following size categories:
small first instars (< 3 mm), medium (3-5 mm), large (> 5 mm) which equated to larval instars I, II, III whose lengths were described by Dobson (1960) as 1.1-2.8, 2.0-5.0 and 3.3-7.3 mm respectively.
(iv). Number of plants with csfb larval damage.

8. Effect of plant population on larval infestation

Two sites (site 56 in Shropshire and site 71 in North Yorkshire) were selected during the early stages of crop emergence (cotyledon to 2 true leaf stages) in autumn 2006. Ten representative areas of crop, each of area 1m², were marked out using plastic canes. A second area of crop was selected which had an actual or simulated plant population achieved by plant removal of 50% of that in the normal area. Plant populations were recorded at GS 1,02 by counting the plants in the 10 x 1m² squares in each of the two areas of crop. Random samples of 20 plants (two from each of the 10 marked areas) were collected in December for larval damage assessment as described in the previous section.

9. Analysis of data

Summaries of data for each of the three harvest years are presented in Tables 4-7.

Regressions of y on x were used to calculate values of y for selected values of x using Excel and Minitab for the following recorded variates.

Water trap catches against plant, cotyledon and damage to first true leaf (years 1 and 2).
Relations between plant damage, cotyledon and first true leaf damage.
Larval number against sticky trap catches (year 1).
Larval number against water trap catches (individual years and data for all 3 years combined).

(i) Total autumn catches, mean weekly catches, maximum weekly catches for adult cabbage stem flea beetles in water traps and subsequent larval damage.
(ii) Regression analysis for mean percentages of plants and mean percentage leaf area for cotyledons (first true leaf if appropriate) damaged by adults and subsequent larval damage.

Results:

Water trapping results in autumn 2004 (year 1).

In autumn 2004, 27 monitoring sites were established as soon as possible after drilling winter oilseed rape. At each site, yellow water traps and yellow sticky traps were set out with two traps of each type placed on a crop headland and two traps positioned in the field. Cabbage stem flea beetle activity was monitored weekly from early crop emergence between September and early November. In harvest year 2005, headland and field-sited water traps at 27 monitoring sites caught totals of 370 and 495 csfb adults respectively (Table 1).

Table 1. Total and mean number of cabbage stem flea beetle adults in headland-sited, field-sited and all water traps in autumn 2004.

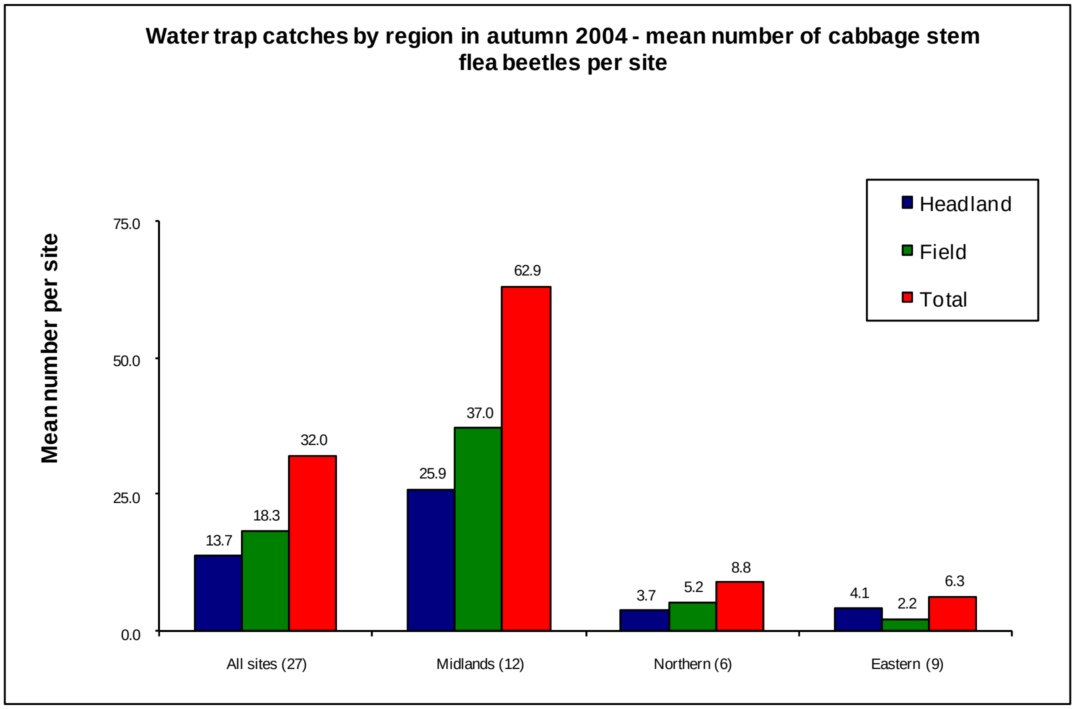
Site code	Area	Total no. csfb in 4 water traps	Mean no. csfb per water trap	Mean no. csfb per trap per week	Peak weekly catch (no. per trap)	Total no. csfb in 2 headland-sited traps	Total no. csfb in 2 field-sited traps	Mean no. csfb per headland-sited water trap	Mean no. csfb per field-sited water trap
1	M	22	5.50	0.61	1.75	11	11	5.5	5.5
2	M	144	36.00	4.00	5.75	45	99	22.5	49.5
3	M	40	10.00	1.11	3.00	13	27	6.5	13.5
4	M	10	2.50	0.28	1.00	2	8	1	4
5	M	123	30.75	3.42	10.75	44	79	22	39.5
6	M	38	9.50	1.06	3.75	17	21	8.5	10.5
7	M	117	29.25	3.66	9.50	65	52	32.5	26
8	M	184	46.00	5.75	15.50	70	114	35	57
9	M	32	8.00	1.00	2.00	19	13	9.5	6.5
10	M	44	11.00	1.38	3.25	25	19	12.5	9.5
11	M	0	0.00	0.00	0.00	0	0	0	0
12	M	1	0.25	0.04	0.25	0	1	0	0.5
13	E	18	4.50	0.64	1.25	12	6	6.0	3.0
14	E	3	0.75	0.11	0.25	3	0	1.5	0.0
15	E	2	0.50	0.07	0.25	1	1	0.5	0.5
16	E	7	1.75	0.25	1.00	5	2	2.5	1.0
17	E	10	2.50	0.36	0.75	8	2	4.0	1.0
18	E	4	1.00	0.14	0.50	2	2	1.0	1.0
19	E	9	2.25	0.32	1.25	5	4	2.5	2.0
20	E	4	1.00	0.14	0.50	1	3	0.5	1.5
21	E	0	0.00	0.00	0.00	0	0	0.0	0.0
22	N	34	8.50	1.42	5.25	16	18	8	9
23	N	3	0.75	0.13	0.25	1	2	0.5	1
24	N	5	1.25	0.21	0.75	2	3	1	1.5
25	N	6	1.50	0.25	1.25	2	4	1	2
26	N	4	1.00	0.17	0.75	1	3	0.5	1.5
27	N	1	0.25	0.04	0.25	0	1	0	0.5
Total		865				370	495		
Mean per site		32.0	8.0	1.0	2.6	13.7	18.3	6.8	9.2

M: Midlands (west and east); E: Eastern England; N: Northern England.
For site locations and cropping details, see Appendix A.

Water trapping results in autumn 2004 (year 1).

For the 27 monitoring sites in autumn 2004, mean number of cabbage stem flea beetle adults was 32.0 per site. A higher mean catch of 18.3 per site was recorded in the field-sited traps compared with a mean of 13.7 for headland-sited traps. Figure 8 shows that the highest catches were recorded in the Midlands with a mean of 62.9 per site (12 sites) compared with lower totals for northern sites with a mean of 8.8 per site (6 sites) and eastern sites; mean 6.3 per site (9 sites).

Figure 8. Summary plot showing mean number of cabbage stem flea beetle adults per water trap for all sites (27 total), mean number per headland or field-sited trap and regional differences in autumn 2004.



In autumn 2004, water traps (4 per site) caught a total of 865 adults, comprising 370 and 495 beetles in two headland and two field-sited traps respectively. Significant regressions were obtained between mean number of adults per water trap, mean number per headland-sited trap (*P* <0.001, R^2 93.5%) and field-sited trap (*P* <0.001, R^2 97.3%). A significant regression was also obtained between headland-sited traps and field-sited traps (*P* <0.001, R^2 83.2%).

Water trapping results in autumn 2005 (year 2).

In autumn 2005, 25 monitoring sites were established as soon as possible after drilling winter oilseed rape. At each site, yellow water traps were set out with two traps placed on a crop headland and two traps positioned in the field. Cabbage stem flea beetle activity was monitored weekly from early crop emergence between September and the end of October. Total catch in autumn 2005 was higher than in autumn 2004 with a mean of 91.7 beetles per site compared with 32.0 per site in autumn 2004. Headland and field-sited water traps at 25 monitoring sites caught totals of 958 and 1335 adults respectively (Table 2).

Table 2. Total and mean number of cabbage stem flea beetle adults in headland-sited, field-sited and all water traps in autumn 2005.

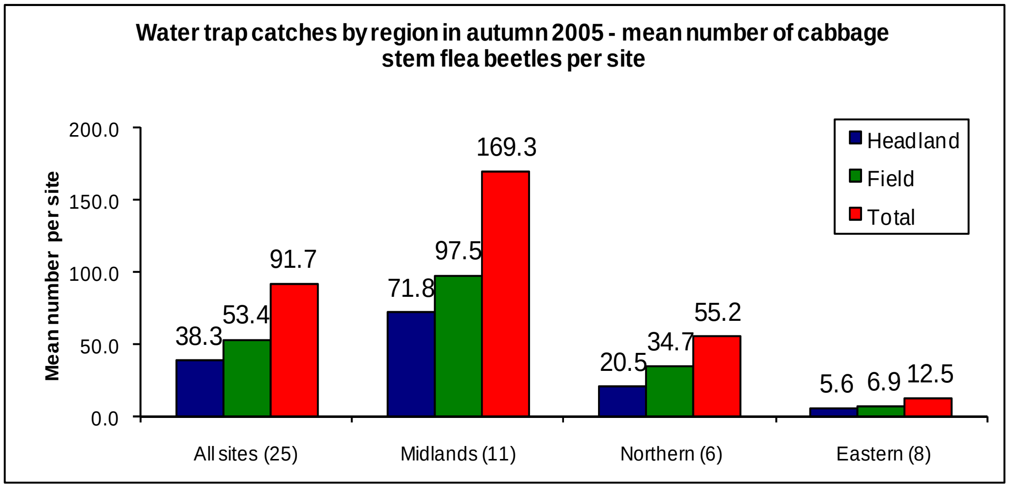
Site no.		Area	Total no. csfb in 4 water traps	Mean no. csfb per water trap	Mean no. csfb per trap per week	Peak weekly catch (no. per trap)	Total no. csfb in 2 headland-sited traps	Total no. csfb in 2 field-sited traps	Mean no. csfb per headland-sited water trap	Mean no. csfb per field-sited water trap
2005 Year code	All years site code									
1	28	M	83	20.75	2.96	8.25	20	63	10	31.5
2	29	M	206	51.50	7.36	14.00	83	123	41.5	61.5
3	30	M	51	12.75	1.82	5.50	20	31	10	15.5
4	31	M	314	78.50	11.82	22.75	101	213	50.5	106.5
5	32	M	125	31.25	4.46	15.25	75	50	37.5	25
6	33	M	140	35.00	5.00	14.00	54	86	27	43
7	34	M	298	74.50	10.64	20.00	113	185	56.5	92.5
8	35	M	387	96.75	13.82	21.25	181	206	90.5	103
9	36	M	243	60.75	8.68	20.50	141	102	70.5	51
10	37	M	13	3.25	0.54	1.75	2	11	1	5.5
11	38	M	2	0.50	0.07	0.25	0	2	0	1
12	39	E	5	1.25	0.18	0.75	3	2	1.5	1.0
13	40	E	24	6.00	0.86	3.50	10	14	5.0	7.0
14	41	E	4	1.00	0.13	0.50	2	2	1.0	1.0
15	42	E	4	1.00	0.13	0.75	1	3	0.5	1.5
16	43	E	5	1.25	0.16	0.75	0	5	0.0	2.5
17	44	E	20	5.00	0.63	2.75	14	6	7.0	3.0
18	45	E	34	8.50	0.85	2.75	14	20	7.0	10.0
19	46	E	4	1.00	0.13	0.50	1	3	0.5	1.5
20	47	N	264	66.00	11.00	39.25	100	164	50.0	82.0
21	48	N	2	0.50	0.08	0.25	1	1	0.5	0.5
22	49	N	9	2.25	0.38	1.00	3	6	1.5	3
23	50	N	2	0.50	0.08	0.25	2	0	1	0
24	51	N	20	5.00	0.83	3.75	6	14	3	7
25	52	N	34	8.50	1.42	3.50	11	23	5.5	11.5
Total			2293				958	1335		
Mean per site			91.7	22.9	3.4	8.2	38.3	53.4	19.2	26.7

M: Midlands (west and east); E: Eastern England; N: Northern England.
For site locations and cropping details, see Appendix B.

Water trapping results in autumn 2005 (year 2).

Results from water trapping at 25 sites (11, 8 and 6 sites in central, eastern and northern England respectively) in autumn 2005 showed a higher incidence of adult activity in the Midlands and north compared with totals recorded in autumn 2004. For the 25 monitoring sites in autumn 2005, mean number of cabbage stem flea beetle was 91.7 per site. A higher mean catch of 53.4 per site was recorded in the field-sited traps compared with a mean of 38.3 for headland-sited traps. Figure 9 shows that the highest catches were recorded in the Midlands with a mean of 169.3 beetles per site (11 sites) compared with means of 55.2 per site in northern England (6 sites) and 12.5 per site (8 sites) for the eastern sites.

Figure 9. Summary plot showing mean number of cabbage stem flea beetle adults per water trap for all sites (25 total), mean number per headland or field-sited trap and regional differences in autumn 2005.



In autumn 2005, water traps (4 per site) caught a total of 2293 adults, comprising 958 and 1335 cabbage stem flea beetle in two headland and two field-sited traps respectively. Significant regressions were obtained between mean number per water trap, mean number per headland-sited trap (*P* <0.001, R^2 94.1%) or field-sited trap (*P* <0.001, R^2 96.8%). A significant regression was also obtained between headland-sited traps and field-sited traps (*P* <0.001 R^2 82.8%). Year 2 results were therefore similar in terms of relationships obtained to those obtained in year 1.

Water trapping results in autumn 2006 (year 3).

In autumn 2006, 19 monitoring sites were established as soon as possible after drilling winter oilseed rape. At each site, yellow water traps were set out with two traps placed on a crop headland and two traps positioned in the field. Cabbage stem flea beetle activity was monitored weekly from early crop emergence between September and early November. Cabbage stem flea beetle catches in autumn 2006 were higher than in autumn 2004 or 2005 with a mean per site of 177.5 with a heavy influence from site 71 in northern England with a total autumn catch of 854. Headland and field-sited water traps at 19 monitoring sites caught totals of 1513 and 1859 cabbage stem flea beetle adults respectively (Table 3).

Table 3. Total and mean number of cabbage stem flea beetle adults in headland-sited, field-sited and all water traps in autumn 2006.

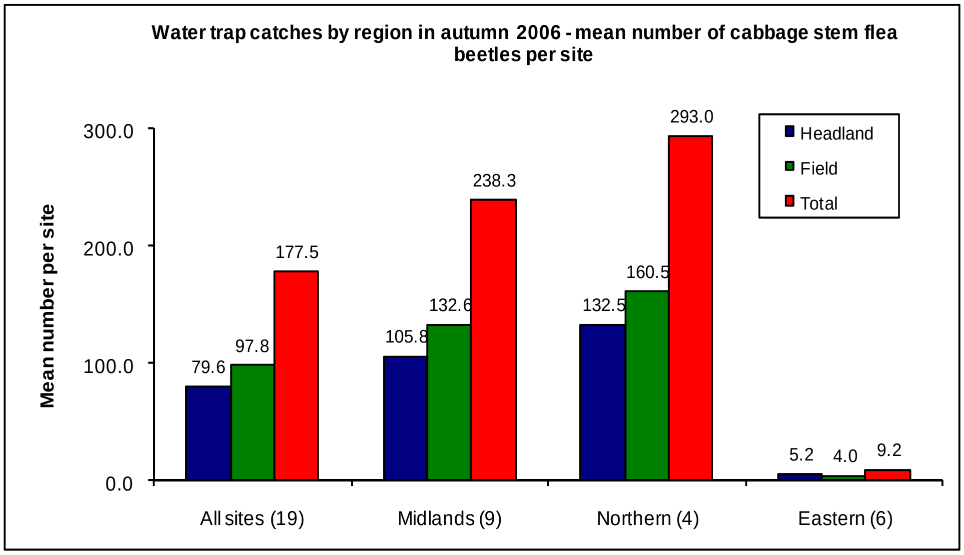
Site no.		Area	Total no. csfb in 4 water traps	Mean no. csfb per water trap	Mean no. csfb per trap per week	Peak weekly catch (no. per trap)	Total no. csfb in 2 headland -sited traps	Total no. csfb in 2 field-sited traps	Mean no. csfb per headland-sited water trap	Mean no. csfb per field-sited water trap
Year code	All years site code									
1	53	M	75	18.75	2.34	3.30	40	35	20.0	17.5
2	54	M	619	154.75	19.34	30.00	285	334	142.5	167.0
3	55	M	193	48.25	6.89	15.80	97	96	48.5	48.0
4	56	M	469	117.25	16.75	26.50	221	248	110.5	124.0
5	57	M	299	74.75	10.68	18.00	101	198	50.5	99.0
6	58	M	98	24.50	3.50	6.00	42	56	21.0	28.0
7	59	M	128	32.00	4.00	7.50	49	79	24.5	39.5
8	60	M	184	46.00	5.75	19.30	81	103	40.5	51.5
9	61	M	80	20.00	2.50	4.80	36	44	18.0	22.0
10	62	E	0	0.00	0.00	0	0	0	0.0	0.0
11	63	E	2	0.50	0.07	0.25	1	1	0.5	0.5
12	64	E	4	1.00	0.14	0.50	1	3	0.5	1.5
13	65	E	2	0.50	0.07	0.25	1	1	0.5	0.5
14	66	E	24	6.00	0.86	2.25	15	9	7.5	4.5
15	67	E	23	5.75	0.82	1.75	13	10	6.5	5.0
16	68	N	60	15.00	2.14	3.50	13	47	6.5	23.5
17	69	N	93	23.25	3.32	5.50	34	59	17.0	29.5
18	70	N	165	41.25	5.16	11.50	69	96	34.5	48.0
19	71	N	854	213.50	26.69	52.50	414	440	207.0	220.0
Total			3372				1513	1859		
Mean per site			177.5	44.4	5.8	11.0	79.6	97.8	39.8	48.9

M: Midlands (west and east); E: Eastern England; N: Northern England.
For site locations and cropping details, see Appendix C.

Water trapping results in autumn 2006 (year 3).

Results from water trapping at 19 sites (9, 6 and 4 sites in central, eastern and northern England respectively) in autumn 2006 showed a higher incidence of adult activity in the Midlands and north compared with totals recorded in autumn 2004 and 2005. For the 19 monitoring sites in autumn 2006, mean number of cabbage stem flea beetles was 177.5 per site. A higher mean catch of 97.8 per site was recorded in the field-sited traps compared with a mean of 79.6 for headland-sited traps. Figure 10 shows that the highest catches were recorded in northern England with a mean of 293.0 per site (4 sites) compared with a mean of 238.3 per site in the Midlands (9 sites) and a mean of 9.2 per site (6 sites) for the eastern sites.

Figure 10. Summary plot showing mean number of cabbage stem flea beetle adults per water trap for all sites (19 total), mean number per headland or field-sited trap and regional differences in autumn 2006.



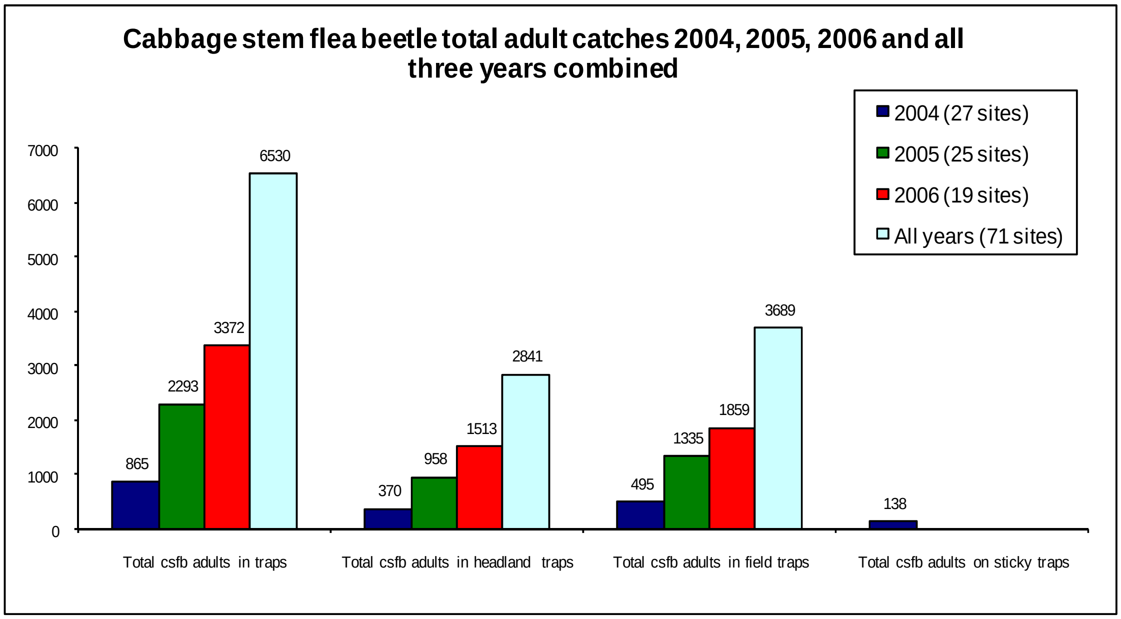
In autumn 2006, water traps (4 per site) caught a total of 3372 adults, comprising 1513 and 1859 cabbage stem flea beetles in two headland and two field-sited traps respectively. The high mean number of 293.0 per trap recorded in northern England was heavily influenced by the high total of 854 recorded in water traps at site 71 in North Yorkshire (Table 6).

As in the previous two years, significant regressions between mean number of cabbage stem flea beetles per water trap (all 4) against mean number per headland-sited trap ($P < 0.001$, R^2 99.0%) or field-sited trap ($P < 0.001$ R^2 99.2%). A significant regression was also obtained between mean numbers per headland trap and field trap ($P < 0.001$, R^2 96.5%). Year 3 results were therefore similar to those obtained in years 1 and 2.

All three years – water trapping results for 71 sites and sticky trap results for 27 sites in autumn 2004.

The summary plot (Figure 11) shows the higher incidence of adult cabbage stem flea beetle activity in autumn 2006 compared with totals in autumn 2004 and 2005. In each year, higher totals of beetles were recorded in field-sited water traps compared with catches in headland-sited traps. Combined trap catches for the three study years show total catches in two field-sited and two headland-sited water traps of 3,689 and 2,841 cabbage stem flea beetle adults respectively. In autumn 2004, catches on four sticky traps were compared with catches in water traps at 27 sites. The total catch of 865 in water traps was 6.3 times as high as the total catch of 138 on sticky traps.

Figure 11. Summary plot showing total number of cabbage stem flea beetle adults caught in four water traps sited at all 71 sites, totals in headland and field-sited traps and total number caught on sticky traps at 27 sites in autumn 2004 only.

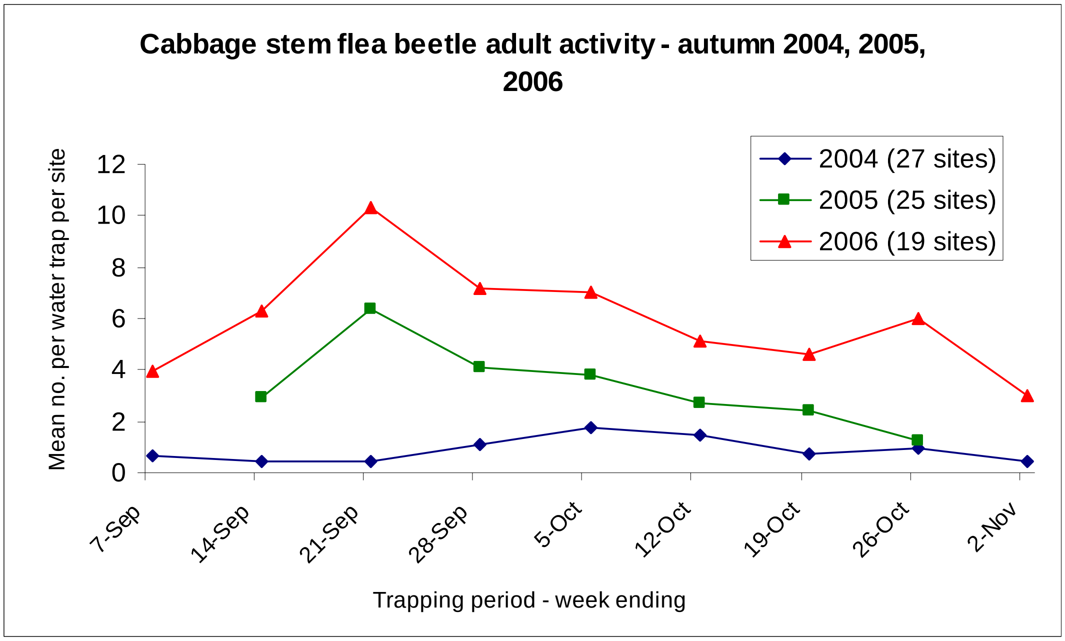


The total catches of 865, 2293 and 3372 in autumn 2004, 2005 and 2006 respectively were equivalent to means of 8.0, 22.9 and 44.4 per water trap or 32.0, 91.7 and 177.5 per site respectively.

Significant regressions ($P < 0.001$) were obtained for mean numbers of beetles per headland-sited water traps (2 traps) or field-sited traps (2 traps) compared with mean numbers per water trap (4 traps) with 97.7% and 98.4% variance explained respectively. This, and the consistency of correlations for each of the three years of the study, suggested that a simplified method of prediction using only two traps might be feasible using only two traps per site.

Higher totals of cabbage stem flea beetle adults were recorded in field-sited traps (total 3689 for 71 sites) compared with headland-sited traps (total 2841 for 71 sites). A significant ($P < 0.001$) relationship between these variates was obtained with 92.5% of the variance explained. The regression equation $y = 1.14x + 3.14$ indicated a catch of 85 beetles per headland trap compared with 100 per field-sited trap.

Figure 12. Summary plot for mean number of cabbage stem flea beetle adults per site for each weekly trapping period in autumn 2004, 2005 and 2006.



First catches were recorded in the first week of September 2004 during the early stages of crop emergence (Figure 12). A peak of adult activity was recorded in early October, followed by decreasing activity until mid October followed by a short-term increase in activity in late October before trap catches declined to a lower incidence in early November. A peak of autumn activity was recorded in late September 2005 and 2006. An earlier (mid October) start of larval invasion of plants was recorded during the warmer than average autumn of 2006.

The pattern of adult activity in each of the three years (Figure 13) of the study was similar to that described by Alford (1979) who noted that the number of adults on four crops peaked in late September or early October and then declined. Few adults were recorded after mid November but low numbers of beetles continued to be caught overwinter. Water trapping in winter oilseed rape trials in 1999-2001 showed mid to late September peaks of adult activity Green (2002). Following a period of summer aestivation, adult cabbage stem flea beetles appear on oilseed rape stubbles and in emerging winter oilseed rape crops (Alford (1979), Oakley (2003)). Studies in Hungary indicated that the period of summer diapause was not affected by temperature, photoperiod, relative humidity or food availability and was considered as a genetically fixed adaptation termed prospective diapause (Saringer, 1984).

Sticky trap results autumn 2004

In autumn 2004, 27 monitoring sites were established as soon as possible after drilling winter oilseed rape. At each site, yellow sticky traps were set out with two traps placed on a crop headland and two traps positioned in the field. Cabbage stem flea beetle activity was monitored weekly from early crop emergence on 6-8 occasions between September and early November. Data are summarised in Table 4.

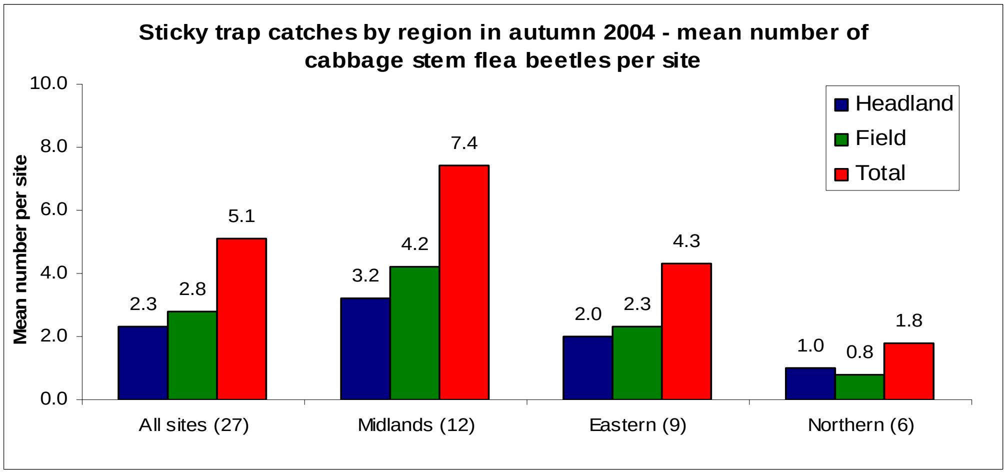
Table 4. Summary of sticky trap catches in autumn 2004 (year 1 only).

Site code	Area	Total no. csfb on 4 traps	Mean no. csfb per sticky trap	Mean no. csfb per trap per week	Total no. csfb on 2 headland -sited traps	Total no. csfb on 2 field-sited traps	Mean no. csfb per sticky trap (headland)	Mean no. csfb per sticky trap (field)
1	M	1	0.25	0.03	0	1	0	0.5
2	M	20	5.00	0.56	7	13	3.5	6.5
3	M	2	0.50	0.06	1	1	0.5	0.5
4	M	1	0.25	0.03	1	0	0.5	0.0
5	M	15	3.75	0.42	3	12	1.5	6.0
6	M	6	1.50	0.17	4	2	2	1.0
7	M	17	4.25	0.53	8	9	4	4.5
8	M	16	4.00	0.50	8	8	4	4.0
9	M	5	1.25	0.16	3	2	1.5	1.0
10	M	5	1.25	0.16	2	3	1	1.5
11	M	0	0.00	0	0	0	0	0.0
12	M	0	0.00	0	0	0	0	0.0
13	E	6	1.50	0.21	3	3	1.5	1.5
14	E	2	0.50	0.07	0	2	0	1
15	E	3	0.75	0.11	2	1	1	0.5
16	E	13	3.25	0.46	4	9	2	4.5
17	E	4	1.00	0.14	2	2	1	1
18	E	2	0.50	0.07	0	2	0	1
19	E	5	1.25	0.18	5	0	2.5	0
20	E	2	0.50	0.07	2	0	1	0
21	E	2	0.50	0.08	0	2	0	1
22	N	3	0.75	0.13	1	2	0.5	1
23	N	2	0.50	0.08	1	1	0.5	0.5
24	N	0	0.00	0.00	0	0	0	0
25	N	1	0.25	0.04	0	1	0	0.5
26	N	1	0.25	0.04	1	0	0.5	0
27	N	4	1.00	0.17	3	1	1.5	0.5
Total		138	34.5	4.44	61	77	30.5	38.5
Mean per site		5.1	1.3	0.2	2.3	2.8	1.1	1.4

M: Midlands (west and east); E: Eastern England; N: Northern England.
For site locations and cropping details, see Appendix A.

At only three of 27 sites (15, 16, 21) were higher numbers recorded on sticky traps compared with water traps and at each of these sites, all in eastern England, beetle numbers were low with a mean of 2.5 or fewer per water trap.

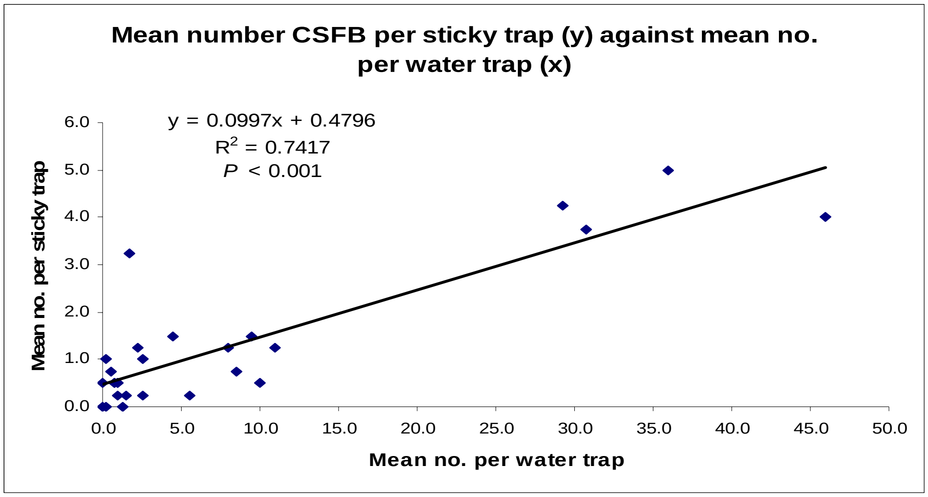
Figure 13. Mean number of cabbage stem flea beetles caught on sticky traps by region and per site (27 sites in total) in autumn 2004.



The total of 865 cabbage stem flea beetle adults in four water traps established at each of 27 sites was 6.3 times as high as the total of 138 on four sticky traps set-out at each site. An overall mean of 5.1 beetles per site for sticky traps compared with 32.0 per site for water traps. The mean catch of 2.8 per site for field-sited sticky traps was higher than the mean of 2.3 per site for headland-sited traps (Figure 13).

Mean number of adults per sticky trap were significantly ($P < 0.001$) correlated with mean number in water traps with 74.2% of the variance explained (Figure 14). However, the much lower numbers of beetles on sticky traps and poorer significance values for tested regressions, compared with those for water trap analyses, indicated that water traps provided a more robust predictor of larval damage and the need for treatment where justified. At four sites (2, 5, 7, 8) in the Midlands, mean number of beetles per sticky trap were 5.0 or fewer where total water traps catches exceeded the higher value of 25 or more per trap, indicating the relative insensitivity of sticky traps for monitoring purposes compared with the use of water traps.

Figure 14. Regression plot for mean number of cabbage stem flea beetles per sticky trap (y axis) against mean number per water trap (x axis).



Cabbage stem flea beetle predictions from plant damage assessments

Plant, cotyledon and leaf 1 damage assessments were made at an average two leaf stage (GS 1,2) in autumn 2004 and 2005. 50 plants in autumn 2005 and 25 plants in autumn 2005 were sampled at random from untreated areas of crop in the areas selected for water or sticky trap monitoring. Plant samples were checked to determine the incidence of plant and leaf damage due to cabbage stem flea beetle adults (Tables 5 and 6). Numbers of slug-damaged plants were also recorded.

Table 5. Summary for plant, cotyledon and leaf 1 damage assessments in autumn 2004.

Site no.	Area	Mean no true leaves	Mean no. plants with csfb damage	Mean no. of cotyledons damaged	Mean % cotyledon area lost	Mean no. of first true leaves damaged	Mean % leaf 1 area lost	Mean no. plants with slug damage
1	M	1.9	0.06	0.03	0.06	0.00	0.00	0.12
2	M	1.8	0.50	0.30	0.70	0.18	0.86	0.00
3	M	1.8	0.14	0.09	0.11	0.04	0.08	0.10
4	M	1.9	0.06	0.03	0.02	0.00	0.00	0.04
5	M	2.7	0.36	0.20	0.37	0.10	0.18	0.34
6	M	2.0	0.10	0.04	0.07	0.06	0.08	0.26
7	M	2.3	0.32	0.21	0.18	0.08	0.12	0.12
8	M	2.0	0.60	0.46	1.02	0.06	0.24	0.10
9	M	1.6	0.52	0.38	0.37	0.14	0.14	0.06
10	M	1.1	0.22	0.15	0.36	0.02	0.14	0.08
11	M	2.0	0.00	0.00	0.00	0.00	0.00	0.00
12	M	2.0	0.00	0.00	0.00	0.00	0.00	0.00
13	E	2.4	0.40	0.06	0.19	0.32	0.92	0.00
14	E	2.1	0.30	0.17	0.41	0.04	0.03	0.04
15	E	2.0	0.30	0.11	0.57	0.38	0.92	0.00
16	E	2.2	0.42	0.28	1.00	0.04	0.30	0.00
17	E	3.9	0.26	0.04	0.07	0.24	0.86	0.00
18	E	3.3	0.16	0.02	0.06	0.14	0.59	0.00
19	E	3.0	0.40	0.20	0.84	0.30	1.24	0.00
20	E	2.2	0.06	0.03	0.02	0.00	0.00	0.20
21	E	2.0	0.04	0.02	0.01	0.00	0.00	0.02
22	N	1.8	0.32	0.17	0.45	0.04	0.04	0.08
23	N	1.5	0.08	0.04	0.08	0.02	0.14	0.14
24	N	1.3	0.18	0.12	0.47	0.02	0.02	0.00
25	N	1.9	0.12	0.03	0.03	0.06	0.08	0.08
26	N	1.6	0.18	0.10	0.49	0.00	0.00	0.00
27	N	1.9	0.34	0.19	0.95	0.04	0.08	0.08
Total		56.1						
Mean per site		2.1	0.24	0.13	0.33	0.09	0.26	0.07

M: Midlands (west and east); E: Eastern England; N: Northern England.
For site locations and cropping details, see Appendix A.

In the first year of the study in autumn 2004, mean number of plants, cotyledons and first true leaves damaged by cabbage stem flea beetle damage averaged 0.24, 0.13 and 0.09 respectively (Table 5). A mean of 0.07 (7%) of plants were damaged by slugs with a mainly low incidence of damage recorded at a total of 16 from 27 sites (Table 6).

Table 6. Summary for plant, cotyledon and leaf 1 damage assessments in autumn 2005.

Site no.	Area	Mean no true leaves	Mean no. plants with csfb damage	Mean no. of cotyledons damaged	% cotyledon area lost	Mean no. of first true leaves damaged	% leaf 1 area lost	Mean no. plants with slug damage
28	M	1.8	0.36	0.22	0.32	0.00	0.00	0.04
29	M	1.8	0.16	0.10	0.06	0.00	0.00	0.04
30	M	2.1	0.24	0.06	0.03	0.12	0.06	0.04
31	M	2.4	0.48	0.30	0.22	0.20	0.76	0.80
32	M	2.6	0.44	0.30	0.28	0.08	0.04	0.53
33	M	2.0	0.48	0.28	0.29	0.04	0.04	0.12
34	M	1.8	0.60	0.44	0.47	0.40	0.86	0.00
35	M	2.0	0.72	0.58	0.38	0.24	0.80	0.00
36	M	2.0	0.80	0.72	1.78	0.44	1.22	0.16
37	M	2.0	0.28	0.16	0.09	0.04	0.02	0.04
38	M	2.6	0.24	0.08	0.04	0.08	0.04	0.04
39	E	2.4	0.56	0.24	0.44	0.44	1.32	0.32
40	E	2.1	1.00	1.00	4.34	1.00	4.20	1.00
41	E	2.4	0.16	0.06	0.12	0.04	0.60	0.40
42	E	2.1	0.24	0.06	0.18	0.16	0.40	0.48
43	E	2.1	0.36	0.12	0.36	0.20	0.36	0.04
44	E	2.4	0.88	0.50	2.74	0.68	1.16	0.08
45	E	2.6	0.76	0.58	0.79	0.56	0.66	0.40
46	E	2.3	0.16	0.12	0.14	0.00	0.00	0.12
47	N	1.5	0.64	0.36	0.72	0.12	0.10	0.40
48	N	1.2	0.20	0.08	0.08	0.04	0.04	0.00
49	N	1.2	0.28	0.10	0.12	0.08	0.08	0.24
50	N	1.7	0.40	0.26	0.44	0.12	0.12	0.36
51	N	1.7	0.44	0.24	0.5	0.16	0.16	0.08
52	N	1.1	0.24	0.14	0.24	0.08	0.08	0.36
Total		49.8						
Mean per site		2.0	0.44	0.28	0.61	0.21	0.52	0.24

M: Midlands (west and east); E: Eastern England; N: Northern England.
For site locations and cropping details, see Appendix B.

In the second year of the study in autumn 2005, cabbage stem flea beetle totals in water traps were higher than in autumn 2004. Damage incidence was greater than in the previous year with means of 0.44, 0.28 and 0.21 plants, cotyledons and first true leaves damaged by cabbage stem flea beetle adults respectively. There were complications with slug damage at some sites. In 2005, a mean of 0.24 plants (24%) was damaged by slugs (Table 6) with damage recorded at 22 from 25 sites (88%). Three sites (31, 32, 40) showed evidence of severe slug damage with more than 50% of plants damaged.

Regressions were tested for selected variates. For autumn 2004, mean number of cabbage stem flea beetle adults per water trap were significantly (*P* = 0.001) correlated with mean number of plants damaged and with mean number of cotyledons damaged (*P* < 0.001) but not with mean number of first true leaves damaged. Mean number of plants damaged was significantly (*P* < 0.001) correlated with mean number of cotyledons damaged. Mean number of cotyledons damaged was not significantly correlated with mean numbers of first true leaves damaged. Regression equations, significance levels and percentages of variance explained are summarised in Table 7.

Table 7. Summary of regression analyses relating adult cabbage stem flea beetle numbers to plant, cotyledon and first true leaf damage in autumn 2004.

Regression test (autumn 2004 data)				
y value	x value	Equation	R^2 %	*P*
Mean no. csfb per water trap	Mean no. plants damaged by csfb adults	y = 43.2x – 2.30	34.5	0.001
Mean no. csfb per water trap	Mean no. cotyledons damaged by csfb adults	y = 69.2x – 0.88	44.9	< 0.001
Mean no. csfb per water trap	Mean no. first true leaves damaged by csfb adults	y = 6.66x + 7.44	0.3%	0.775
Mean no. plants damaged	Mean no. cotyledons damaged	y = 1.26x + 0.0761	81.2	< 0.001
Mean no. first true leaf damaged	Mean no. cotyledons damaged	y = 0.141x + 0.0677	2.5	0.437

Similar tests were performed for data obtained in autumn 2005. Table 8 shows that mean number of cabbage stem flea beetle adults per water trap were not significantly correlated with mean number of plants damaged by adults (*P* = 0.083), mean number of cotyledons damaged (*P* = 0.065) or with mean number of first true leaves damaged (*P* = 0.917). These results were statistically different from those obtained in autumn 2004. Mean number of plants damaged was significantly (*P* < 0.001) correlated with mean number of cotyledons damaged. Mean number of cotyledons damaged was significantly correlated with mean numbers of first true leaves damaged (*P* < 0.001).

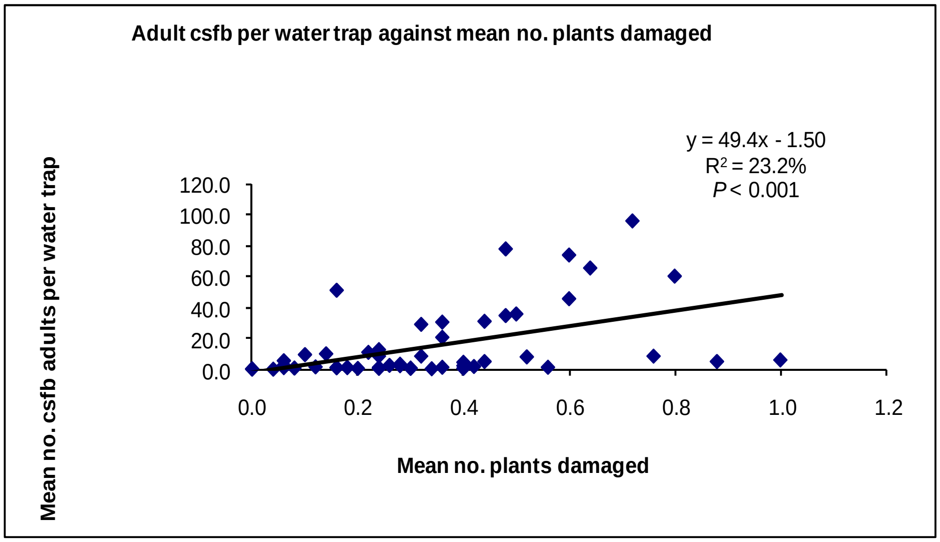
Table 8. Summary of regression analyses relating adult cabbage stem flea beetle numbers to plant, cotyledon and first true leaf damage in autumn 2005.

Regression test (autumn 2005 data)				
y value	x value	Equation	R^2 %	*P*
Mean no. csfb per water trap	Mean no. plants damaged by csfb adults	y = 3.5 + 43.7x	12.5	0.083
Mean no. csfb per water trap	Mean no. cotyledons damaged by csfb adults	y = 9.46 + 47.4x	14.1	0.065
Mean no. csfb per water trap	Mean no. first true leaves damaged by csfb adults	y = 22.4 + 2.7x	0.0	0.917
Mean no. plants damaged	Mean no. cotyledons damaged	y = 0.172 + 0.961x	88.3	< 0.001
Mean no. first true leaf damage	Mean no. cotyledons damaged	y = 0.869x – 0.0340	70.4	< 0.001

Plant damage assessments (52 sites) - autumn 2004 and autumn 2005 data combined.

Significant regressions ($P < 0.001$) were obtained between mean number of beetles per water trap and mean number of plants and cotyledons damaged but in each case with under 25% of variance explained (Figures 15 and 16). Mean number of beetles per trap were not significantly ($P = 0.364$) correlated with mean number of first true leaves with cabbage stem flea beetle adult feeding damage (plot not shown). The plots for plant and cotyledon damage show that obvious damage occurred at some sites even where catches of beetles in water traps were low.

Figure 15. Regression plot of mean number of beetles per trap against plant damage.

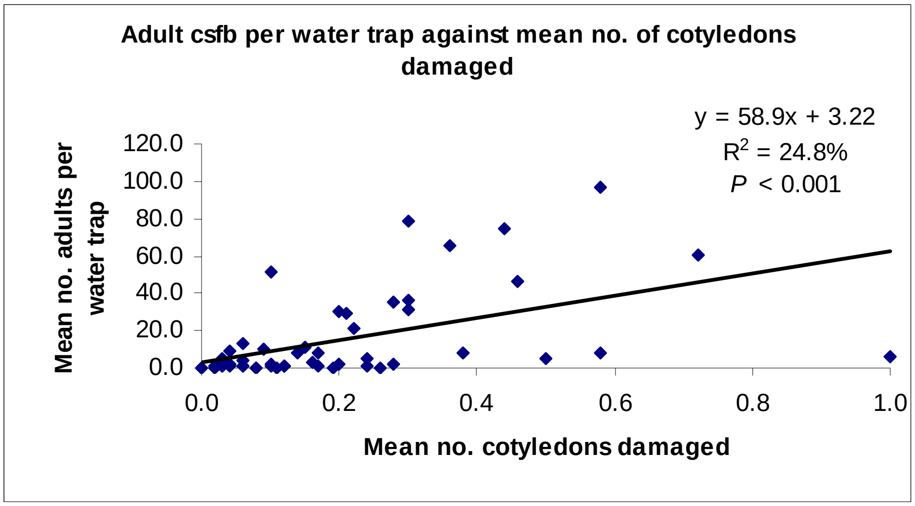


In autumn 2005, more than 50% of plants at four sites (39, 40, 44, 45) in eastern England showed evidence of plant damage, despite low numbers (mean 1.25-8.0 per trap) of cabbage stem flea beetle adults in water traps. Three of these four sites (39, 40, 45) also showed an obvious incidence of slug damage as summarised in Table 6, suggesting that prediction of plant or cotyledon damage from beetle numbers in traps was not reliable when damage from both cabbage stem flea beetle and slugs is present. A total of 9 of the 52 sites monitored in autumn 2004 and 2005 showed a higher incidence of slug damaged plants compared with plants damaged by cabbage stem flea beetle. This was particularly the case in autumn 2005 when slug damage was recorded at 22 from 25 sites (88% of total) compared with 16 from 27 sites (59% of total) in 2004.

More than 50% of cotyledons (Figure 17) were damaged by cabbage stem flea beetle at three sites in eastern England (sites 40, 44, 45) where water trap catches were low (5.0-8.5 per trap). Two of these sites (sites 40, 45) also showed obvious slug damage with 100% and 40% of plants respectively damaged by slugs. This complicated the damage assessment and compromised the validity of predicting cabbage stem flea beetle numbers and damage from plant damage assessments. In addition, cotyledon losses were attributed to downy mildew at some sites and considerable crop protection expertise was required to correctly determine the cause of damage.

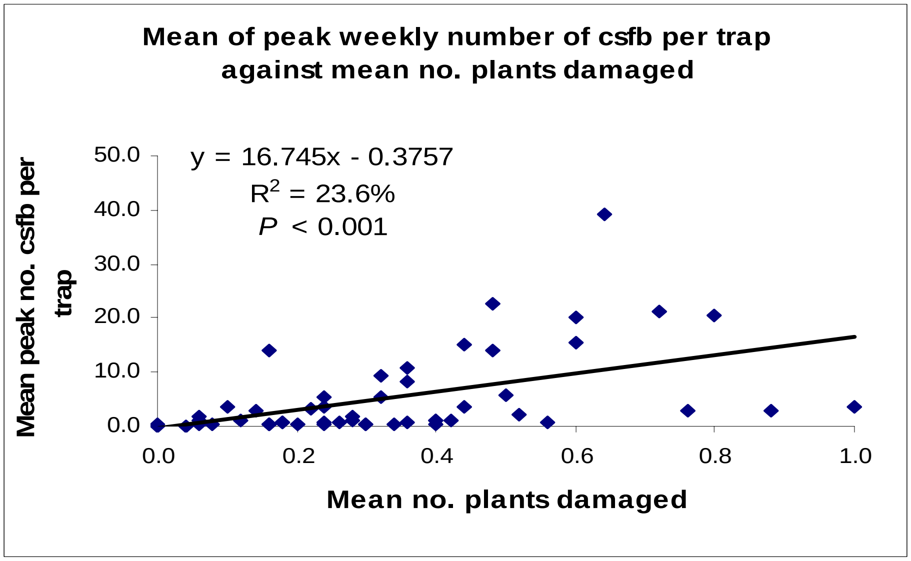
Relationships between larval number and plant, cotyledon or leaf one damage are considered later.

Figure 16. Regression plot of mean number of beetles per trap against cotyledon damage.



As plant samples were collected in late September during or close to the period that peak catches of adults were being recorded in water traps, the regression between peak weekly total of beetles and plant damage was also tested (Figure 17). This provided a similar plot to that shown in Figure 17, which, although significant at $P < 0.001$, explained only 23.6% of the variance and therefore showed a poor relationship in these studies between plant damage and beetle numbers.

Figure 17. Regression plot of mean peak weekly number of beetles per trap against plant damage.



Larval assessments

Harvest year 2005

A total of 25 plants were randomly sampled at each site in December or early January. Plant samples were taken from untreated areas of crop in the areas that had been marked out to record the numbers of adult beetles in water traps or on sticky traps. Plant samples were dissected to determine the number of cabbage stem flea beetle larvae and the incidence of larval damage to plants and leaves as summarised in Table 9.

Table 9. Summary for larval assessments in harvest year 2005.

Site no.	Area	Total number of small larvae (< 2 mm)	Total number of medium larvae (2-4 mm)	Total number of large larvae (> 4 mm)	Total number of larvae (all stages)	Mean number of csfb larvae per plant	Percentage of plants infested with csfb larvae	Percentage of leaves infested with csfb larvae
1	M	3	6	0	9	0.36	20	7.6
2	M	64	19	0	83	3.32	88	65.1
3	M	3	11	0	14	0.56	32	9.8
4	M	0	4	0	4	0.16	8	2.4
5	M	7	13	3	23	0.92	36	11.4
6	M	1	0	0	1	0.04	4	0.6
7	M	1	3	1	5	0.2	16	4.0
8	M	27	30	0	57	2.28	68	35.4
9	M	6	0	0	6	0.24	16	5.8
10	M	5	4	0	9	0.36	20	4.3
11	M	0	0	0	0	0	0	0
12	M	0	0	0	0	0	0	0
13	E	0	0	0	0	0	0	0
14	E	0	0	0	0	0	0	0
15	E	0	0	0	0	0	0	0
16	E	0	0	0	0	0	0	0
17	E	0	0	0	0	0	0	0
18	E	0	0	0	0	0	0	0
19	E	0	0	0	0	0	0	0
20	E	0	0	0	0	0	0	0
21	E	0	0	0	0	0	0	0
22	N	8	0	0	8	0.32	12	2.2
23	N	0	0	0	0	0	0	0
24	N	0	0	0	0	0	0	0
25	N	0	0	0	0	0	0	0
26	N	0	0	0	0	0	0	0
27	N	0	0	0	0	0	0	0
Total		125	90	4	219			
Mean per site		4.63	3.33	0.15	8.11	0.32	11.85	5.50

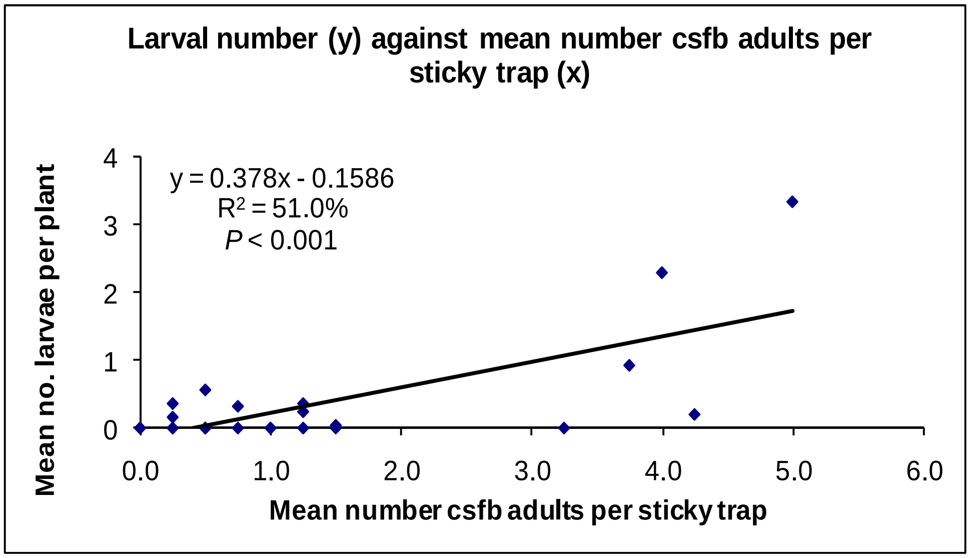
The highest larval numbers were recorded at sites in the Midlands with infestations of up to 3.32 per plant. A total of two sites (both in the Midlands) developed larval infestations greater than two larvae per plant. No larvae were recovered from plants collected at sites in eastern England where adult beetle activity had previously been low. Site 22 in North Yorkshire, with a mean of 0.32 larvae per plant, was the only one of six sites in northern England at which larval damage was recorded. In total, 57% and 41% of larvae dissected from plants were first and second instar larvae respectively.

Cabbage stem flea beetle larval predictions from sticky trap catches.

In harvest year 2005, regression analysis was used to predict larval number from sticky trap catches at a total of 27 sites. Infestations greater than a mean of two larvae per plant developed at two sites in harvest year 2005 (site 2 with 3.32 larvae per plant and site 8 with 2.3 larvae per plant).

Mean numbers of larvae per plant were significantly ($P < 0.001$) correlated with mean number of adult cabbage stem flea beetles per sticky trap with 51.0% of variance explained (Figure 18). An infestation of two larvae per plant was calculated from a mean of 5.7 adult beetles per sticky trap.

Figure 18. Larval predictions from sticky trap catches – harvest year 2005.



Neither of the sites with above threshold larval number of two per plant were successfully predicted for treatment from number of adult beetles on sticky traps. Sticky traps caught lower numbers of cabbage stem flea beetle adults caught compared with numbers in water traps. Sticky traps were difficult to use visually in the field, particularly in early autumn when many large non target species such as hoverflies (Diptera: Syrphidae) were also caught and had the effect of masking the usually low catches of cabbage stem flea beetle adults. Greater predictive success might have been obtained if higher infestations of larvae had been recorded.

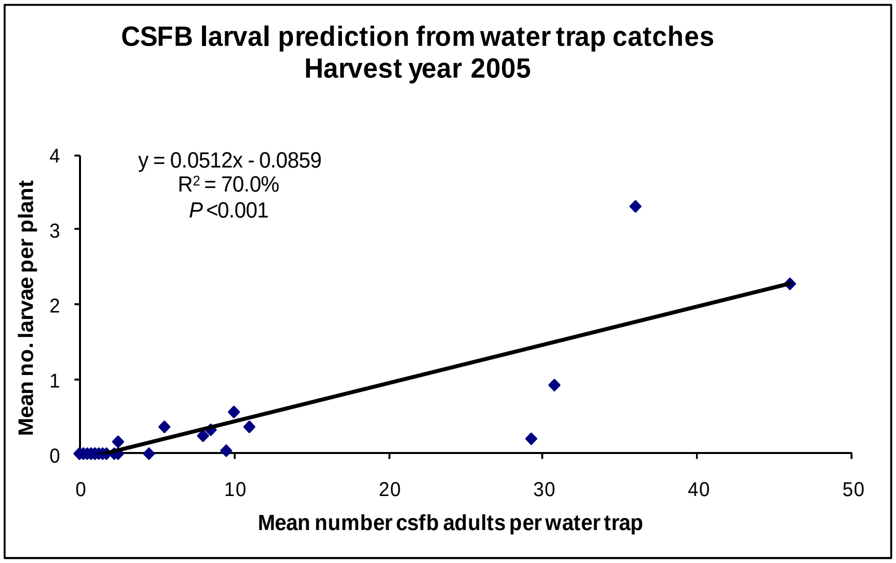
Regressions were tested for mean number of larvae per plant against mean number of adults per headland, or field-sited sticky traps providing the regression equations $y = 0.3746x – 0.0987$ (R^2 35.8%, $P = 0.001$) and $y = 0.2825x – 0.0784$ (R^2 49.3%, $P < 0.001$) respectively. With lower percentages of variance explained, the use of two headland or two field-sited traps offered poorer predictive values than the regression between larval number and mean number of adults per trap overall for the total of four traps per site.

Cabbage stem flea beetle larval predictions from water trap catches.

Incidence of larval damage was low in harvest year 2005 and only two sites developed larval infestations above the current economic control threshold of two larvae per plant in late autumn.

Mean numbers of larvae per plant were significantly ($P < 0.001$) regressed against mean number of adult cabbage stem flea beetles per water trap with 70.0% of variance explained (Figure 19).

Figure 19. Larval predictions from water trap catches – harvest year 2005.



The heaviest infestations were recorded in the Midlands at site 2 with a mean of 3.3 larvae per plant from a mean of 36.0 beetles per water trap, and site 8 with a mean of 2.3 larvae per plant from a mean of 46.0 beetles per water trap.

An infestation of two larvae per plant was calculated from a mean of 40.7 adult beetles per water trap with a standard error of 13.6 providing 95% confidence limits rounded to 14-60 per trap. Significant relationships were also obtained between mean number of larvae per plant against mean number of adults per headland-sited water traps ($y = 0.054x – 0.046$, R^2 49.1%, $P < 0.001$) and mean number of larvae per plant against mean number of adults per headland-sited water traps ($y = 0.044x – 0.078$, R^2 80.0%, $P < 0.001$).

From the regression calculation, site 2 would not have been predicted from the median value obtained from the regression analysis as the adult catch was below 40.7 per trap although it fell within the lower 95% confidence limit. An 'outlier' site (site 7) indicated only 0.20 larvae per plant despite a high mean of 29.3 adults per water trap. The low larval count is difficult to explain with no evidence that, for example, a pyrethroid spray may have been applied to the farm crop surrounding the area used for trapping and with no indication from the pattern of adult catches that an insecticidal spray was applied before the end of water trapping.

If the relationship between larval number and number of beetles in water traps is tested after removal of the outlier site 7 from the regression calculation, then the predictive power is improved with 81.5% of the variance explained. The revised calculation then successfully predicted the two sites with more than two larvae per plant from water trapping. An infestation of two larvae per plant would then be derived from a mean of 35.6 beetles per water trap.

Summary for harvest year 2005:

A significant ($P < 0.001$) regression plot was obtained between mean number of larvae per plant and mean number of adults per water trap with 70.0% of the variance explained.

An infestation of two larvae per plant was calculated from a mean of 40.7 beetles per water trap.

If the outlier site (7) is removed from the regression calculation, the predictive power was improved with 81.5% of the variance explained. An infestation of two larvae per plant was then calculated from a mean of 35.6 beetles per water trap enabling both sites with more than two larvae per plant to be successfully predicted. This showed that an unexplained result from one site could have an undue influence on the prediction for any one year if data from a relatively small number of sites only were available for analysis.

Significant regressions were obtained between mean number of larvae per plant and mean number of cabbage stem flea beetle adults per field-sited or headland-sited water traps.

A significant regression ($P < 0.001$) was obtained between mean number of larvae per plant and mean number of on sticky traps with 51.0% of variance explained.

Significant but relatively weak regressions were obtained for predictions of larval number from assessments of plant damage ($P = 0.005$, R^2 27.7%) and cotyledon damage ($P = 0.001$, R^2 35.0%) made at an average two leaf stage. Larval damage could not be predicted from damage to the first true leaf with a non significant ($P = 0.696$) regression explaining only 0.6% of variance.

Larval assessments harvest year 2006

A total of 20 plants were randomly-sampled in December or early January from untreated areas of crop in the areas that had been selected for monitoring adult beetle activity using water traps. Plant samples were dissected to determine the incidence of plant and leaf damage due to cabbage stem flea beetle larvae as summarised in Table 10.

Table 10. Summary for larval assessments in harvest year 2006.

Site		Area	Total number of small larvae (<3 mm)	Total number of medium larvae (3-5 mm)	Total number of large larvae (> 5 mm)	Total number of larvae (all stages)	Mean number of csfb larvae per plant	Percentage of plants infested with csfb larvae	Percentage of leaves infested with csfb larvae
Year code	All years site code								
1	28	M	7	6	0	13	0.65	40	6.8
2	29	M	25	29	1	55	2.75	90	31.4
3	30	M	23	43	7	73	3.65	90	38.2
4	31	M	65	131	11	207	10.35	100	65.9
5	32	M	5	15	0	20	1.00	50	11.8
6	33	M	13	34	1	48	2.40	80	22.1
7	34	M	10	34	8	52	2.60	75	33.3
8	35	M	19	50	15	84	4.20	90	39.9
9	36	M	1	6	3	10	0.50	20	5.6
10	37	M	0	0	0	0	0.00	0	0.0
11	38	M	0	0	0	0	0.00	0	0.0
12	39	E	5	0	0	5	0.25	20	3.0
13	40	E	2	1	0	3	0.15	15	1.5
14	41	E	0	0	0	0	0.00	0	0.0
15	42	E	1	0	0	1	0.05	5	0.4
16	43	E	5	1	0	6	0.30	25	3.5
17	44	E	3	0	0	3	0.15	15	1.4
18	45	E	19	45	33	97	4.85	100	40.1
19	46	E	5	4	0	9	0.45	30	11.9
20	47	N	77	54	1	132	6.60	100	78.4
21	48	N	5	0	0	5	0.25	30	7.8
22	49	N	5	2	2	9	0.45	25	15.1
23	50	N	8	11	3	22	1.10	35	17.5
24	51	N	0	0	0	0	0.00	5	1.7
25	52	N	14	4	2	20	1.00	65	25.6
Total			317	470	87	874			
Mean per site			12.68	18.80	3.48	34.96	1.75	44.2	18.5

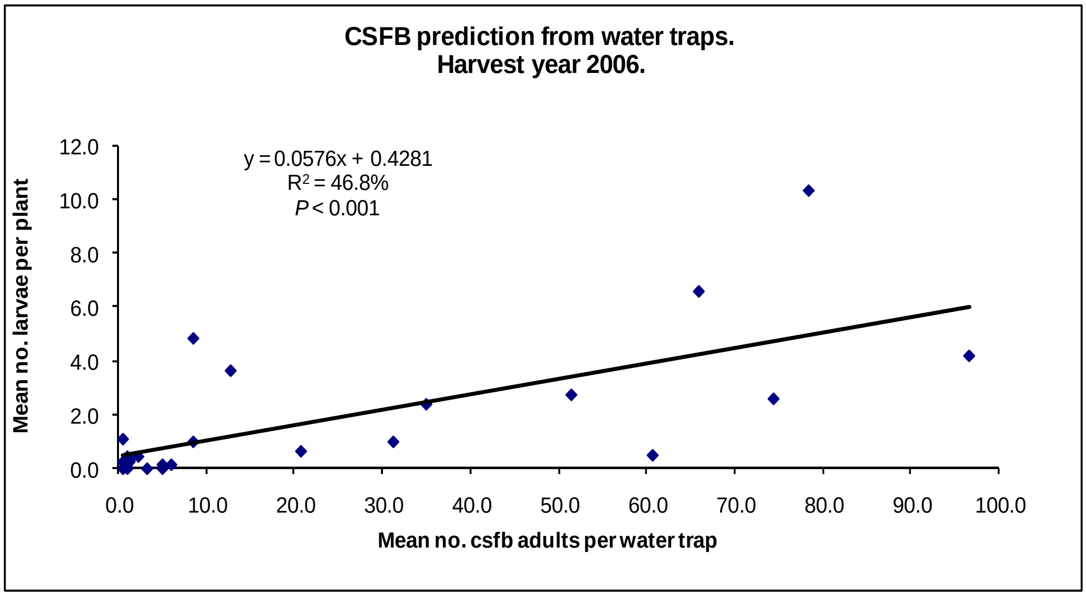
A heavier mean larval infestation of 1.75 larvae per plant (25 sites) was recorded in harvest year 2006 compared with a mean of 0.32 larvae per plant in harvest year 2005 (27 sites). A total of eight sites developed larval infestations greater than two larvae per plant. Low infestations were recorded at eastern sites with the exception of site 18 in Norfolk with 4.85 larvae per plant. Nine from eleven sites in the Midlands showed evidence of larval damage and six sites developed infestations greater than the control threshold of two larvae per plant. One site in Shropshire developed a heavy larval infestation averaging 10.3 larvae per plant. In total, 36% and 54% of larvae dissected from plants were first and second instar larvae respectively, representing a smaller proportion of first instar larvae than in the previous autumn (57% first instar) when larval invasion occurred later in the autumn.

Cabbage stem flea beetle larval predictions from water trap catches

Incidence of larval damage was greater in harvest year 2006 compared with 2005 and a total of eight sites developed larval infestations greater than two larvae per plant.

Mean numbers of larvae per plant were significantly (*P* < 0.001) regressed against mean number of adult cabbage stem flea beetles per water trap with 46.8% of variance explained (Figure 20).

Figure 20. Larval predictions from water trap catches – harvest year 2006.



An infestation of two larvae per plant was calculated from a mean of 27.3 adult beetles per water trap (standard error 4.4 and 95% confidence limits providing values rounded to 19-35 per trap).

Six of the eight sites that developed larval infestations greater than two larvae per plant were correctly predicted for treatment as adult catches were greater than a mean of 27.3 beetles per water trap.

Two sites would not have been predicted for spraying on basis of water trap catches alone. These sites developed infestations of 3.65 per plant (site 30) and 4.85 per plant (site 45) from water trap catches of 12.8 and 8.5 per trap respectively. The pattern of beetle catches in water traps at site 30 suggested that an early post emergence pyrethroid had been applied to the field but not to the area of the field being used for water trapping where an obvious larval infestation developed. The majority of the cabbage stem flea beetle adults at this site were trapped until the end of September with very few caught afterwards. This was a different activity pattern compared with that at the other sites where catches continued to be recorded until the end of October. No similar explanation was forthcoming for site 45 in Norfolk where a larval infestation of 4.85 larvae per plant was derived from a water trap catch of only 8.5 beetles per trap. At this site, there was no evidence for an insecticidal spray treatment or that the crop had an unusually dense canopy which might have partially shaded the traps with a possible loss of trap catch efficacy.

A mean of 0.5 larvae per plant was recorded at site 36 despite a high mean catch of 60.8 beetles per water trap. Plant sampling was done from an untreated area of crop being used for monitoring within the surrounding farm crop that received a field application of a pyrethroid spray. The effect of this may have reduced the larval infestation to a level below that which would have been predicted from high water trap catches at this potentially high-risk site. As a trial, removal of this 'outlier' site from the regression calculation improved the predictive power with 54.9% of the variance explained. Although an improved data fit was obtained, it still failed to predict two sites with more than two larvae per plant. The revised regression showed that two larvae per plant was likely from a mean of 24.5 adult cabbage stem flea beetles per water trap.

Summary for harvest year 2006:

A significant ($P < 0.001$) regression plot was obtained between mean number of larvae per plant and mean number of adults per water trap with 46.8% of variance explained.

An infestation of two larvae per plant was calculated from a mean of 27.3 beetles per water trap.

Significant regressions were obtained between mean number of larvae per plant and mean number of beetles in two field-sited ($P = 0.001$, R^2 56.8%, $y = 0.054x + 0.306$) or headland-sited water traps ($P = 0.004$, R^2 30.2%, $y = 0.0535x + 0.7223$).

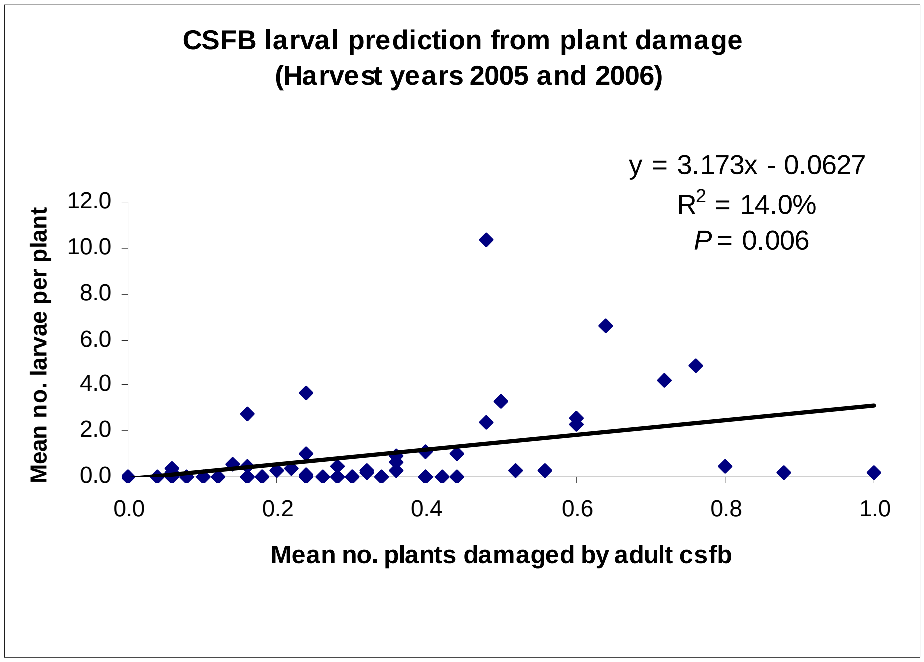
Non significant regressions were obtained for larval number against plant damage ($P = 0.324$, R^2 4.2%), cotyledon damage ($P = 0.446$, R^2 2.5% at 1-2 leaf stage. Predictive successes from plant and cotyledon damage were weaker than those obtained in year 1, partly due to complications of slug damage which compounded the effects of cabbage stem flea beetle adult damage to plants and cotyledons.

Larval damage could not be predicted from damage to the first true leaf with a non significant ($P = 0.962$) regression explaining 0% of variance. This result was similarly poor to that obtained in autumn 2004.

Larval predictions from plant, cotyledon and first true leaf damage assessments.

Plant damage: Data were combined for the two harvest years 2005 and 2006 in which assessments of damage due to adult beetle feeding damage on plants were made. A total of 10 sites from a total of 52 monitored sites developed infestations of two or more larvae per plant. Regression calculation indicated that two larvae per plant was likely if a mean of 0.65 plants (65%) were damaged by cabbage stem flea beetle adults (Figure 21).

Figure 21. Prediction of larval damage from plant damage - combined data for harvest years 2005 and 2006.



Although the regression was significant (*P* = 0.006), it was overall a poor predictor of larval damage with only 14.0% variance explained (Figure 22). Three sites (sites 36, 40, 44) showed a low incidence of larval damage where 80-100% plants were damaged. Site 40 also showed a very high incidence of slug damage (100% plants damaged) indicating that it could be difficult to separate the effects of superficially similar slug and cabbage stem flea beetle damage.

Five sites had plant damage incidence greater than 0.65 (with one just outside at 0.64) indicating that five sites would have been predicted with more than two larvae per plant. Three of these five sites developed infestations between only 0.15 and 0.5 larvae per plant and would have been incorrectly predicted for treatment. Two sites (35 and 45) with potentially damaging infestations averaging 4.2 larvae and 4.9 larvae per plant respectively were correctly predicted for treatment from plant damage assessments. A number of sites also showed an obvious incidence of slug damage, notably in autumn 2005, which complicated the damage assessments for cabbage stem flea beetle. Unless obvious slime was present, leaf grazing damage due to slugs was found to be difficult to separate from the effects of plant damage due to cabbage stem flea beetle adults.

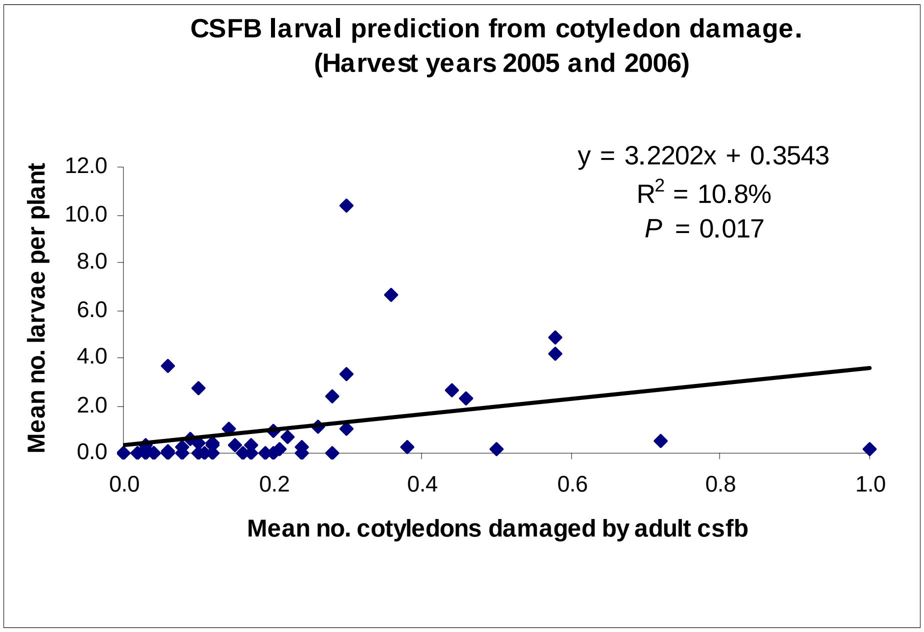
Regressions of larval number against plant damage were also tested for the individual harvest years 2005 and 2006. In harvest year 2005, a significant (*P* = 0.005) regression was obtained between larval number and plant damage with 27.7% of the variance explained. A non significant (*P* = 0.324) regression was obtained in harvest year 2006 with only 4.2% of the variance explained. The predictive success of larval number from plant damage assessments was therefore greater in autumn 2004 than in autumn 2005 when slug damage compounded the effects of cabbage stem flea beetle damage.

A mean of two larvae per plant was calculated from regression analyses in autumn 2004 and 2005 from means of 94.5% and 56.3% of plants damaged by adults respectively (individual year plots not shown). In 2004, two sites (2 and 8) developed infestations greater than two larvae per plant. Although both sites showed an obvious incidence of plant damage from cabbage stem flea beetle adults with means of 50% and 60% of plants damaged respectively (Table 2), neither site would have been successfully predicted for treatment using fitted values. Given the obvious incidence of plant and cotyledon damage at these two sites and a zero or low incidence of slug damage, it is possible that crops at these sites would have received a preventative spray with a pyrethroid insecticide. This would have particularly likely at site 8 that was not treated with imidacloprid + beta-cyfluthrin seed treatment (Appendix A).

In autumn 2005, eight sites developed infestations greater than two larvae per plant with most of these sites showing obvious, but inconsistent adult feeding damage. These studies showed that a predictive method for larval damage from plant damage assessments was inconsistent and could be difficult to apply with precision particularly at sites where obvious slug damage occurred during crop establishment.

Cotyledon damage: Data were combined for the two harvest years 2005 and 2006 in which assessments of damage due to adult beetle feeding damage on plants were made. A total of 10 sites from a total of 52 monitored sites developed infestations of two or more larvae per plant. Regression analysis showed that an infestation of two larvae per plant was likely if a mean of 0.51 cotyledons (51%) was damaged by cabbage stem flea beetle adults (Figure 22).

Figure 22. Larval damage prediction from cotyledon damage - combined data for harvest years 2005 and 2006.



Although a significant (P = 0.017) regression was obtained, only 10.8% of the variance was explained (Figure 20).

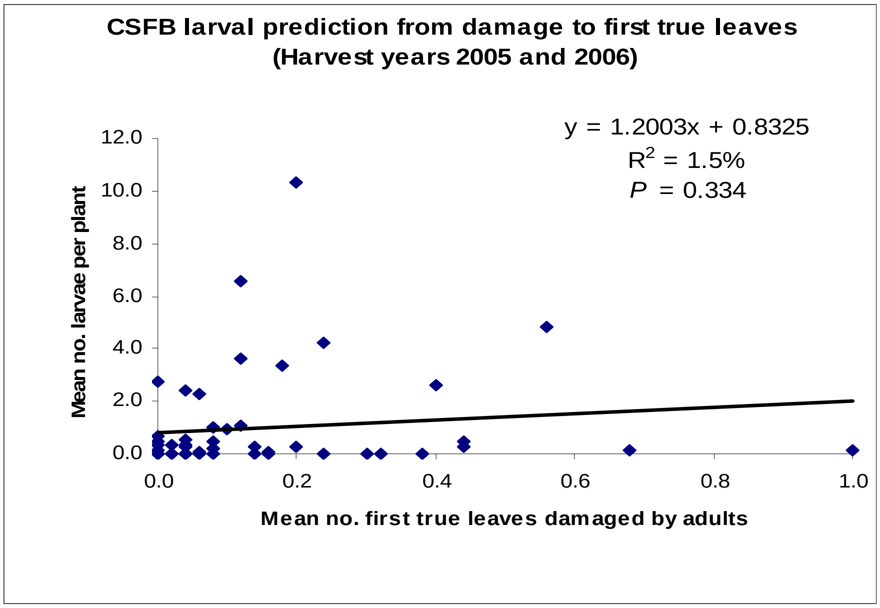
Using cotyledon damage as a predictor of larval damage, four sites (35, 36, 40, 45) from a total of 52 were predicted for treatment with one site (44) with 50% of cotyledons damaged marginally below the 51% damage level. Correct 'to spray' predictions were made for two sites with 4.2 and 4.9 larvae per plant (sites 35 and 45 respectively). Sites 36 and 40 developed only 0.5 and 0.15 larvae per plant respectively and these sites would have been incorrectly predicted for treatment.

A predictive method based on cotyledon damage proved to be of poor predictive value with only two sites that justified treatment being predicted accurately from the ten sites that developed threshold numbers of larvae. In addition, 50% or more of cotyledons were damaged at three sites (36, 40 and 44) where subsequent larval damage was low and in the range 0.15-0.5 larvae per plant (Figure 20). Some of these sites also showed obvious slug damage which prejudiced a prediction made on the basis of shot holing damage assessments on cotyledons.

Leaf 1 damage:

Data were combined for the two harvest years 2005 and 2006 in which assessments of damage due to adult beetle feeding damage on plants were made. A non significant (*P* = 0.334) regression was obtained which was a poor predictor of larval damage with only 1.5% of variance explained (Figure 23).

Figure 23. Larval damage prediction from first true leaf damage - combined data for harvest years 2005 and 2006.



Regression calculation indicated that two larvae per plant were likely if a mean of 0.97 (97%) of the first true leaves were damaged by cabbage stem flea beetle adults. Only one site would have been predicted on this basis for treatment and this site developed only a low larval infestation of 0.15 larvae per plant. None of the ten sites with larval infestations greater than two larvae per plant would have been successfully predicted for treatment.

In these studies, prediction of larval number from damage to the first true leaf had no value as a predictive tool.

Larval assessments harvest year 2007

20 plants were sampled in December or early January from untreated areas of crop in the areas that had been selected for water or sticky trap monitoring. Plant samples were dissected to determine the incidence of plant and leaf damage due to cabbage stem flea beetle larvae as summarised in Table 11.

Table 11. Summary for larval assessments in harvest year 2007.

Site		Area	Total number of small larvae (< 3 mm)	Total number of medium larvae (3-5 mm)	Total number of large larvae (> 5 mm)	Total number of larvae (all stages)	Mean number of csfb larvae per plant	Percentage of plants infested with csfb larvae	Percentage of leaves infested with csfb larvae
Year code	All years site code								
1	53	M	8	19	0	27	1.35	70	14.4
2	54	M	40	65	8	113	5.65	90	49.2
3	55	M	12	18	1	31	1.55	80	32.1
4	56	M	54	98	9	161	8.05	100	63.9
5	57	M	26	31	3	60	3.00	80	36.3
6	58	M	0	10	0	10	0.50	35	7.8
7	59	M	10	38	5	53	2.65	95	28.3
8	60	M	4	44	4	52	2.60	95	30.0
9	61	M	5	38	5	48	2.40	80	25.1
10	62	E	0	0	0	0	0.00	0	0.0
11	63	E	0	0	0	0	0.00	0	0.0
12	64	E	0	1	0	1	0.05	5	0.9
13	65	E	2	12	1	15	0.75	35	12.8
14	66	E	5	8	0	13	0.65	40	16.7
15	67	E	5	15	6	26	1.30	70	22.8
16	68	N	5	0	0	5	0.25	20	10.4
17	69	N	1	0	0	1	0.05	5	1.0
18	70	N	13	7	2	22	1.10	40	21.9
19	71	N	110	97	5	212	10.60	100	98.1
Total			300	501	49	850			
Mean per site			15.8	26.4	2.6	44.7	2.24	54.7	24.8

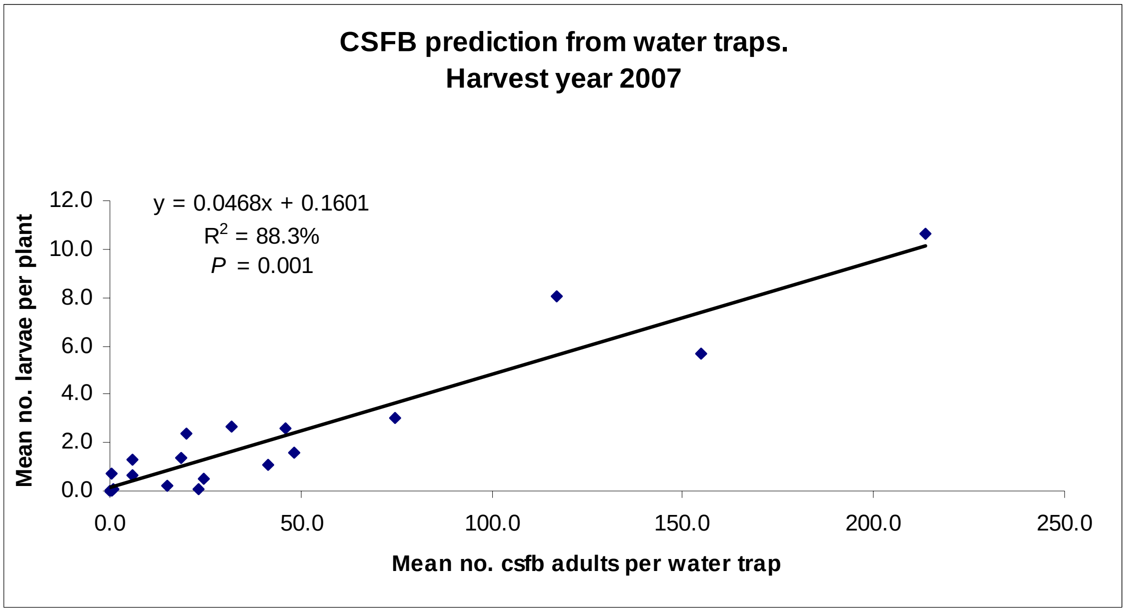
An earlier, mid-October start of larval invasion was recorded in the milder than average weather in autumn 2006. Larval infestations were higher in harvest year 2007 than in the first two years of the study, with an overall mean of 2.24 larvae per plant (19 sites) compared with means of 0.32 and 1.75 per plant in harvest years 2005 and 2006 respectively. In total, 35% and 59% of larvae dissected from plants were first and second instar larvae respectively with a similar proportion of first instar larvae to that recorded in autumn 2005. Seven from 19 sites developed infestations greater than two larvae per plant with three sites having more than 5 larvae per plant (sites 54, 56 and 71 with 5.65, 8.05 and 10.60 larvae per plant respectively). All nine sites in the Midlands developed larval infestations which ranged from 0.5 - 8.1 per plant, with six sites in this region having more than two larvae per plant.

The highest infestation in the three year study was recorded at site 71 (North Yorkshire) where an infestation of 10.6 larvae per plant followed very high beetle numbers averaging 213.5 per water trap (Table 3). Site 70, which was on the same farm as site 71, developed a larval infestation of 1.1 larvae per plant from a water trap catch averaging 41.2 beetles per trap illustrating the large variation in infestation levels from field to field. The larval infestation at site 70 was lower than might have been expected but the crop of winter oilseed rape was drilled on 11 September, some three weeks later than site 71 which was drilled on 22 August. Later-drilled crops were shown by Alford (1979) to develop later larval infestations than early-drilled sites.

Cabbage stem flea beetle larval predictions from water trap catches

Incidence of larval damage was greater in harvest year 2007 compared with 2006 and 2005. Seven from 19 sites in harvest year 2007 developed infestations greater than the control threshold of two larvae per plant with three sites having more than five larvae per plant (Figure 24).

Figure 24. Larval predictions from water trap catches. Harvest year 2007.



Mean numbers of larvae per plant were significantly (*P* < 0.001) correlated with mean number of adults per water trap with 88.3% of variance explained (Figure 25). For harvest year 2007, a significant (*P* = 0.001) regression was obtained between larval numbers and number of beetles in traps. An infestation of two larvae per plant was calculated from a mean of 39.3 adult beetles per water trap (standard error of 6.2 providing 95% confidence limits rounded to 27-51 beetles per trap).

Larval infestations greater than two larvae per plant were successfully predicted at 5 of 7 sites (71% success rate). Two sites would not have been predicted for spraying on basis of a mean water trap catch of 39.3 beetles per trap (Figure 25). Sites 59 and 61 in the Midlands developed larval infestations of 2.6 and 2.4 larvae per plant from water trap catches of 32.0 and 20.0 beetles per trap respectively. Crop development had been rapid at these sites in the warm autumn of 2006 and the dense crop canopies that developed may have suppressed water trap catches.

Summary for harvest year 2007:

Significant (*P* < 0.001) relationship between larval damage and adult catches in four water traps.

A control threshold of two larvae per plant was likely from 39.3 beetles per water trap for harvest year 2007 data.

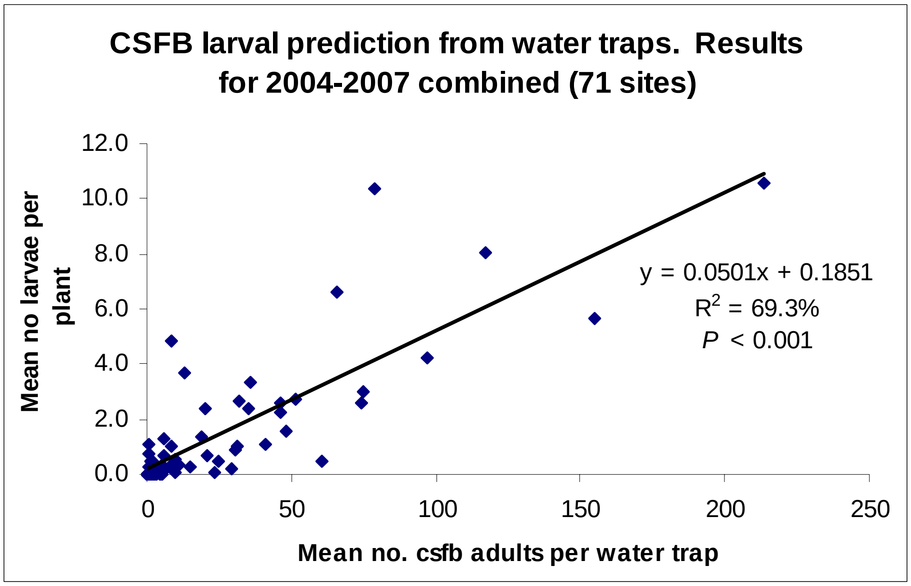
Significant relationship between larval damage and adult catches in two field-sited (*P* = 0.001, R^2 85.8%, or headland-sited water traps (P < 0.001, R^2 89.4%).

Cabbage stem flea beetle larval predictions for 71 sites.

During the three years of this study, peaks of cabbage stem flea beetle adult activity were recorded in early October (in autumn 2004) or during late September (in autumn 2005 and 2006). The highest incidence of adult beetle activity was recorded in harvest year 2007. A total of 17 from 71 sites (24%) developed larval infestations greater than two larvae per plant. Three sites (47, 54, 56) developed infestations between 5-10 larvae per plant. More than 10 larvae per plant developed at two sites (31, 71).

The fitted trendline for the all-71 sites regression plot (Figure 25) indicated two larvae per plant from a mean of 36.2 per water trap with a standard error (SE) of 3.20 providing 95% confidence limit values (1.994 x SE (70 degrees of freedom)) for threshold prediction between 29.8 and 42.6 adults per water trap. Plots showing 95% confidence limits, and error bars for x axis values are shown in Figures 29 and 30 respectively.

Figure 25. Cabbage stem flea beetle larval predictions from water trap catches from all 71 sites (harvest years 2005-2007).



Three sites shown in Figure 25 developed larval infestations of 2.4, 3.6 and 4.85 larvae per plant from trap catches of 20.0, 12.7 and 8.5 beetles per trap respectively which would not have been predicted for spray treatment. An additional three sites had larval numbers above two per plant from water trap catches averaging between 32.0-36.0 beetles per trap which fell just outside the calculated value of 36.2 beetles. As these values were close to and within 9% of the calculated threshold, it would probably have been wise from a crop protection point of view to have included these sites for treatment. In such a borderline situation, farmers and agronomists would probably prefer to treat to minimise risk of economic yield loss.

Adoption of a margin within the 95% confidence limits between 29.8-42.6 beetles per water trap (16% range) captured these three sites and improved the accuracy of the forecasting method. Use of a value of 29.8 beetles per trap still failed to capture three sites (30, 45, 61) that exceeded two larvae per plant from water trap catches averaging 20 or fewer. These sites remain as ‘wrong side’ errors i.e. these sites would have justified a spray treatment but would not have been successfully predicted from water trapping.

Figure 26. Regression plot showing 95% confidence limits for mean number of cabbage stem flea beetle larvae per plant (y axis) number against mean number of adults per water trap (x axis) for all 3 years of the study providing 71 sites in total.

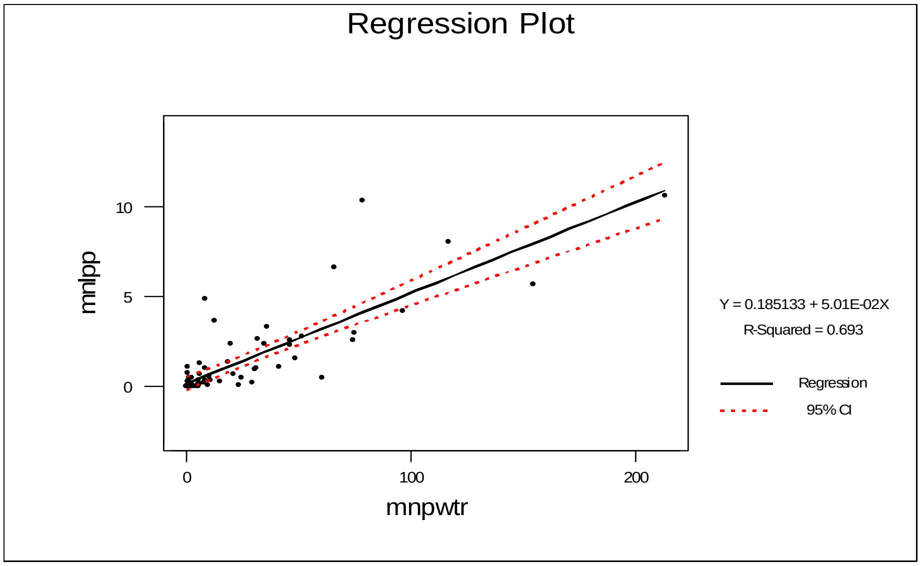
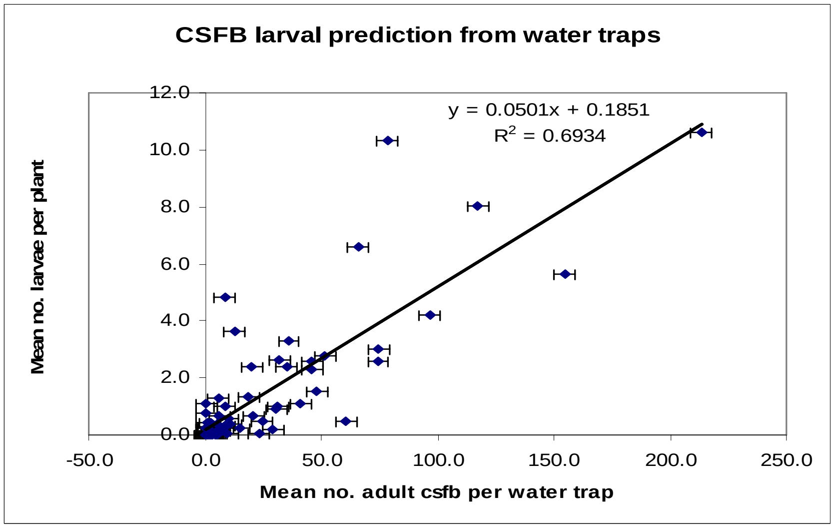


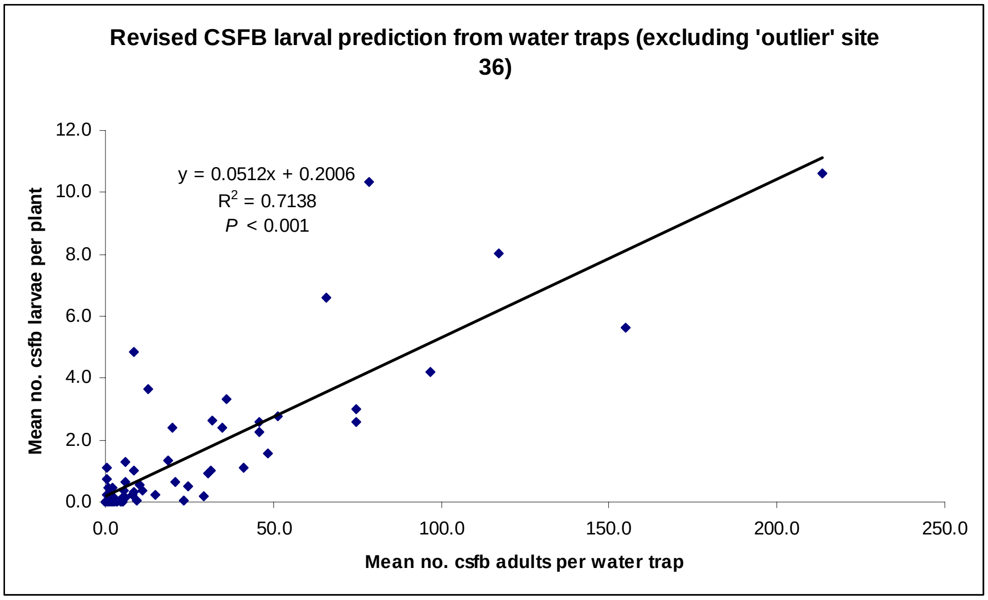
Figure 27. Regression plot for mean number of cabbage stem flea beetle larvae per plant (y axis) number against mean number of adults per water trap (x axis) for all 3 years of the study providing 71 sites in total, showing standard error bars.



In summary, combined data from the 71 sites showed that crops at risk from larval damage could be identified before the main autumn spraying period enabling an effective insecticide treatment to be applied where necessary. Numbers of larvae per plant were significantly ($P < 0.001$) correlated with mean numbers of beetles in water traps and an average catch of 36.2 (95% confidence interval between 29.8-42.6) cabbage stem flea beetle adults per water trap equated to the current economic threshold for control of two larvae per plant. The accuracy of prediction methods is considered in the next section.

Site 36 in harvest year 2006 could be regarded statistically as an 'outlier' site with a low larval infestation developing in harvest year 2006 from a high water trap catch of 60.7 per trap. There was an indication that a pyrethroid spray may have been applied to the field surrounding the area of crop used for monitoring. A regression calculation was made excluding this site which provided a small improvement in predictive value with 71.4% of the variance explained (Figure 28) with a threshold value of two larvae per plant likely to be attained from a mean of 35.1 beetles per water trap.

Figure 28. CSFB larval predictions from water trap catches all three years with one 'outlier' site 36 excluded from analysis (total 70 sites).



Accuracy of prediction methods

Infestations greater than two cabbage stem flea beetle larvae per plant were recorded at 17 sites designated by the symbol **S** in Table 12 indicating that a recommendation to treat would be made. A correct treatment decision is defined as a water trap catch exceeding the value derived from the regression equation to provide an infestation of two larvae per plant *and* if an infestation of two or more larvae per plant was subsequently recorded. The regression plot for data from all 71 sites (Figure 25) indicated two larvae per plant from a mean of 36.2 adults per water trap, with a standard error of 3.20 providing 95% confidence limit values of plus or minus 6.38 and water trap values between 29.8 - 42.6 beetles per trap. The successes of predictive methods using water trap catches averaging 36.2, 29.8 or 42.6 per trap are shown in Table 12.

Table 12. Sites with water trap catches greater or lesser than means of 36.2 (SE 3.20 providing 95% confidence interval values between 29.8 and 42.6 adults per trap (sorted by descending mean number of beetles). A correct decision to treat from water trap catches is indicated by + (spraying required for infestations exceeding 2 larvae per plant). An incorrect treatment decision from water trap catches is indicated by -. **S** indicates spray requirement for sites with > 2 larvae per plant.

Year	Site (all years code)	Mean no. csfb adults per water trap	Mean no. larvae per plant		Prediction using 36.2 beetles per trap).	Prediction using 29.8 beetles per trap	Prediction using 42.6 beetles per trap
2006	71	213.5	**10.6**	**S**	+	+	+
2006	54	154.7	**5.6**	**S**	+	+	+
2006	56	117.2	**8.0**	**S**	+	+	+
2005	35	96.7	**4.2**	**S**	+	+	+
2005	31	78.5	**10.3**	**S**	+	+	+
2006	57	74.7	**3.0**	**S**	+	+	+
2005	34	74.5	**2.6**	**S**	+	+	+
2005	47	66.0	**6.6**	**S**	+	+	+
2005	36	60.7	0.5		-	-	-
2005	29	51.5	**2.7**	**S**	+	+	+
2006	55	48.2	1.5		-	-	-
2006	60	46.0	**2.6**	**S**	+	+	+
2004	8	46.0	**2.3**	**S**	+	+	+
2006	70	41.2	1.1		-	-	+
2004	2	36.0	**3.3**	**S**	-	+	-
2005	33	35.0	**2.4**	**S**	-	+	-
2006	59	32.0	**2.6**	**S**	-	+	-
2005	32	31.2	1.0		+	-	+
2004	5	30.7	0.9		+	-	+
2004	7	29.2	0.2		+	+	+
2006	58	24.5	0.5		+	+	+
2006	69	23.2	0.1		+	+	+
2005	28	20.7	0.6		+	+	+
2006	61	20.0	**2.4**	**S**	-	-	-
2006	53	18.7	1.3		+	+	+
2006	68	15.0	0.2		+	+	+
2005	30	12.7	**3.6**	**S**	-	-	-
2004	10	11.0	0.4		+	+	+
2004	3	10.0	0.6		+	+	+
2004	6	9.5	0.1		+	+	+
2005	45	8.5	**4.9**	**S**	-	-	-
2005	52	8.5	1.0		+	+	+
2004	22	8.5	0.3		+	+	+
2004	9	8.0	0.2		+	+	+

Table 12 (continued).

Year	Site (all years code)	Mean no. csfb adults per water trap	Mean no. larvae per plant (S indicates spray need)	Prediction using 36.2 (SE 3.2 beetles per trap	Prediction using 29.8 beetles per trap	Prediction using 42.6 beetles per trap
2006	66	6.0	0.7	+	+	+
2005	40	6.0	0.2	+	+	+
2006	67	5.7	1.3	+	+	+
2004	1	5.5	0.4	+	+	+
2005	44	5.0	0.1	+	+	+
2005	51	5.0	0	+	+	+
2004	13	4.5	0	+	+	+
2005	37	3.2	0	+	+	+
2004	4	2.5	0.2	+	+	+
2004	17	2.5	0	+	+	+
2005	49	2.2	0.4	+	+	+
2004	19	2.2	0	+	+	+
2004	16	1.7	0	+	+	+
2004	25	1.5	0	+	+	+
2005	43	1.2	0.3	+	+	+
2005	39	1.2	0.2	+	+	+
2004	24	1.2	0	+	+	+
2005	46	1.0	0.4	+	+	+
2005	42	1.0	0.1	+	+	+
2006	64	1.0	0.1	+	+	+
2004	18	1.0	0	+	+	+
2004	20	1.0	0	+	+	+
2004	26	1.0	0	+	+	+
2005	41	1.0	0	+	+	+
2004	14	0.7	0	+	+	+
2004	23	0.7	0	+	+	+
2005	50	0.5	1.1	+	+	+
2006	65	0.5	0.7	+	+	+
2005	48	0.5	0.2	+	+	+
2004	15	0.5	0	+	+	+
2005	38	0.5	0	+	+	+
2006	63	0.5	0	+	+	+
2004	12	0.2	0	+	+	+
2004	27	0.2	0	+	+	+
2004	11	0	0	+	+	+
2004	21	0	0	+	+	+
2006	62	0	0	+	+	+

Sites with > 36.2 beetles per water trap

If a water trap catch of 36.2 was used to predict the need for treatment, correct decisions to spray were made at 11 of 17 sites (65% correct ‘to spray’ decisions were made) where larval infestations greater than 2 per plant developed.

Catches averaging 36.2 or more beetles per water trap were recorded at 14 sites (Table 12). Eleven of these 14 sites developed larval infestations greater than the two per plant threshold for control and all of these sites were correctly predicted for treatment using 36.2 beetles per trap. Using a predictive value of 36.2 meant that three sites (36, 55 and 70) would have been wrongly advised for spraying as larval infestations did not subsequently develop to the two per plant threshold. Site 36 developed only a low larval infestation of 0.5 larvae per plant despite a high catch averaging 60.7 adults per water trap. There was evidence that a pyrethroid spray treatment was applied to the crop surrounding the untreated monitoring area, thereby providing a plausible explanation why the infestation at this site was lower than would have been predicted.

Sites with > 29.8 beetles per water trap
If a water trap catch at the lower 95% confidence limit level of 29.8 beetles per trap was used to predict the need for treatment, correct decisions to spray were made at 14 of 17 sites (82% correct 'to spray' decisions were made) where larval infestations greater than 2 per plant developed.

If 29.8 or more beetles per water trap was used to predict the need for treatment, 19 sites were above this level and would therefore have been recommended for treatment. Fourteen of these 19 sites developed larval infestations greater than the two per plant threshold and all these sites were correctly predicted for treatment using 29.8 beetles per trap. Using a predictive value of 29.8 beetles per trap meant that five sites (5, 32, 36, 55 and 70) would have been advised for treatment unnecessarily as larval infestations remained below the two per plant spray threshold. Overall, 14 correct decisions to spray were made for the 19 sites where water trap catch averaged 29.8 or more beetles per trap. The use of 29.8 per trap meant that 5 from 19 sites (26.3%) would have been unnecessarily advised for treatment.

Sites with > 42.6 beetles per water trap
If a water trap catch of 42.6 was used to predict the need for treatment, correct decisions to spray were made at 11 of 17 sites (65% correct 'to spray' decisions were made) where larval infestations greater than two per plant developed.

If 42.6 or more beetles per water trap is used as the predictor, 13 sites were above this level and would therefore have been recommended for treatment. Eleven of these 13 sites developed larval infestations greater than the 2 per plant threshold and all these sites were correctly predicted for treatment using 42.6 beetles per trap. Using a predictive value of 42.6 beetles per trap meant that two sites (36, 55) would have been advised for treatment unnecessarily as larval infestations remained below the two per plant spray threshold.

Accuracy of decisions recommending no treatment.

Sites with < 36.2 beetles per water trap
Fewer than 36.2 beetles per trap were recorded at 57 sites. Correct decisions not to spray were made at 51 of these sites. Six sites (2, 30, 33, 45, 59, 61) developed infestations above two larvae per plant and were not predicted for spraying using 36.2 per water trap. Three of these sites (2, 33, 59) had 32, 35 and 36 beetles per trap and were therefore within 9% of the median value of 36.2 beetles per trap. Traps at sites 30, 45 and 61 caught means of 12.7, 8.5 and 20.0 beetles per trap and were well below the predictor value of 36.2 per trap. A possible explanation for the low numbers in traps was discussed for site 30 but no such explanations were forthcoming for sites 45 and 61.

Sites with < 29.8 beetles per water trap
Fewer than 29.8 beetles per trap were recorded at 52 sites. Correct decisions not to spray were made at 49 of these sites. Low water trap catches were recorded at three sites (30, 45, 61) where infestations greater than two larvae per plant developed. These sites were not predicted for spraying using 29.8 per water trap.

Sites with < 42.6 beetles per water trap
Fewer than 42.6 beetles per trap were recorded at 58 sites. Correct decisions not to spray were made at 52 of these sites. Six sites (2, 30, 33, 45, 59, 61) developed more than two larvae per plant and were not predicted for spraying using 42.6 beetles per water trap.

Accuracy of predictions for sites with more than two larvae per plant and fewer than two per plant.

Number of correct predictions for sites with two or more larvae per plant.

Regression analysis of larval numbers against mean number of beetles per water trap provided a calculated value of two larvae per plant derived from a mean of 36.2 beetles per water trap ($P < 0.001$) with a standard error of +/-3.20 providing a range of trap catches between 29.8-42.6 beetles per trap. The successes of predictive methods using water trap catches averaging 36.2, 29.8 or 42.6 beetles per trap are summarised in Tables 13 and 14.

Table 13. Sites with > 2 larvae per plant (sorted by descending larval numbers).

year	Site (all years code)	Mean no. larvae per plant	Mean no. csfb adults per water trap	Prediction using a mean of 36.2 beetles per trap	Prediction using a mean of 29.8 beetles per trap	Prediction using a mean of 42.6 beetles per trap
2006	71	10.6	213.5	+	+	+
2005	31	10.35	78.5	+	+	+
2006	56	8.05	117.3	+	+	+
2005	47	6.6	66.0	+	+	+
2006	54	5.65	154.7	+	+	+
2005	45	4.85	8.5	-	-	-
2005	35	4.2	96.7	+	+	+
2005	30	3.65	12.7	-	-	-
2004	2	3.32	36.0	-	+	-
2006	57	3.0	74.7	+	+	+
2005	29	2.75	51.5	+	+	+
2006	59	2.65	32.0	-	+	-
2005	34	2.6	74.5	+	+	+
2006	60	2.6	46.0	+	+	+
2005	33	2.4	35.0	-	+	-
2006	61	2.4	20.0	-	-	-
2004	8	2.3	46.0	+	+	+
+ correct decision				11	14	11
- wrong decision				6	3	6

A total of 17 from 71 sites (24%) developed larval infestations greater than two larvae per plant and this is assumed to be the infestation level at which treatment was justified. Five sites developed infestations greater than 5 larvae per plant; two sites developed more than 10 larvae per plant.

If the median value of 36.2 (SE 3.20) adults per trap is used to predict the need for treatment, Table 13 shows that correct treatment decisions were made at 11 from 17 sites where water trap catches exceeded 36.2 beetles per trap (65% correct decisions). Means of 32-36 beetles per trap were recorded at three sites (2, 33 and 59) and these fell just under the 36.2 per trap median value. These sites are captured if a threshold of 29.8 beetles per trap derived from the lower 95% confidence interval was used in the prediction.

Using the lower 95% confidence limit of 29.8 beetles per trap, 14 from 17 predictions for the need to treat were correct (82% correct treatment decisions).

Using the upper 95% confidence limit of 42.6 per trap gave the same result in terms of predictive success as for 36.2 beetles per trap with 11 correct ‘to spray’ decisions made for the 17 sites with two or more larvae per plant.

Table 14. Sites with < 2 larvae per plant (sorted by descending larval numbers).

Year	Site all years code	Mean no larvae per plant	Mean no. csfb adults per trap	Prediction from 36.2 per trap	Prediction from 29.8 per trap	Prediction from 42.6 per trap
2006	55	1.55	48.25	-	-	-
2006	53	1.35	18.75	+	+	+
2006	67	1.30	5.75	+	+	+
2006	70	1.10	41.25	-	-	-
2005	50	1.10	0.50	+	+	+
2005	32	1.00	31.25	+	-	+
2005	52	1.00	8.50	+	+	+
2004	5	0.92	30.75	+	-	+
2006	65	0.75	0.50	+	+	+
2005	28	0.65	20.75	+	+	+
2006	66	0.65	6.00	+	+	+
2004	3	0.56	10.00	+	+	+
2005	36	0.50	60.75	-	-	-
2006	58	0.50	24.50	+	+	+
2005	49	0.45	2.25	+	+	+
2005	46	0.45	1.00	+	+	+
2004	10	0.36	11.00	+	+	+
2004	1	0.36	5.50	+	+	+
2004	22	0.32	8.50	+	+	+
2005	43	0.30	1.25	+	+	+
2006	68	0.25	15.00	+	+	+
2005	39	0.25	1.25	+	+	+
2005	48	0.25	0.50	+	+	+
2004	9	0.24	8.00	+	+	+
2004	7	0.20	29.25	+	+	+
2004	4	0.16	2.50	+	+	+
2005	40	0.15	6.00	+	+	+
2005	44	0.15	5.00	+	+	+
2006	69	0.05	23.25	+	+	+
2005	42	0.05	1.00	+	+	+
2006	64	0.05	1.00	+	+	+
2004	6	0.04	9.50	+	+	+
2005	51	0.00	5.00	+	+	+
2004	13	0.00	4.50	+	+	+
2005	37	0.00	3.25	+	+	+
2004	17	0.00	2.50	+	+	+
2004	19	0.00	2.25	+	+	+
2004	16	0.00	1.75	+	+	+
2004	25	0.00	1.50	+	+	+
2004	24	0.00	1.25	+	+	+
2004	18	0.00	1.00	+	+	+
2004	20	0.00	1.00	+	+	+
2004	26	0.00	1.00	+	+	+
2005	41	0.00	1.00	+	+	+
2004	14	0.00	0.75	+	+	+
2004	23	0.00	0.75	+	+	+
2004	15	0.00	0.50	+	+	+
2005	38	0.00	0.50	+	+	+
2006	63	0.00	0.50	+	+	+
2004	12	0.00	0.25	+	+	+
2004	27	0.00	0.25	+	+	+
2004	11	0.00	0.00	+	+	+
2004	21	0.00	0.00	+	+	+
2006	62	0.00	0.00	+	+	+
+ correct decision				51	49	51
- wrong decision				3	5	3

At a total of 54 from 71 sites larval infestations were lower than 2 larvae per plant. Use of the calculated median value 36.2 beetles per water trap enabled 51 correct ‘no-spray’ decisions to be made from the 54 sites (94% correct decisions not to spray).

At the lower 95% confidence limit value of 29.8 beetles per trap, correct decisions not to spray were made at 49 from 54 sites, providing an overall predictive success of 91%.

At the upper 95% confidence limit value of 42.6 beetles per trap, correct decisions not to spray were made at 52 from 54 sites, providing an overall predictive success of 96%.

Summary:

Table 15 summarises the number and percentage successes for use of water trap catches for the prediction of larval infestations. For a mean of 36.2 per trap, a total of 11+51 = 62 correct ‘to spray’ or ‘not to spray’ decisions respectively were made at the 71 sites monitored (87% correct decisions). This assumed that sites would have been recommended for spray treatment where larval numbers developed to two or more larvae per plant.

At the lower (more risk averse) 95% confidence interval value of 29.8 per trap, a total of 14+49 = 63 correct ‘to spray’ or ‘not to spray’ decisions respectively were made at the 71 sites monitored (89% correct decisions). The predictive value of the method tested was therefore marginally improved if the lower confidence limit of 29.8 per trap is used as a threshold.

Using the upper 95% confidence interval value of 42.6 per trap, a total of 11+52 = 63 correct ‘to spray’ or ‘not to spray’ decisions respectively were made at the 71 sites monitored (89% correct decisions). The predictive value of the method tested was therefore similar or identical to the results obtained using means of 30 or 36.2 per trap.

Table 15. Summary of prediction accuracy of ‘to spray’ and ‘no spray required’ decisions. Percentage of correct decisions made from mean water trap catches in brackets. A total of 17 sites from 71 developed infestations of two or more larvae per plant.

Water trap threshold tested (mean no. beetles per water trap)	Total no. sites above defined water trap catch	Correct decision to spray (% of sites in brackets).	Correct decision not to spray (% of sites in brackets)	Total number of correct decisions	Total number of incorrect decisions	Overall % success of predictive method tested
>36.2	14	11 (65%)	51 (94%)	62	9	87%
>29.8	19	14 (82%)	49 (91%)	63	8	89%
>42.6	13	11 (65%)	52 (96%)	63	8	89%

Taking all decisions into account, the percentages of correct decisions to spray or not to spray were similar for the three categories of water trap catches (means of 29.8, 36.2 or 42.6 per trap). Predictive-success rates ranged from 87% for a mean of 36.2 per trap to 89% for means of 29.8 and 42.6 cabbage stem flea beetle adults per water trap.

The lower 95% confidence limit value of 29.8 per trap gave the highest success rate (82%) at predicting sites where economic damage (larval number greater than two per plant) was likely. Although the predictive value of 65% for 36.2 per trap is clearly lower than the result for 29.8 per trap (82% correct decisions to treat), the result should be put into context. Two sites recorded only marginally lower water trap catches of 35 and 36 beetles per trap with a catch averaging 32 per trap at one site. Inclusion of these sites fell would provide the same ‘to spray’ result to that obtained from 29.8 per trap.

Similar success rates between 91-96% were obtained for correct decisions not to spray from water trap catches under 36.2, 29.8 or 42.6 per trap. Use of the 29.8 per trap threshold indicated that two more sites would be recommended for treatment unnecessarily compared with the decision made from 36.2 per trap.

Larval predictions from catches in two headland-sited or two field-sited traps.

Significant regressions (*P* < 0.001) were obtained for mean numbers of beetles per water trap (4 traps) compared with mean number per headland-sited water trap (2 traps) or field-sited trap (2 traps) with 97.7% and 98.4% variance explained respectively. This suggested that, as catches were closely related, that a simplified method of prediction using only two traps might be feasible.

Headland-sited traps: The regression equation and fitted trendline indicated two larvae per plant from a mean of 32.9 beetles per headland-sited water trap with 62.2% of the variance explained and a standard error of 3.49 providing 95% confidence limits of 32.9 +/- 7.0 and values between 25.9 and 39.9 beetles per headland-sited trap (Figure 29). Fitted 95% confidence interval values are shown in Figure 30.

Figure 29. Larval predictions from two headland-sited water trap catches all three years (total 71 sites).

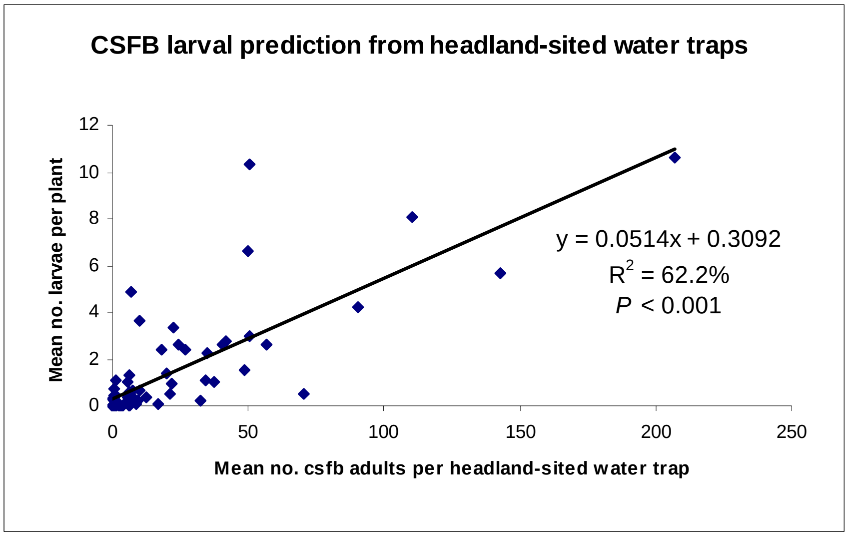
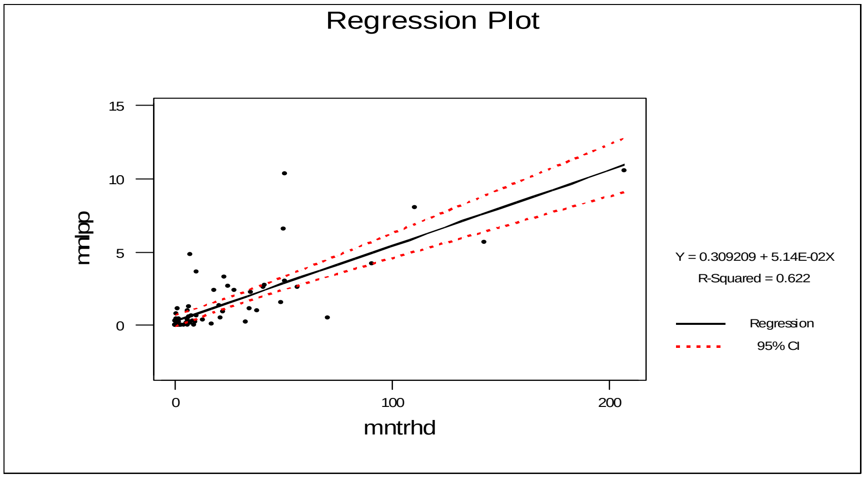


Figure 30. Regression plot for headland-sited traps for all three years (total 71 sites), showing 95% confidence intervals.



Field-sited traps: The regression equation and fitted trendline indicated two larvae per plant from a mean of 40.1 beetles per field-sited water trap with 73.2% of the variance explained and a standard error of 3.19 providing 95% confidence limits of 40.1 +/- 6.32 and values between 33.8 and 46.4 beetles per field-sited trap (Figure 31). Fitted 95% confidence interval values are shown in Figure 32.

Figure 31. Larval predictions from two field-sited water trap catches all three years (total 71 sites).

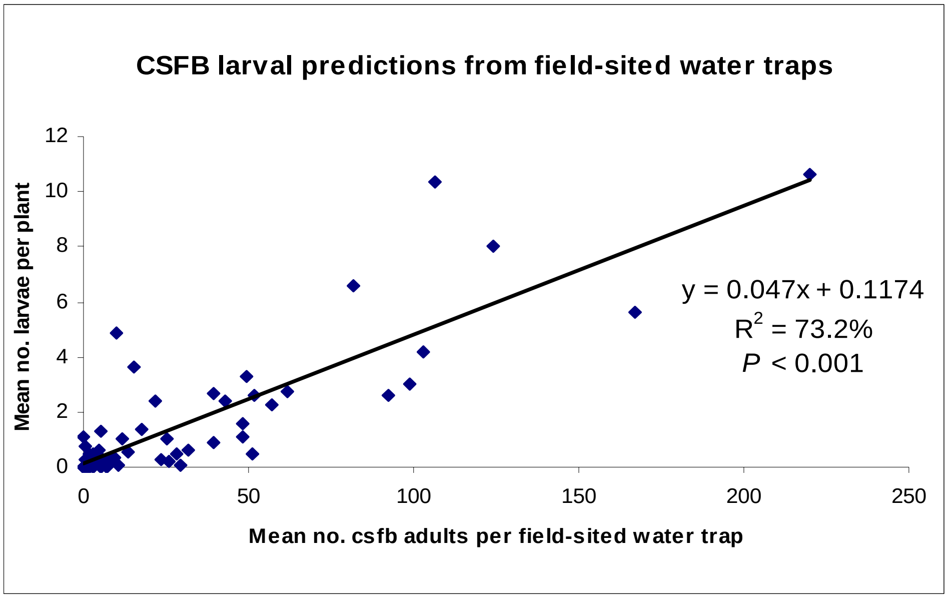
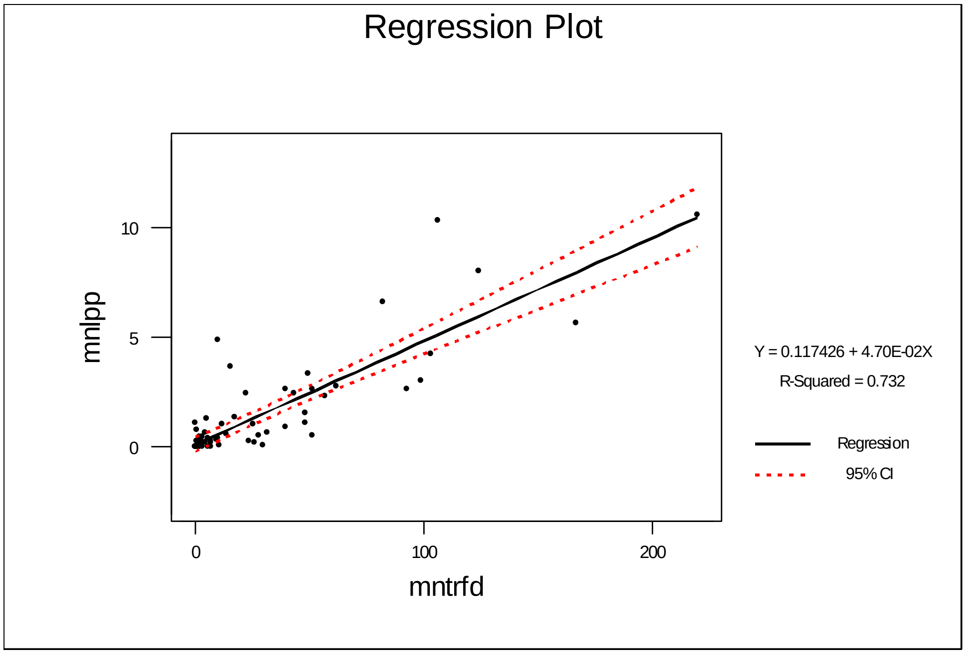


Figure 32. Regression plot for field-sited traps for all three years (71 sites) showing 95% confidence intervals.



With 73.2% of the variance explained, the use of field-sited traps offered greater potential for prediction of larval infestation than use of headland-sited traps which explained 62.2% of the variance.

Higher totals of cabbage stem flea beetle adults were recorded in field-sited traps (total 3689 for 71 sites) compared with headland-sited traps (total 2841 for 71 sites). A significant *(P* < 0.001) relationship between these variates was obtained with 92.5% of the variance explained (Figure 25). The regression equation y = 1.14x + 3.14 indicated a catch ratio of 85 beetles per headland trap compared with 100 beetles per field-sited trap.

Accuracy of predictions of larval number from headland or field-sited water traps

Headland-sited traps: Regression analysis showed that an infestation of two larvae per plant was likely from a mean of 32.9 beetles per headland-sited water trap. Larval infestations of two or more larvae per plant were recorded at 17 from 71 sites in total with 11 of these sites being correctly predicted for treatment. Six sites summarised in Table 13 developed infestations of two or more larvae per plant from water trap catches of under 32.9 (SE 3.49 with 95% confidence limit values between 25.9 and 39.9) beetles per trap. Four sites had more than 32.9 beetles per trap and fewer than two larvae per plant. Use of headland traps would therefore have indicated that 6 sites which subsequently developed larval infestations of two or more larvae per plant would not have been recommended for treatment. Four sites would have been recommended for spraying unnecessarily providing an overall correct predictive success of 61 sites from the total of 71 with 86% correct decisions made on the basis of trapping using two headland-sited water traps.

Table 16. Summary for incorrect ‘no spray’ or ‘to spray’ predictions from headland-sited traps using a mean of 32.9 cabbage stem flea beetle adults per trap.

Headland-sited traps (71 sites total)					
< 32.9 beetles per trap and > 2 larvae per plant			> 32.9 beetles per trap and < 2 larvae per plant		
Site	Beetles per trap	Larvae per plant	Site	Beetles per trap	Larvae per plant
45	7.0	4.8	70	34.5	1.1
30	10.0	3.6	32	37.5	1.0
61	18.0	2.4	55	48.5	1.6
2	22.5	3.3	36	70.0	0.5
59	24.5	2.6			
33	27.0	2.4			

Field-sited traps: Regression analysis showed that an infestation of two larvae per plant was likely from a mean of 40.1 (SE 3.19 with 95% confidence limit values between 33.8 and 46.4) beetles per field-sited water trap. Larval infestations of two or more larvae per plant were recorded at 17 from 71 sites in total with 13 of these sites being correctly predicted for treatment using field-sited traps. Four sites summarised in Table 17 developed infestations greater than two larvae per plant but where recorded water trap catches had been fewer than a mean of 40.1 beetles per trap; one of these sites (site 59) was only marginally below this figure with 39.5 beetles per trap. Use of field-sited traps would therefore have indicated that four sites which subsequently developed larval infestations of two or more larvae per plant would not have been recommended for treatment. Three sites would have been recommended for spraying unnecessarily providing an overall correct predictive success of 64 sites from 71 total with 90% correct decisions made on the basis of trapping using two field-sited water traps.

If the values are recalculated for the lower 95% confidence limit value of 33.8 beetles per water trap, site 59 shown in Table 17 would then be successfully predicted for treatment. Use of this value enabled an improvement in predictive success to be obtained with 14 from 17 sites that developed infestations greater than two larvae per plant being successfully predicted for treatment. One additional site (5) would have been recommended for spraying unnecessarily. The overall result was that predictive success using the lower confidence interval of 33.8 per trap was the same as that described for the median value of 40.1 per trap, with the result that the same numbers of correct decisions 'to treat' or 'not to treat' were taken at 64 sites from the total of 71 monitored.

Table 17. Summary for incorrect 'no spray' or 'to spray' predictions from field-sited traps using a mean of 40.1 cabbage stem flea beetle adults per trap.

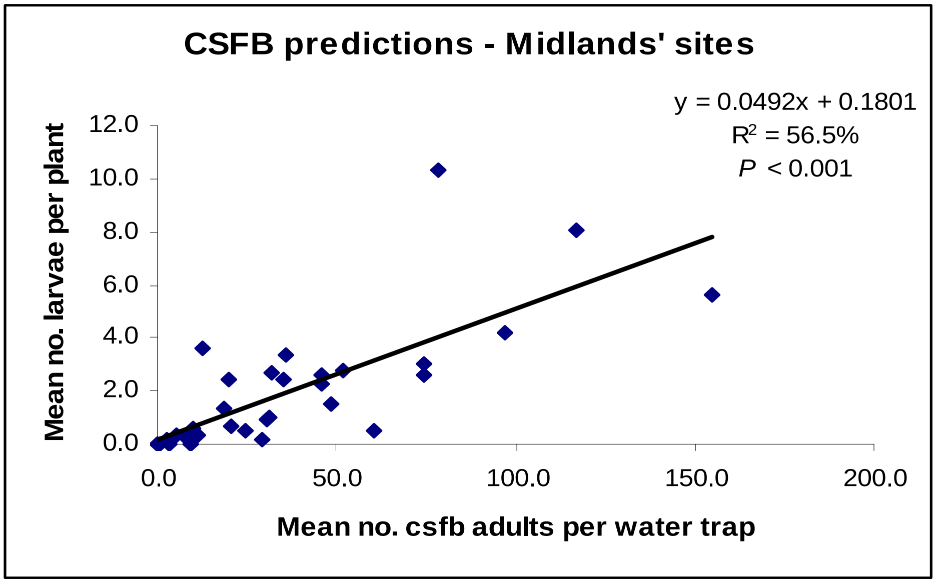
Field-sited traps (71 sites total)					
< 40.1 beetles per trap and > 2 larvae per plant			> 40.1 beetles per trap and < 2 larvae per plant		
Site	Beetles per trap	Larvae per plant	Site	Beetles per trap	Larvae per plant
45	10.0	4.85	55	48.0	1.6
30	15.5	3.65	70	48.0	1.1
61	22.0	2.4	36	51.0	0.5
59	39.5	2.65			

The accuracies of the predictions whether or not to recommend spray treatment from mean number of beetles in field-sited traps were similar to the predictive success made from mean number of cabbage stem flea beetle adults using four water traps per site. These data indicated that beetle numbers per trap using only two traps sited in the field (12 and 24 metres from the crop boundary) enabled damaging above threshold infestations to be determined.

Regional effects - data analysis by region

Midlands region: A total of 32 sites were monitored in the Midlands region (sites in Shropshire, Staffordshire, Herefordshire, Warwickshire, Leicestershire and Derbyshire) comprising 12, 11 and 9 sites in harvest years 2005, 2006 and 2007 respectively. A total of 14 from 32 sites (44% of the total) developed larval infestations greater than two larvae per plant. The incidence of threshold infestation levels was greater in this region than in eastern or northern regions.

Figure 33. Cabbage stem flea beetle larval predictions from water trap catches at 32 sites in the Midlands region in harvest years 2005-2007.



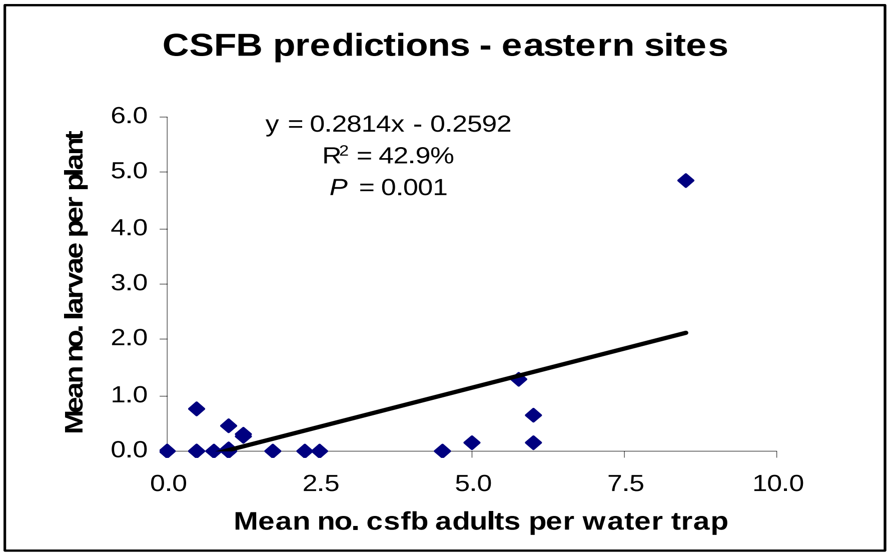
Regression analysis showed a significant (*P* < 0.001) correlation between larval numbers and number of cabbage stem flea beetle adults in water traps with 56.5% of the variance explained (Figure 33). An infestation of two larvae per plant was likely to be attained from a mean of 37.0 beetles per water trap; a similar trap catch to the median value of 36.2 beetles per trap obtained from the all sites analysis. Two sites in the Midlands (sites 30, 61) with 3.6 and 2.4 larvae per plant respectively were not successfully predicted for treatment.

There was an indication that site 30 received a pyrethroid spray at early crop emergence to the field area surrounding the unsprayed monitoring area, leading to a reduction in trap catches post spraying compared with other sites in this region in autumn 2005. The influence of this site on the regression is however quite small - If the data are re-analysed with site 30 excluded, a slightly improved R^2 value of 60.6% was obtained and regression analysis then indicated two larvae per plant from 38.9 beetles per water trap (modified plot not shown).

Eastern England

A total of 23 sites were monitored in the eastern region (sites in Cambridgeshire, Essex, Suffolk and Norfolk) comprising 9, 8 and 6 sites in harvest years 2005, 2006 and 2007 respectively (Figure 34). A total of only one from 23 sites in this region (4% of the total) developed a larval infestation greater than two larvae per plant.

Figure 34. Cabbage stem flea beetle larval predictions from water trap catches at 23 sites in Eastern England in harvest years 2005-2007.



Regression analysis showed a significant (*P* = 0.001) correlation between larval numbers and number of cabbage stem flea beetle adults in water traps but with only 42.9% of the variance explained. Two larvae per plant was likely to be attained from a mean of 8.0 beetles per water trap. The data were heavily influenced by the result from site 45 where an above threshold infestation of 4.85 larvae per plant was recorded from a low water trap catch of 8.5 per trap. At several sites, no larval infestations were recorded even where low numbers of beetles had previously been caught in water traps.

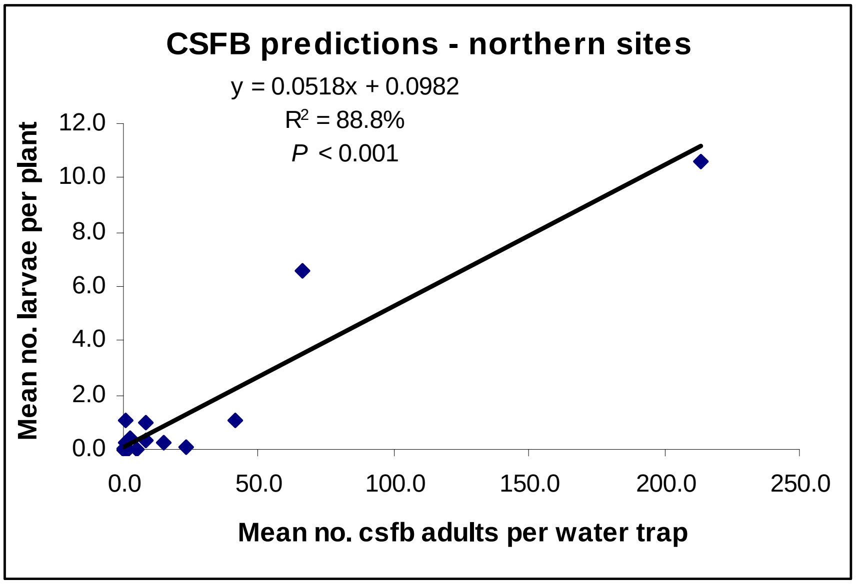
Inconclusive data were obtained from the eastern sites, probably due to the low incidence of adult numbers and larval damage at all except site 45 in Norfolk, where an infestation of 4.85 larvae per plant was recorded following a low water trap catch averaging 8.5 adults per trap. This site had the effect of greatly influencing the slope of the fitted trendline. Further site investigation produced no explanation for this unexplained result with no evidence that a spray had been applied which may have suppressed beetle catches.

Excluding site 45 from the regression calculation resulted in a prediction of two larvae per plant from a mean of 26.4 beetles per water trap (*P* = 0.035 but with only 20.4% of the variance explained) which was closer to the results obtained from larval predictions made for the Midlands' and northern regions and for the all sites analysis.

Northern England

A total of 16 sites in the northern region (sites in North and East Yorkshire) were monitored comprising 6, 6 and 4 sites in harvest years 2005, 2006 and 2007 respectively (Figure 35). A total of two from 16 sites (12.5% of the total) developed a larval infestation greater than two larvae per plant.

Figure 35. Cabbage stem flea beetle larval predictions from water trap catches at 18 sites in Northern England in harvest years 2005-2007.



Regression analysis showed a significant ($P = 0.001$) correlation between larval numbers and number of cabbage stem flea beetle adults in water traps with 88.8% of the variance explained. An infestation of two larvae per plant was likely to be attained from a mean of 36.7 beetles per water trap. This relationship was similar to those obtained from the all sites' and Midlands' sites analyses.

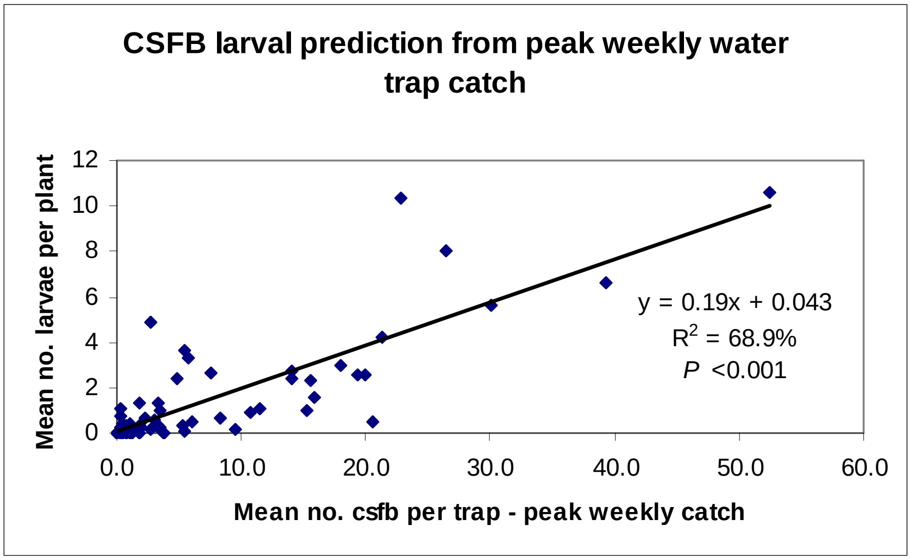
A total of two from 16 sites in northern England developed larval infestations greater than two larvae per plant. Both of these sites were sited on the Wolds in North Yorkshire. In harvest year 2006, an infestation of 6.6 larvae per plant was recorded at site 47 following a high water trap catch of 66.6 per trap. In harvest year 2007 at site 71, the highest larval infestation recorded in the three year study (mean of 10.6 larvae per plant) developed following a very high water trap catch of 213.5 beetles per trap. These sites would have been successfully predicted for treatment using water trapping results.

Data for individual regions, notably eastern England where infestations were mainly slight, should perhaps be treated with caution as relatively small numbers of sites were monitored within each regional area.

Other test predictions

Peak weekly catch of adults in water traps: Regression analysis showed a significant (P = 0.001) correlation between larval numbers and the peak weekly means for number of cabbage stem flea beetle adults per water trap with 68.9% of the variance explained (Figure 36).

Figure 36. Larval prediction from peak weekly catch (mean number of beetles per water trap).

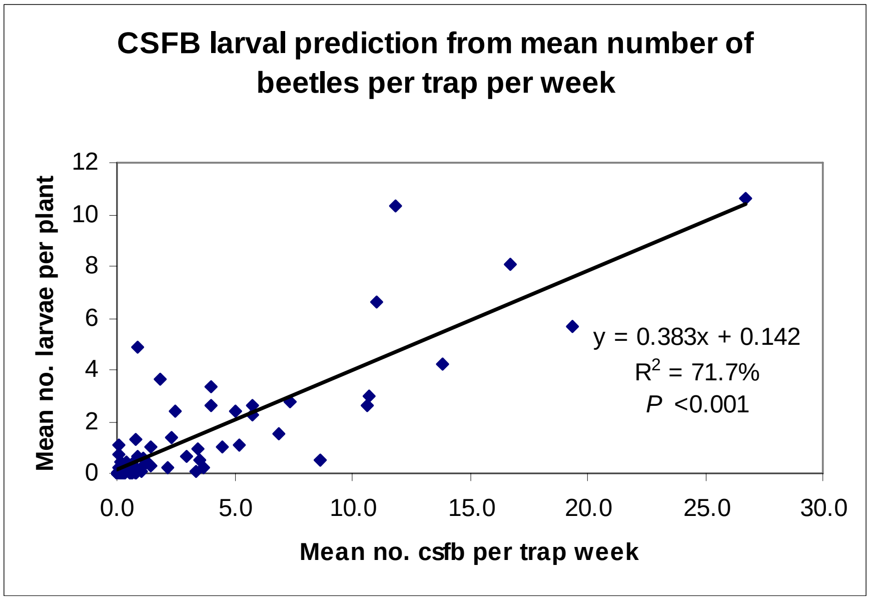


Two larvae per plant was likely to be attained if a peak weekly total of 10.3 beetles per water trap was recorded. In terms of variance explained, the prediction from peak numbers was similar to an R^2 value of 69.3% obtained from mean number of adults per trap shown earlier in Figure 26.

Although the predictive success in terms of variance explained was similar to that using mean number of beetles per trap, it is suggested that using peak trap catch data would be an unreliable predictor of damage as the peak weekly catch would be reliably known only at the end of the monitoring period. Also if traps were sited only during the early stages of crop establishment, then low trap catches might be obtained prior to a peak of activity being recorded later at the end of September or early October. If local warnings of high beetle activity were received, then it might be possible to site traps in response to these warnings so as to obtain at least some information on beetle activity prior to making a decision whether to spray or not.

Mean weekly catch of adults in water traps:
Regression analysis showed a significant (*P* = 0.001) correlation between larval numbers and number of cabbage stem flea beetle adults in water traps with 71.7% of the variance explained (Figure 37).

Figure 37. Prediction from mean weekly catch of beetles per water trap.



Two larvae per plant was likely to be attained from a mean weekly catch of 4.9 beetles per water trap per week. Although regression analysis indicates potential for this method as a predictive tool, as for peak number per trap, the value would be known with precision only at the end of the trapping period. A weekly catch greater than 4.9 beetles per trap might indicate a threshold for spraying but be followed by a reduction in beetle activity when the threshold based on mean number per trap might not be reached with spraying then unnecessary.

Effect of seed treatments

Although the study was not designed to investigate the effect of seed treatment, the agronomic details for the study sites indicated that 50 from 71 sites (70% of total) were drilled with seed treated with Chinook (imidacloprid + beta-cyfluthrin (100:100 g/l)) with 21 non-Chinook treated sites (Tables 18 and 19 respectively). The percentage of treated crops was therefore slightly greater than the 63% of crops treated in 2004 (Pesticide Usage Survey Report 202, 2004) and similar to the 68% of crops treated in 2006. The opportunity was therefore taken to examine the data for Chinook-treated and for non Chinook-treated sites. Fourteen from 50 Chinook-treated sites developed infestations greater than 2 larvae per plant. Three from 21 non-Chinook treated sites had > 2 larvae per plant.

Table 18. Chinook treated sites (descending order for mean number of beetles per water trap).

Site	Mean no. beetles per trap	Mean no. larvae per plant	Site	Mean no. beetles per trap	Mean no. larvae per plant
71	213.5	10.6	67	5.8	1.3
54	154.8	5.7	1	5.5	0.4
56	117.3	8.1	44	5.0	0.2
35	96.8	4.2	51	5.0	0.0
31	78.5	10.4	13	4.5	0.0
57	74.8	3.0	17	2.5	0.0
47	66.0	6.6	16	1.8	0.0
29	51.5	2.8	25	1.5	0.0
60	46.0	2.6	39	1.3	0.3
70	41.3	1.1	18	1.0	0.0
2	36.0	3.3	20	1.0	0.0
33	35.0	2.4	26	1.0	0.0
59	32.0	2.7	46	1.0	0.5
5	30.8	0.9	64	1.0	0.1
58	24.5	0.5	14	0.8	0.0
69	23.3	0.1	23	0.8	0.0
61	20.0	2.4	15	0.5	0.0
53	18.8	1.4	38	0.5	0.0
68	15.0	0.3	50	0.5	1.1
3	10.0	0.6	63	0.5	0.0
6	9.5	0.0	65	0.5	0.8
22	8.5	0.3	12	0.3	0.0
45	8.5	4.9	11	0.0	0.0
52	8.5	1.0	21	0.0	0.0
40	6.0	0.2	-	-	-

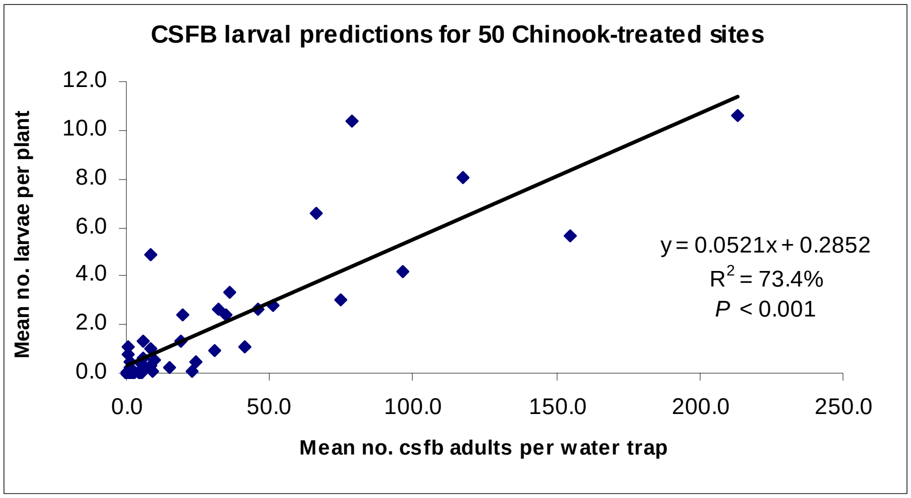
Table 19. Non-Chinook treated sites (sorted in descending order for mean number of beetles per water trap).

Site	Mean no. beetles per trap	Mean no. larvae per plant	Site	Mean no. beetles per trap	Mean no. larvae per plant
34	74.5	2.6	4	2.5	0.2
36	60.8	0.5	19	2.3	0.0
55	48.3	1.6	49	2.3	0.5
8	46.0	2.3	24	1.3	0.0
32	31.3	1.0	43	1.3	0.3
7	29.3	0.2	41	1.0	0.0
28	20.8	0.7	42	1.0	0.1
30	12.8	3.7	48	0.5	0.3
10	11.0	0.4	27	0.3	0.0
9	8.0	0.2	62	0.0	0.0
37	3.3	0.0	-	-	-

Chinook-treated sites:

The regression equation indicates a mean two larvae per plant from mean of 32.9 beetles per water trap with 73.4% of variance explained (Figure 38). The fitted trendline was therefore shown to provide a similar result to that obtained from regression analysis using all sites data.

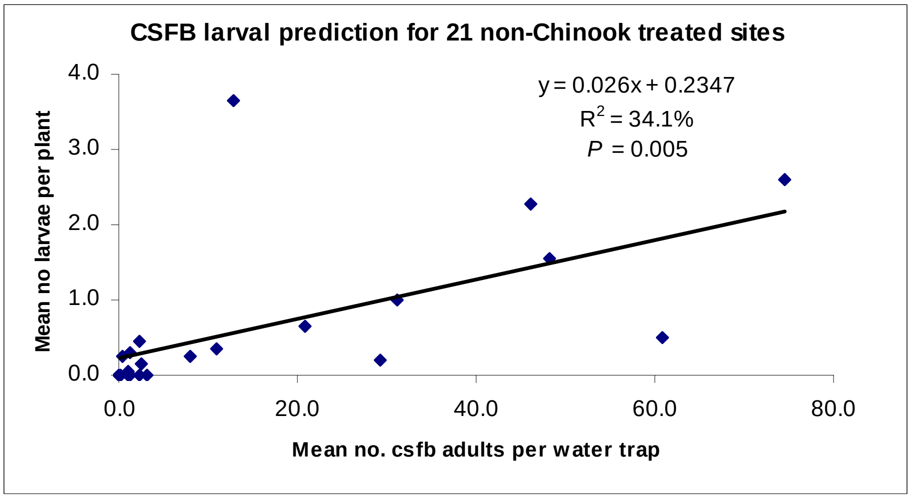
Figure 38. CSFB larval predictions from Chinook-treated sites



Sites not treated with Chinook:

The regression equation indicates a mean of two larvae per plant from mean of 67.9 beetles per water trap with only 34.1% of variance explained (Figure 39).

Figure 39. CSFB larval predictions from non-Chinook-treated sites



Predictors for larval damage for treated and non-treated sites differed with the relationship poorly defined for non-Chinook treated sites where adult and larval numbers were low at the majority of sites. Based on this analysis it is not possible to provide an explanation for the difference that was unexpected in its magnitude. The results do however indicate that much higher numbers of beetles were required at no-Chinook treated sites to result in a given level of larval damage. It is speculated that usage of seed treatment may have been lower in areas where economically-damaging attacks by cabbage stem flea beetle larvae were not expected by farmers or agronomists.

The fitted trendline shown in Figure 39 was heavily influenced by two sites (7 and 36) where substantial catches of beetles (29.3 and 60.8 per trap) were recorded but which developed only low infestations of larvae (0.2 and 0.5 larvae per plant respectively). There was an indication that the field crop surrounding the untreated sampling area at site 36 received a spray treatment but no such evidence was forthcoming for site 7. A test regression calculation without site 36 provided a fitted trendline with 45.1% of variance explained (revised plot not shown) but which still provided poorer predictive success compared with that for Chinook-treated sites. The revised calculation then showed that two larvae per plant were derived from a mean of 54.2 beetles per water trap which was still substantially higher than the prediction made for the all sites analysis.

Success of predictions of larval infestations at Chinook or non-Chinook treated sites.

From a total of 71 sites, seventeen develop larval infestations greater than two larvae per plant thereby justifying a pyrethroid spray treatment. For the Chinook-treated sites, infestations greater than two larvae per plant were present at 14 sites with this infestation level reached at only three of the non-Chinook treated sites (Table 20). Using the previously calculated mean value of 36.2 (SE 3.20) beetles per water trap, which was shown to be equivalent to two larvae per plant, provided the following summary for predictive success of sites that developed infestations greater than two larvae per plant i.e. ones which would have justified a spray treatment with a pyrethroid insecticide. The lower confidence limit value of 29.8 beetles per trap was also tested for predictive success.

Table 20. Summary for predictive success at Chinook and non-Chinook treated sites.

Seed treatment usage	Mean number of adults per water trap	Correct decision to treat (number of sites)	Overall correct decisions to treat (number of sites)	% correct decisions overall
With Chinook	>36.2 per trap	9 of 14	11/17	65%
Without Chinook	>36.2 per trap	2 of 3		
With Chinook	>29.8 per trap	12 of 14	14/17	82%
Without Chinook	>29.8 per trap	2 of 3		

Using a mean of 36.2 beetles per trap showed a predictive success of 65% for sites at which spraying was required. If the lower 95% confidence interval value of 29.8 per trap was used, the predictive success was improved to 82%. Use of this threshold value also improved the predictive success for Chinook-treated sites enabling 12 of 14 (86%) Chinook-treated sites that developed infestations greater than two larvae per plant to be predicted for treatment. The Pesticide Usage Survey Report for Arable Crops in Great Britain in 2006 (Garthwaite *et. al.* (2007) showed that 68% of the oilseed rape crop area was treated with beta-cyfluthrin + imidacloprid (Chinook) seed treatment and the predictive success is therefore likely to be typical for the majority of winter oilseed rape crops currently grown in the UK.

The reason for the poorer predictive success for non-Chinook treated sites is harder to explain, although the number of sites at which infestations greater than two larvae per plant developed were low with only three sites reaching this infestation level from the total of 21 sites that did not receive Chinook treatment. The majority of the non-Chinook treated sites showed a low incidence of larval damage and usually only small numbers of cabbage stem flea beetle were recorded in water traps.

Influence of trap size on cabbage stem flea beetle catches

At three sites in the Midlands region, (sites 54 and 57 in Shropshire and site 59 in Staffordshire) in year three of the study in autumn 2006, large rectangular yellow water traps of dimensions 30 x 40 cm were compared with round ‘standard’ yellow water traps 25 cm in diameter. Four traps of each type were sited per study field with two traps of each type on the crop headland and two traps of each type sited in the field 12 and 24 m from the field boundary. Traps were sited in crops in early September during the early stages of crop emergence. Numbers of adult cabbage stem flea beetles per trap were recorded weekly from early September to early November as summarised in Table 21.

Table 21. Total number of cabbage stem flea beetle adults caught in 25 cm round traps and 40x30 cm, large water traps at three sites in autumn 2006.

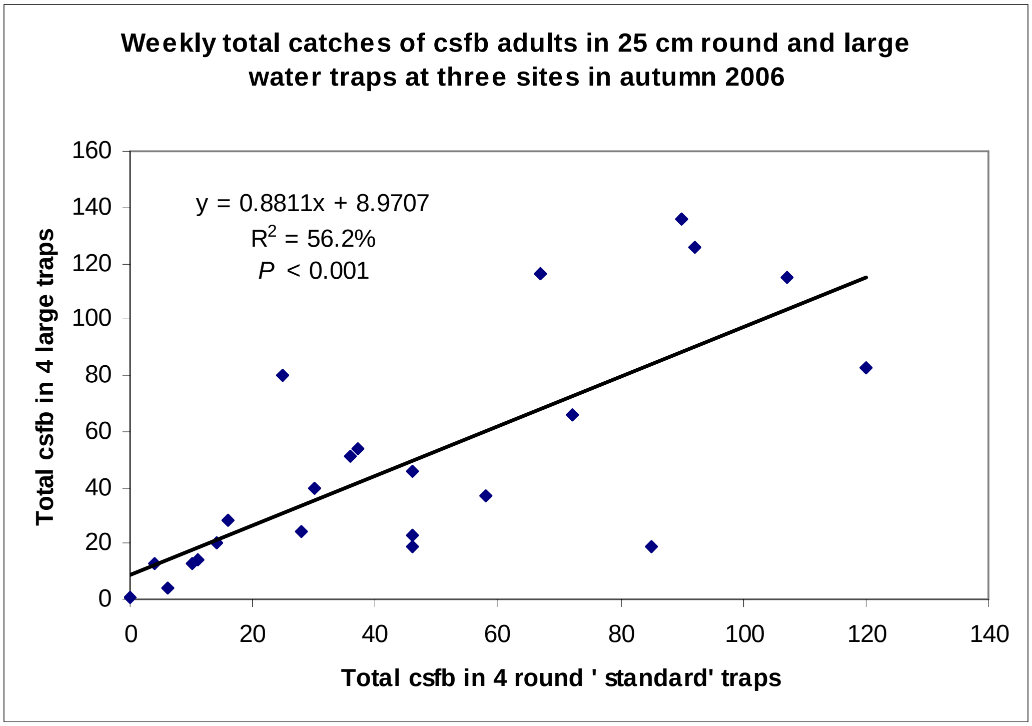
Trapping period week ending	Site 54			Site 57			Site 59		
	Crop growth stage	25 cm round	40 x 30 cm traps	Crop growth stage	25 cm round	40x30 cm traps	Crop growth stage	25 cm round	40x30 cm traps
8 Sept	1,1	67	116				1,1	4	13
15 Sept	1,2	92	126	1,2	16	28	1,2	30	40
22 Sept	1,4	120	83	1,3	72	66	1,4-1,6	25	80
29 Sept	1,4-1,6	85	19	1,4	46	19	1,6-1,8	28	24
06 Oct	1,6	58	37	1,6	46	23	1,8-1,9	14	20
14 Oct	1,6-1,8	107	115	1,6-1,8	36	51	1,8	10	13
24 Oct	1,8	90	136	1,8-1,10	37	54	1,8-1,10	11	14
02 Nov	1,8	0	1	1,8-1,10	46	46	1,8-1,10	6	4
total		619	633		299	287		128	208

At sites 54 and 57, similar total numbers of cabbage stem flea beetle adults were trapped. Totals of 619 and 633 beetles were recorded in standard and large traps respectively at site 54 with 299 in standard traps and 287 in large traps at site 57 (Table 21). These unexpectedly similar results contrasted with the results obtained at site 59, where large traps caught higher numbers of beetles (total of 208) compared with a total of 128 in the standard traps. One factor may have been that crop development was very rapid at this site providing almost complete ground cover after late September. This had the effect of partially covering the traps by crop foliage with the smaller traps being more affected than the larger traps.

Possibly as a result of greater coverage of the smaller traps by oilseed rape foliage, the large water traps at site 59 caught higher beetle numbers than the standard traps. Although the average growth stages during the autumn at site 57 were similar to those at site 59, the plant population was not so high with a resultant lower incidence of trap cover. Traps at site 54 were visible throughout the trapping period as a turnip sawfly larval infestation developed with larval feeding slowing the rate of crop development and leading to a more open canopy structure during October.

Combined data for three sites showed that total number of cabbage stem flea beetles in large traps (y axis) were significantly ($P < 0.001$) correlated with total numbers in standard traps (x axis) with 56.2% of the variance explained (Figure 40). Taking a trap catch of 36.2 beetles in a standard round trap (shown previously to be significantly related to a control threshold of two larvae per plant), a calculated value of 40.8 was likely to be obtained in a large trap.

Figure 40. Effect of trap size on weekly total catches of cabbage stem flea beetle adults in rectangular compared with round traps



Regressions for large and standard traps were tested for each of the three sites, but with only a maximum of 8 data sets per site, percentages of variance explained per site were 21.3% at site 57, 39.8% at site 54 and 46.6% at site 59.

These data tentatively suggest from a small number of sites that trap size had less influence on total catch than had been expected. The data showed that a similar or slightly higher catch per large trap would be expected compared with that obtained from standard round traps. Assuming a calculated value of 36.2 per standard trap (a water trap catch likely to result in a subsequent larval infestation of two larvae per plant), a value of 40.8 per large trap would be applicable.

As the data for trap-size comparisons were inconclusive, more sites would be required to investigate trap size more thoroughly. However, for the key objective defined at the start of this study, it was determined that ‘standard’ traps 25 cm in diameter were effective at catching cabbage stem flea beetle adults and that trap catches expressed as mean number of larvae per plant were significantly correlated with mean number of cabbage stem flea beetles per water trap.

Plant population effect

At site 56 in Shropshire and site 71 in North Yorkshire, cabbage stem flea beetle larval infestations in crop areas with a normal plant population were compared with infestations in crop areas with approximately 50% of the normal plant population. Two methods were used to achieve this. At site 56, crop areas with a naturally lower plant population were compared with normally-established crop areas. At site 71, an artificially low plant population was achieved by physically removing 50% of crop plants by hoeing at the four leaf stage. Results are summarised in Table 22.

Table 22. Mean number of cabbage stem flea beetle larvae per plant at two sites with normally-established crop areas compared with reduced plant population areas in autumn 2006.

Site	Mean number of adults per water trap	Plant population (mean number of plants/m²)	Mean number of larvae per plant	Growth stage at time of larval assessment	Mean percentage of leaves damaged by larvae
56	117.3	36.4/m²	8.1	1,10	63.9
		17.2/m²	4.3	1,10	37.3
71	213.5	49.4/m²	14.9	1,5	99.1
		21.2/m²	21.9	1,6	98.4

At both of the study sites, obvious infestations of cabbage stem flea beetle larvae developed by December following on from a very high incidence of adult beetle activity during September and October. The high totals caught at site 71 were particularly noteworthy and resulted in a marked visual effect on the crop due to heavy larval damage.

At site 56, infestation levels for cabbage stem flea beetle larvae in normally established crop areas (mean 36.4 plants/m²) were compared with infestation levels in crop areas where a low plant population had established (mean 17.2 plants/m²). Mean number of larvae per plant averaged 8.1 per plant in the normally-established plant population area compared with a mean of 4.3 larvae per plant in the low plant population area.

At site 71, infestation levels for cabbage stem flea beetle larvae in normally established crop areas (mean 49.4 plants/m²) were compared with infestation levels in crop areas where a low plant population was artificially achieved by hand removal of 50% of plants at GS 1,4 (mean 21.2 plants/m²). Mean number of larvae per plant averaged 14.9 per plant in the normally-established plant population area compared with 21.9 larvae per plant in the low plant population area.

Although these results appear conflicting, it is possible to offer reasons for the differences. At site 56, the lower plant population area developed a lower infestation of larvae compared with the infestation that developed in the normally-established plant population area. Although egg numbers in the soil were not assessed, it is possible that the more open nature of the study field in the low plant population areas proved less attractive to cabbage stem flea beetle adults in the autumn resulting in smaller totals of eggs being laid in the soil.

Ay site 71, a substantial incidence of beetle activity had been recorded in the study field prior to plant removal at the four leaf stage in late October shortly before first larval invasion was noted. As the plant population was artificially reduced as adult activity was declining, similar numbers of eggs were likely to have been laid in the two areas of crop selected for study. During the time that larvae were invading plants from early November, fewer plants remained in the low plant population areas. Assuming that similar egg numbers were present in the normal and low plant population areas, a heavier larval infestation of 21.9 larvae per plant developed in the reduced plant population area compared with an infestation of 14.9 larvae per plant in the normal area.

Discussion:

The overall objective of the study was to determine whether water or sticky trap catches of cabbage stem flea beetle adults could be used to determine the need for an autumn application of insecticide to control a subsequent larval infestation in winter oilseed rape crops. For the purposes of this study, a larval control threshold of two larvae per plant was used throughout. This value was used to calculate by regression analysis the number of adult beetles likely to result in this level of infestation. A larval control threshold of two larvae per plant was identified by Oakley & Green (2006) in a HGCA pest review to be more appropriate for winter oilseed rape crop in the UK than a previously-used threshold of five larvae per plant (for example Purvis (1986), Oakley (2003)). Underpinning this revision was the increased price for oilseed rape seed and the low cost of control using autumn-applied pyrethroid insecticide sprays, particularly where application costs are shared with tank-mixed applications of fungicide and/or herbicide. Control thresholds are not static concepts and if future crop economics dictate a revision, values obtained from the various regressions tested in this study can be recalculated.

During a period spanning three harvest years, four ground-placed, yellow, circular water traps 25 cm. in diameter were placed in commercial winter oilseed rape crops at a total of 71 sites during the early stages of emergence of winter oilseed rape drilled mainly at optimal times in late August or early September. At each site, two traps were sited 6m from the crop headland with two traps designated field-sited traps placed 12m and 24m into the crop. In autumn 2004, 2005 and 2006, monitoring was undertaken at 27, 25 and 19 sites respectively. As a number of other trap types had been tested in earlier studies, for example ground-placed, white, rectangular sticky traps were used by Alford (1979) to monitor adult cabbage stem flea beetle activity at sites in eastern England; yellow water traps have been used in Germany (Hossfeld (1993), Johnen & Meier (2000) and yellow sticky traps have been used to monitor for flea beetles *(Phyllotreta* spp.) in North America (Knodel & Olson, 2002). In autumn 2004 only, four vertically mounted sticky traps were also used to monitor cabbage stem flea beetle adult activity. The trap-catch results were compared with those obtained from water traps.

Adult cabbage stem flea beetle activity:
Infestation levels varied in the three years of the study with evidence for increased adult activity during the three years of the study. Means of 8.0, 22.9 and 44.4 adults per water trap were recorded in autumn 2004, 2005 and 2006 respectively (Figure 11). Peaks of adult activity were recorded during early October 2004 and in late September 2005 and 2006. The pattern of adult activity (Figure 12) in each of the three years of the study was similar to that described by Alford (1979) who noted that the number of adults on four crops in eastern England peaked in late September or early October and then declined. Trapping continued through the winter in Alford’s studies and it was noted that, although numbers of adults on traps fell during November, small totals of beetles continued to be recorded overwinter. Similar or slightly earlier peaks of adult activity were recorded at winter oilseed rape trial sites in 1999-2001 which showed mid to late September peaks of adult activity (Green, 2002). It can be concluded that traps should be in position in oilseed rape during the early stages of crop emergence with the objective of having traps in place in early September in advance of the main period of cabbage stem flea beetle activity in the autumn.

Larval number:
Larval infestations increased during the three years of this study. Means of 0.32, 1.75 and 2.24 larvae per plant were recorded in harvest years 2005, 2006 and 2007 respectively. Overall, a total of 17 from the total of 71 sites (24%) developed infestations greater than two larvae per plant; a threshold suggested by Oakley & Green (2006) to justify an autumn insecticide treatment likely to provide an average yield response to an autumn-applied insecticide of 0.16 t/ha. In harvest years 2005, 2006 and 2007, infestations greater than two larvae per plant were recorded at 7%, 32% and 37% of sites respectively. The highest proportion of sites with infestations greater than two larvae

per plant occurred in the Midlands where infestations greater than this value developed at 14 of 32 sites (44%), compared with only one from 23 sites (4%) in eastern England and two from 16 sites (12.5%) in northern England. In the latter area, above threshold infestations, of 6.6 and 10.6 larvae per plant, were recorded only at ADAS High Mowthorpe, North Yorkshire in harvest years 2006 and 2007 respectively. Nationally, five sites from 71 (7%) developed infestations greater than five larvae per plant, a previous control threshold used in the UK (Purvis, 1986). Two sites became heavily infested with 10.3 and 10.6 larvae per plant and such levels of infestation would be likely to cause a preventable yield loss averaging around 0.6 t/ha worth around £150 per hectare at current oilseed rape prices. These two sites had both been treated with an insecticidal seed treatment of beta-cyfluthrin + imidacloprid, confirming that substantial larval infestations can develop at higher-risk sites showing a high incidence of adult activity, despite the earlier use of an insecticidal seed treatment. The manufacturer stated in product literature that a follow-up foliar spray treatment may be justified at sites with a high and continuing incidence of adult flea beetle activity, although the species involved was not specifically mentioned.

In this study, 7% of sites developed larval numbers greater than five per plant; a higher percentage of sites than the 2% of crops (2 from 95) reported by Turner *et. al.* (2002). Although infestations of cabbage stem flea beetles are known to vary from year to year, another possible reason for the difference was that sites for the current study were selected on the basis of risk from cabbage stem flea beetle, whereas those in Turner’s survey were randomly selected. It was also noted that control strategies for pests and diseases were inadequate or unnecessary in many cases and that improved guidance, possibly through a developing Decision Support System, should improve targeting and influence the cost effectiveness of inputs. In one of the survey years (1998/99), 75% of crops were treated with an autumn-applied insecticide which indicated an imbalance between the frequency of treatment and actual pest levels. Garthwaite *et. al.* (2007) described a similar percentage of 68% of crops treated in autumn for cabbage stem flea beetle control. Many sites appeared to be routinely treated in autumn for cabbage stem flea beetle control and more reliable forecasts of the need to treat would minimise economic losses at higher-risk sites and the environmental impact of unnecessary treatments.

Predictions of larval number from water trap catches:

Plant samples were collected, usually in December, to determine the mean number of larvae per plant at each of 71 sites. This enabled larval numbers to be tested by regression analysis against numbers of adults caught in water traps. Analysis of data combined for all 71 sites produced a significant regression ($P < 0.001$) between larval number and adult numbers with 69.3% of variance explained (Figure 25). A threshold value of two larvae per plant was likely to be attained from a catch averaging 36.2 (rounded to 36) per water trap with a standard error of 3.20 and 95% confidence limits between 29.8 (rounded to 30) and 42.6 (rounded to 43) beetles per trap.

The inevitable variability of data around the calculated best-fit line indicated that adoption of a threshold of 36 beetles per water trap might occasionally result in failure to identify fields in which an autumn spray treatment was justified. A critical examination of data for individual sites showed that at three sites (2, 33 and 59), larval numbers above two per plant developed from water trap catches averaging 36.0, 35.0 and 32.0 beetles per trap respectively; therefore falling just below the median value of 36 beetles per trap derived from the regression equation. As these values were close to and within 9% of the calculated threshold, it would probably have been wise from a crop protection point of view to have included these sites for treatment. In such a borderline situation, farmers and agronomists would probably prefer to treat to minimise the risk of economic yield loss.

One site (site 36) in harvest year 2006 could be regarded statistically as an ‘outlier’ site as only a low larval infestation of 0.5 larvae per plant developing from a high water trap catch averaging 60.7 adults per trap. There was an indication that a pyrethroid spray may have been applied to the field surrounding the area of crop used for monitoring. A regression calculation was made excluding this site which provided an improvement in predictive value with 71.4% of the variance explained. Figure 28, which plots the revised regression with data for site 36 removed from the all-sites analysis, indicates that a threshold averaging two larvae per plant was likely to be attained from a mean of 35 beetles per water trap.

Analysis of predictive successes using the median, lower and upper 95% confidence interval values showed that the highest percentage of correct predictions ‘to treat’ or ‘not to treat’ were made at the lower 95% confidence limit value averaging 30 beetles per trap. For the predictive method to be of value commercially, it is essential that the monitoring method should identify not only sites where a spray treatment would be justified but also avoid the need to treat an unacceptably high proportion of sites where a control threshold was not reached. Predictions of larval number using 30 adults per water trap enabled the predictive success for sites where treatment would have been recommended (sites developing infestations greater than two larvae per plant) to be improved to 14 of 17 sites (82%) correctly identified for treatment compared with 65% of sites predicted using 36 per trap. A total of 49 of 54 sites (91%) would not have been recommended for treatment using 30 per trap, as larval numbers remained below two larvae per plant. Taking account of all sites in the study, an overall predictive success of 89% was obtained with correct decisions being taken for a total of 63 sites from the 71 monitored. Analyses of predictive successes are summarised for all sites in Tables 12-15.

Predictions based on 30 beetles per trap still failed to capture three sites that exceeded two larvae per plant from water trap catches averaging 20 or fewer. These sites remain as ‘wrong side’ errors as these sites would have justified a spray treatment but would not have been successfully predicted from water trapping using the thresholds tested. In one case, it was possible to advance a reason for the poorer than expected prediction of an above threshold infestation of 3.6 larvae per plant (site 30 in year 2 of the study) as there was an indication that an early post-emergence pyrethroid spray had been applied to the field surrounding the untreated area used for monitoring. This had the effect of reducing adult cabbage stem flea beetle activity in the field, resulting in a low mean catch of 12.7 per water trap and a different pattern of adult catches in traps compared with other sites where adults continued to be trapped.

The effect of agronomic practices also appeared to influence the predictive success of the method using water trap catches. For example, totals of cabbage stem flea beetle adults in autumn 2006 at sites 70 and 71, which were both on the same farm in North Yorkshire, indicated that treatment would be advisable at both sites. Larval assessment showed that only the earlier-drilled field (site 71, sown on 22 August) developed a larval infestation greater than two larvae per plant by the December larval sampling date. Site 70 was drilled three weeks later on 11 September and at this site, peak adult activity was recorded in water traps in early October compared with the third week of September during the early stages of crop emergence at the early-drilled site. Egg laying is therefore likely to have occurred later than at the early-drilled site with a later start of egg-hatch which is temperature-dependent. Alford (1979) commented that early-germinated crops were invaded by larvae earlier than later-germinating fields with the result that there can be considerable field to field variation for infestation levels by late autumn.

In these studies, only one sample per site was collected, usually in December, to determine the incidence of larval infestation by plant dissection. Egg hatch may continue to occur overwinter and into the spring and therefore an initial estimate of larval numbers may underestimate the final level of infestation. It is important to consider whether the predictive method is jeopardised by this, as it was possible that at some sites, larval numbers may ultimately have been higher than recorded in December. This is most likely to be the case with later-drilled crops established in September, for example as described in the previous paragraph for sites 70 and 71 during harvest year 2007.

Various types of trap have been used to monitor cabbage stem flea beetle activity. For example, Hossfeld (1993) noted that adult numbers in yellow dish traps could be used as a control threshold but commented that agronomic differences and climate would also need to be considered as a constant correlation between trap catches and later larval numbers could not be ascertained. For Schleswig-Holstein, a threshold value of 50 adults per yellow dish caught within three weeks during the main migration period was established. Numbers below this value did not result in a critical population of larvae averaging 3-5 larvae per plant and it was suggested that monitoring of adults provided a basis for the likely need for treatment.

Spray timing:
There is an extensive literature indicating a relative timing insensitivity to autumn-applied sprays for cabbage stem flea beetle control. The main difficulty is perhaps likely to arise if egg laying, prolonged by warm autumn weather, leads to a winter-hatch of larvae, particularly at later-drilled sites. However, effective reductions in larval numbers have been shown to be obtainable from treatments of pyrethroid insecticides applied in the autumn at adult or larval control timings. This effect was convincingly demonstrated by Reed & Nicholls (1984) who reported on field-based studies using alpha-cypermethrin; by Smith & Hewson (1984) using deltamethrin and by Northwood & Verrier (1986) using lambda-cyhalothrin. These studies showed average reductions in larval numbers of 83-94% from sprays applied at an adult control timing in late September or early October and 86-93% control from treatments applied during early larval invasion. Green (2001, 2002) similarly described an average 78% reduction from a single spray application made during the early stages of larval invasion. A number of reasons have been proposed to account for the wide range of timing for effective spray treatments. The pyrethroids tested were not systemic although they were strongly adsorbed onto cuticular wax. Treatment applied at adult timings kill beetles by contact action or by acting as a stomach poison if adults subsequently feed on treated foliage with the probable result that fewer eggs are laid in the soil near to oilseed rape plants. Cabbage stem flea beetle larvae have been observed to exit and re-enter infested petioles, thereby coming into contact with treated plant tissue for a lengthy period in autumn following the application of a spray treatment.

Lane & Cooper (1989) noted that, although an average reduction in larval number of 50% was obtained from a pyrethroid treatment applied in late-winter at sites where larval invasion continued overwinter, this was smaller than the control obtained from an autumn-applied spray. Purvis (1986) commented that no extra yield response was obtained from spring-applied treatment if an effective autumn-applied treatment had been made. Therefore if an autumn spray was applied on the basis of water trap catches, then this would in most cases be expected to provide control of a subsequent larval infestation even if overwinter egg hatch occurred.

Predictions from plant, cotyledon and first true leaf damage:
In the first two years of the study, assessments of adult-feeding damage were made on plants, cotyledons and first true leaves from samples collected at an average two-leaf stage. Plant damage data derived from assessments made in autumn 2004 and 2005 were combined to enable mean number of beetles per water trap to be regressed against mean number of plants and cotyledons damaged by adults. Although mean number of cabbage stem flea beetle adults in water traps were significantly ($P < 0.001$) correlated with plant and cotyledon damage, percentages of variance explained were low at 23.2% and 24.8% respectively (Figures 15 and 16). As plant samples were collected in late September during or close to the period that peak catches of adults were being recorded in water traps, the regression between mean weekly number of adults per trap against plant damage was also tested with a similar result obtained with 23.6% of the variance explained (Figure 17).

In each year, plant samples were collected mainly in December, to determine the number of cabbage stem flea beetle larvae in leaf petioles and stems. Regression analysis of the data sets obtained showed that larval damage was significantly related to plant and cotyledon damage ($P = 0.006$ and 0.017 respectively) but with only 14.0% and 10.8% of the variances explained. Overall, larval damage predictions made from plant damage assessments were weak and inconsistent, particularly in the second year of the study when slug damage complicated assessments of cotyledon and plant damage. In harvest years 2005 and 2006, the control threshold of two larvae per plant was reached at a total of ten sites. For these two years, a mean of two larvae per plant was likely if a mean of 0.65 (65%) of plants or 0.51 (51%) of cotyledons had been damaged by adult beetles. Predictive success was weak with only two sites justifying treatment being successfully predicted from plant or cotyledon damage. Predictions of larval number from damage to first true leaves was weaker and non significant ($P = 0.334$) with only 1.5% of the variance explained with no value as a predictive method as no sites were successfully predicted for treatment.

Guidelines for the control of adult cabbage stem flea beetle are imprecise and poorly defined. Judgements on the need for control must consider not only the infestation level but also the plant population, rate of crop development and the balance between the rate of feeding damage and the rate of production of new leaves. Typically, control measures would be recommended if 25% or more leaf area loss occurred at the 1-2 leaf stage or if significant plant loss was occurring (Oakley, 2003). It is therefore likely that the more severely damaged crops, irrespective of the subsequent incidence of larval infestation, would be recommended for a pyrethroid spray treatment, usually if an insecticidal seed treatment had not been applied.

Predictions from sticky traps:
During the first year of the study in autumn 2004, four yellow sticky traps were compared with water traps as predictive methods to determine larval infestations at 27 sites. Sticky traps caught fewer cabbage stem flea beetles than water traps with a mean of 1.3 per sticky trap compared with a mean of 8.0 per water trap (Figure 13). A significant regression was obtained ($P < 0.001$) with 51.0% of variance explained with two larvae per plant likely to be attained from a mean of 5.7 beetles per sticky trap. However, the use of sticky traps provided a poor predictive method compared with water traps and the method tested did not predict the two sites in 2004 where above threshold numbers of larvae developed. The much lower numbers of beetles on sticky traps and poorer significance values for tested regressions, compared with those for water trap analyses, indicated that water traps provided a more robust predictor of larval damage and the need for treatment where justified.

Trap size:
In the final year of the study in harvest year 2007, large rectangular yellow water traps with an area of 1200 cm^2 were compared with round, yellow ('standard') water traps of area 491 cm^2 at three sites in the Midlands. Total numbers of cabbage stem flea beetle adults recorded during the autumn were similar at two sites where totals of 619 and 633 beetles were recorded in 'standard' and large traps respectively at site 54, and 299 and 287 beetles respectively at site 57. At a third site (59), a different result was obtained, with large traps catching a total of 208 adults compared with 128 in the 'standard' traps. Possibly as a result of greater coverage of the smaller traps by oilseed rape foliage, the large water traps at site 59 caught higher beetle numbers than the standard traps. Although the average growth stages during the autumn at site 57 were similar during the autumn to those at site 59, the plant population was not so high with a resultant lower incidence of trap shading. Traps at site 54 were visible throughout the trapping period as a turnip sawfly (*Athalia rosae)* larval infestation developed with larval feeding slowing the rate of crop development and leading to a more open canopy structure during October.

Although not specifically mentioning cabbage stem flea beetle, Finch (1990) indicated that the area of fluorescent-yellow water traps involved with catching cabbage root fly (*Delia radicum)* was effectively twice the surface area of the water. Some species differences were observed but it is not known whether such differences would apply also to cabbage stem flea beetle. As the data for trap-size comparisons were inconclusive in the current study, more sites would be required to investigate trap size more rigorously. However, for the key objective of predicting larval number from water trap catches, it was determined that 'standard' traps 25 cm in diameter were effective at catching cabbage stem flea beetle adults and that trap catches expressed as mean number of larvae per plant were significantly correlated with mean number of beetles per water trap. Differences in water trap area had an unexpectedly small effect on total beetle catches at two of the three sites studied. The data indicated that a similar or slightly higher catch per large trap would be applicable compared with a standard round trap if the traps were shaded by crop foliage.

One drawback in the field from the use of large versus standard traps was the greater amount of time required to check and re-set the larger traps which required approximately 25 litres of water to replenish four traps per site, compared with only six litres of water to replenish four smaller traps.

Plant population effect on larval infestation:
It has sometimes been speculated that crops with low plant populations are inherently more sensitive to the effects of pest damage compared with crops with optimum plant populations, although the effect of autumn-feeding pests such as cabbage stem flea beetle in crops with different plant populations has not been clearly defined. In the final year of the study, two sites with evidence of a high incidence of adult activity were selected with one site in Shropshire (site 56) and one in North Yorkshire (site 71). From plant samples collected in December, cabbage stem flea beetle larval infestations in crop areas with normally-established plant populations were compared with infestations in crop areas with approximately 50% of the normal plant population. Two methods were used to achieve this. At site 56, crop areas with a naturally lower plant population were compared with normally-established crop areas. At site 71, an artificially low plant population was achieved by physically removing 50% of crop plants at the four leaf stage.

At the site where the reduced plant population was achieved artificially by plant removal, a higher infestation of 21.9 larvae per plant was recorded in the low plant population area (21.2 plants/m^2) compared with 14.9 larvae per plant in the area with a normal plant population (49.4 plants/m^2). At the site with a naturally low plant population in the area of the field selected for study, a lower infestation of larvae averaging 4.3 per plant was recorded in the low plant population area (mean 17.2 plants/m^2) compared with 8.1 larvae per plant where the mean plant population was 36.4/m^2. Although egg numbers in the soil were not assessed, it is possible that the more open nature of the crop in the low plant population area proved less attractive to cabbage stem flea beetle adults during the autumn egg-laying period, resulting in smaller numbers of eggs being laid in the soil close to oilseed rape plants. Alternatively, the difference could be due to higher egg or larval mortality in the area with a naturally low plant population.

A substantial incidence of beetle activity had been recorded in the study field (site 71) prior to plant removal at the four leaf stage in October, shortly before first larval invasion was noted. As the plant population was artificially reduced when adult activity was declining, similar numbers of eggs seem likely to have been laid in the two areas of crop selected for study. During the time that larvae were invading plants from early November, fewer plants remained in the low plant population areas. As similar egg numbers were probably present in the normal and low plant population areas, a heavier larval infestation was able to develop in the reduced plant population area. Such an effect might be agronomically important if plants were lost post-emergence, perhaps due to slug or woodpigeon damage, at sites showing an obvious incidence of adult cabbage stem flea beetle during the crop establishment period. Such an aspect could be investigated further if provision was made to assess egg numbers in the soil as well as the final infestation incidence of larvae per plant. Plant growth stage also differed in the two crops studied. At the time of larval assessment in December, the crop at site 56 was at an average ten leaf stage whereas that at site 71 in northern England was at the 5-6 leaf stage.

Conclusion:
The overall conclusion from this study was that monitoring for adult activity using water traps enabled an assessment of the risk of larval damage to be made in time for application of autumn-applied insecticide where needed. As this information would be available in or by mid-late October, it enables any necessary spray treatments to be applied in autumn during favourable spraying conditions, possibly as convenient tank mixes with autumn-applied herbicides and/or fungicides. Many of these tend to be applied in mid-late October before field conditions deteriorate making access for spraying difficult. Although previous studies have indicated a relative insensitivity to spray timing, it is considered important to treat before large (third instar) larvae burrow deeply within plant stems to overwinter. As with most studies of this type, some caveats need to be included as at some sites larval infestations justifying control were recorded, despite lower than

threshold catches of adults in water traps. Although inconvenient, it would be prudent if such a situation was suspected, to undertake a subsequent check for larvae in leaves or to undertake a leaf scarring check before deciding on the need for treatment.

Pesticide Usage Surveys (Garthwaite *et. al.* (2003, 2005, 2007) indicated that the majority of winter oilseed rape crops received an autumn pyrethroid insecticide treatment, often applied as, or almost as routine and in many cases as a follow-up to insecticidal seed treatment based on beta-cyfluthrin + imidacloprid. In addition to control of cabbage stem flea beetle, pyrethroid sprays are also applied during the autumn to control aphids such as peach-potato aphid *(Myzus persicae)* which is the main vector of Beet Western Yellows Virus (BWYV) and autumn pests such as rape winter stem weevil *(Ceutorhynchus picitarsis).* Despite the many reasons underpinning autumn spray treatments on winter oilseed rape, a more reliable and easy to use method of forecasting the need for control of cabbage stem flea beetle was considered useful for example in a HGCA-commissioned review of oilseed rape pests published by Alford *et. al.* (2001). Development of a targeted rather than routine approach to cabbage stem flea beetle control using autumn-applied insecticides was perceived as useful for both economic and environmental reasons.

This study investigated and tested a number of relationships between cabbage stem flea beetle larval number against plant, cotyledon and first true leaf damage and against catches of adult beetles in water and on sticky traps. The most reliable predictor of larval damage was obtained from catches of cabbage stem flea beetle adults in water traps. This study based the need for control on an action threshold of two larvae per plant as determined by Oakley & Green (2006) having been re-evaluated from a previous threshold applied in the UK averaging five larvae per plant (Purvis, 1986). A control threshold value of two larvae per plant was likely to be attained from water trap catches averaging between 30 and 36 beetles per water trap which can more conveniently be expressed as 30-35 beetles per trap to facilitate use by agronomists and farmers.

Control thresholds are susceptible to market forces and need revision if crop profitability changes due to changes in seed prices and costs of crop protection inputs. If appropriate values for larval number are substituted into the regression equation obtained from the all-71 sites analysis, two larvae per plant were likely to be attained from a median value of 36 adults per water trap. By way of example, means of three and five larvae per plant would be derived from catches averaging around 56 and 96 respectively.

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Appendix A. Cropping year 2004/2005, site locations and cropping details (27 sites).

Site code		Area	County	Location	Drilling date (2004)	Chinook + or -
Year code	All years site code					
1	1	M	Staffs.	Codsall	31 Aug.	+
2	2	M	Staffs.	Perton	28 Aug.	+
3	3	M	Staffs.	Brewood	2 Sept.	+
4	4	M	Shrops.	Upton Magna	1 Sept.	-
5	5	M	Shrops.	Much Wenlock	28 Aug.	+
6	6	M	Shrops.	Billingsley	8 Sept.	+
7	7	M	Staffs.	Wigginton	2 Sept.	-
8	8	M	Staffs.	Clifton Campville	6 Sept.	-
9	9	M	Leics.	Stretton	6 Sept.	-
10	10	M	Derbs.	Cauldwell	2 Sept.	-
11	11	M	Herefords.	Rosemaund 1	2 Sept.	+
12	12	M	Herefords.	Rosemaund 2	3 Sept.	+
13	13	E	Cambs.	Boxworth Grange Piece	2 Sept.	+
14	14	E	Cambs.	Boxworth Long Field	3 Sept.	+
15	15	E	Essex	Thaxted	31 Aug	+
16	16	E	Essex	Shalford	1 Sept.	+
17	17	E	Suffolk	Boxford	28 Aug.	+
18	18	E	Suffolk	Clare	29 Aug.	+
19	19	E	Essex	Steeple Bumpstead	30 Aug.	-
20	20	E	Lincs.	Pinchbeck	4 Sept.	+
21	21	E	Norfolk	Terrington	5 Sept.	+
22	22	N	Yorks.	High Mowthorpe	1 Sept.	+
23	23	N	Yorks.	Beeford	1 Sept.	+
24	24	N	Yorks.	Beltoft	29 Aug.	-
25	25	N	Yorks.	Hayton	31 Aug.	+
26	26	N	Yorks.	Lund	1 Sept.	+
27	27	N	Yorks.	Thirsk	2 Sept.	-

M: Midlands
E: Eastern England
N: Northern England

Appendix B. Cropping year 2005/2006, site locations and cropping details (25 sites).

Site code		Area	County	Location	cv	Drilling date	Chinook + or -
Year code	All years site code						
1	28	M	Staffs.	Perton	Winner	31 Aug.	-
2	29	M	Shrops.	Boningale	Castille	28 Aug.	+
3	30	M	Shrops.	Upton Magna	Royal	21 Aug.	-
4	31	M	Shrops.	Much Wenlock	Castille	22 Aug.	+
5	32	M	Staffs.	Brewood	Winner	25 Aug.	-
6	33	M	Shrops.	Billingsley	Castille	5 Sept.	+
7	34	M	Staffs.	Clifton Campville	Lioness	31 Aug.	-
8	35	M	Staffs.	Wigginton	Expert	29 Aug.	+
9	36	M	Warks.	Polesworth	Expert	1 Sept.	-
10	37	M	Leics.	Chilcote	Recital	5 Aug.	-
11	38	M	Herefords.	Rosemaund	NK Bravour	4 Sept.	+
12	39	E	Cambs.	Boxworth Pamplins	Winner	2 Sept.	+
13	40	E	Cambs.	Boxworth Whitepits	Winner	2 Sept.	+
14	41	E	Essex	Steeple Bumpstead	Es Astrid	31 Aug.	-
15	42	E	Essex	Thaxted	Castille	26 Aug.	-
16	43	E	Suffolk	Clare	Winner	8 Sept.	-
17	44	E	Suffolk	Boxford	Winner	15 Aug.	+
18	45	E	Norfolk	Terrington Pits	Labrador	21 Aug.	+
19	46	E	Norfolk	Terrington Bullock Rd	Winner	7 Sept.	+
20	47	N	Yorks	High Mowthorpe	Pollen	1 Sept.	+
21	48	N	Yorks.	Thirkleby	Winner	8 Sept.	-
22	49	N	Yorks.	Thirsk	Winner	1 Sept.	-
23	50	N	Yorks.	Beeford	Castille	24 Aug.	+
24	51	N	Yorks.	Beverley	Royal	8 Sept.	+
25	52	N	Yorks.	Kiplingcotes	Expert	1 Sept.	+

M: Midlands
E: Eastern England
N: Northern England

Appendix C. Cropping year 2006/2007 site locations and cropping details (19 sites).

Site code		Area	County	Location	cv	Drilling date	Chinook + or -
Year code	All years site code						
1	53	M	Staffs.	Perton	Castille	23 Aug.	+
2	54	M	Shrops.	Boningale	Lioness	23 Aug.	+
3	55	M	Shrops.	Upton Magna	Castille	19 Aug.	-
4	56	M	Shrops.	Much Wenlock Barn Field	Castille	23 Aug.	+
5	57	M	Shrops.	Much Wenlock Lays Field	Castille	23 Aug.	+
6	58	M	Shrops.	Billingsley	Castille	28 Aug.	+
7	59	M	Staffs.	Brewood (Oakley west)	Castille	20 Aug.	+
8	60	M	Staffs.	Brewood (Oakley east)	Castille	20 Aug.	+
9	61	M	Staffs.	Kiddemore Green	Castille	25 Aug.	+
10	62	E	Cambs.	Knapwell	Expert	5 Aug.*	-
11	63	E	Cambs.	Boxworth Sampsons East	Winner	4 Sept.	+
12	64	E	Cambs.	Boxworth Childerley Field	Winner	30 Aug.	+
13	65	E	Cambs.	Boxworth Extra Close Field	Winner	29 Aug.	+
14	66	E	Norfolk	Terrington Propagation Field	Winner	11 Sept.	+
15	67	E	Norfolk	Terrington Tebbs North	Lioness	9 Sept.	+
16	68	N	Yorks.	Beeford	Royal	10 Sept.	+
17	69	N	Yorks.	Beverley	Royal	8 Sept.	+
18	70	N	North Yorks.	High Mowthorpe Crow Tree Field	Bravour	11 Sept.	+
19	71	N	North Yorks.	High Mowthorpe Old Type Field	Bravour	22 Aug.	+

* broadcast crop (Autocast) on which Chinook seed treatment is not permitted.
M: Midlands
E: Eastern England
N: Northern England