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Autumn survey of wheat bulb fly incidence 2023

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1. Abstract

Wheat bulb fly (WBF) is potentially one of the most serious pests of wheat in the UK. It is most prevalent in the east and north east of England. However, its numbers vary annually so the main aim of this project is to predict the risk for the 2023/24 season.

The specific objectives of the project are:

1. To measure the incidence of wheat bulb fly in autumn 2023 in the east and north east of England.
2. To forecast the need for seed treatment in autumn 2023.
3. To test the model for prediction of WBF risk.

A total of 30 fields were sampled for WBF eggs in September 2023 in areas prone to the pest, with 15 in the east of England and 15 in the north east of England. The sites were chosen to represent some of the main preceding crops, leading to a risk of WBF damage in each area.

For crops sown in September and October the damage threshold (the egg population that might be expected to have an economic impact on yield) is 250 eggs/m² (2.5 million eggs/ha, Gough *et al.*, 1961). In autumn 2023, two of the sampled fields was considered at high risk (egg numbers 250-500/m^2), seven at moderate risk (egg numbers 100-249/m^2) and 21 at low risk (egg numbers <100/m^2). This was equivalent to 7%, 23% and 70% of fields in the high, moderate and low risk infestation categories respectively. Therefore, 7% of sites had egg numbers above the 250 eggs/m^2 threshold for crops sown in September and October. Since 1984 the proportion of sites sampled with egg numbers above 250/m^2 (7%) has only been lower than in 2023 on eight occasions. It is possible that the wheat harvest in 2023 was sufficiently rapid to limit the development of saprophytic fungi in cereal ears, which would result in limited food for adult WBF females and low numbers of eggs being laid.

Late-sown (November onwards) or slow developing crops are at greater risk from WBF than those that are early sown (September/October) due to slower tiller development. As a result, a lower threshold of 100 eggs/m^2, or 1 million eggs/ha is applicable for these crops. In the east of England 33% of sites were above this level and in the north east it was 27%. All fields in the moderate category or above would benefit from a seed treatment if sown from November onwards. Crops sown between January and March would benefit from a seed treatment if any WBF eggs are found.

In 2022, 2021 and 2020, samples taken from organic soils had a much higher mean egg count than the samples from mineral soils. The mean egg count for the previous three years is as

follows; 2022 (organic 81/m^2, mineral 23/m^2), 2021 (organic 236/m^2, mineral 36/m^2) and 2020 (organic 306/m^2, mineral 21/m^2). Although this trend was repeated in 2023 the difference between the two soil types was much less marked with a mean of 83 eggs/m^2 in organic soil (eight samples), compared with 80 eggs/m^2 in mineral soils (seven samples). Therefore, the potential for WBF damage in eastern England in organic and mineral soils is similar.

Average egg numbers in were higher in the east (81 eggs/m^2) than in the north east (72 eggs/m^2). Over all sites, the highest risk was after sugar beet with a mean of 140 eggs/m^2. The next highest risk was after seed potatoes with 73 eggs/m^2.

The model for predicting WBF risk showed that predicted egg counts for the east and north east combined showed poor correlation with mean egg counts (east and north east regions combined) from soil analysis of all 30 sites sampled. Predicted egg counts for individual regions were also poorly correlated with soil counts of eggs for the same areas.

2. Introduction

All cereals except oats can be attacked by wheat bulb fly (WBF, Gratwick, 1992). Eggs are laid in late summer in bare soil following fallows or early harvested crops, such as vining peas, particularly if fields are cultivated between mid-July and mid-August. Fields cropped with root crops, such as sugar beet, potatoes and onions, are also favoured as egg-laying sites as the pest is able to access bare soil between the rows (AHDB, 2016). The pest is most prevalent in the east and north east of England. In outbreak years, widespread damage can occur.

Eggs are laid in late July and August in England and up to mid-September in Scotland. The eggs remain dormant throughout late autumn and early winter until the larvae hatch between January and March. Soon after hatching, the larvae invade the shoots of cereal crops which wither or become yellow and stunted. These symptoms are known as ‘deadhearts’.

The level of WBF risk each year fluctuates greatly, although differences between years have been less marked since 2012. Young & Cochrane (1993) suggest that this is due mainly to July and August rainfall and the harvest dates of the previous wheat crops. The longer crops remain in the ground, the longer adult flies have to feed on saprophytic fungi within the cereal ears and mature their eggs. Incidence generally increases following a wet harvest period, such as in 2004, and is lowest after a hot, dry summer, such as in 1995. The proportion of fields having an egg count greater than the 250 eggs/m^2 damage threshold (the egg population that might be expected to have an economic impact on yield) ranged from 3% to 44% in the period 1984–1999 (Oakley & Young, 2000) and from 0% to 50% between 2000 and 2021 (Figure 1).

Egg numbers can be estimated by soil sampling and related to damage threshold levels of 250 eggs/m² (2.5 million eggs/ha) for crops sown in September or October, or 100 eggs/m² (1.0 million eggs/ha) for crops sown from November onwards. At lower infestation levels economic damage is less likely. Although winter cereal crops sown from November onwards, or those sown in spring before the end of March, can be particularly vulnerable. Larvae attack shoots of wheat, barley and rye from January to April, with yield loss depending on tiller density at the time of attack. Crops still at the single shoot stage in February are most vulnerable and may be completely destroyed (Young, 2000). Yield losses of up to about 4 t/ha have been recorded following severe damage (Young & Ellis, 1996).

The options for control of WBF have been reduced by pesticide reviews and withdrawals and are currently limited to a cypermethrin seed treatment (Signal 300 ES). Seed treatment is the most effective option for late-sown crops, for example those at risk following potatoes, sugar beet, onions or red beet. Young (1992) demonstrated that November and December drillings of winter wheat were more vulnerable to WBF damage than earlier sowings and are therefore more likely to benefit from the use of a preventive insecticidal seed treatment.

The overall objective of the autumn survey of wheat bulb fly incidence is to establish the annual incidence of WBF in autumn 2023, and the risk of subsequent damage and to test the model for prediction of WBF risk.

The specific objectives of the project are:

1. To measure the incidence of wheat bulb fly in autumn 2023 in the east and north east of England.
2. To forecast the need for seed treatment in autumn 2023.
3. To test the model for prediction of WBF risk.

3. Materials and methods

A total of 30 fields were sampled in September 2023 in areas prone to WBF, with 15 in the east of England and 15 in the north east of England (Table 1). The survey was stratified to represent some of the main preceding crops (Table 2) leading to a risk of WBF damage in each area.

For each field sampled, 32 cores each of 7.2 cm diameter (Cambridgeshire and Norfolk sites) or 20 cores each of 10 cm diameter (East and North Yorkshire sites) were taken to cultivation depth.

Fields were sampled in a standard W sampling pattern. The difference in number of cores taken was to take account of the different size diameter of corer used for the east and north east sites. WBF eggs were extracted following soil washing and flotation in saturated magnesium sulphate. Egg numbers were expressed as number of eggs per m².

Table 1. Location of sampling sites, by region and county.

Region	County	Number of fields sampled
Eastern England	Cambridgeshire	8
	Norfolk	7
	Total	15
Northern England	East Yorkshire	12
	North Yorkshire	3
	Total	15

Table 2. Preceding crop for sampled fields.

Preceding crop	Eastern England	Northern England
Dwarf beans	1	0
Onions	2	0
Potatoes	2	1
Potatoes (seed)	0	4
Red beet	2	0
Spring beans	1	0
Sugar beet	7	0
Vining peas	0	10
Winter beans	0	0
Total	15	15

A predictive model was used that was developed in a previous AHDB project (Leybourne *et al.*, 2020, 2022) to predict WBF risk for each region in the UK, which has been shown to have a predictive power of 70% (11% greater than that of the previous Young and Cochrane model) (Young & Cochrane, 1993). The model uses egg counts and meteorological data to make its predictions of egg counts. Egg number data was extracted from two sources, historic data from East Anglia extracted from the study by Young and Cochrane (1993), and results from the AHDB Autumn survey of wheat bulb fly incidence (2005-2019). The model was run using the data set (meteorological data and egg counts) available when it was first developed (up to 2019), and an updated model that included meteorological data and egg counts gathered in the interim years from 2019-2022 was also used. The model was also run to make predictions specifically for the eastern and north eastern regions using only meteorological data and egg counts available for these regions to determine if this improved predictive power.

4. Results

In autumn 2023, two of the sampled fields was considered at high risk (egg numbers 250-500/m^2), seven at moderate risk (egg numbers 100-249/m^2) and 21 at low risk (egg numbers <100/m^2). This was equivalent to 7%, 23% and 70% of fields in the high, moderate and low risk infestation categories respectively. A total of 7% of sites had egg numbers above the 250 eggs/m^2 threshold for crops sown in September and October (Figure 1). In total 9 of 30 sites sampled (30%) had egg numbers above 100 eggs/m^2. Since 1984 the overall risk has been higher than 2023 on 30 occasions and lower than 2023 on eight occasions and equal to 2023 on one occasion.

Average egg numbers in the east of England were 81/m^2 which is higher than in the north east of England where 72/m^2 were recorded (Figure 2). Over all sites, the highest risk was after sugar beet with a mean of 140 eggs/m^2. The next highest risk was after seed potatoes with 73 eggs/m^2. The three highest individual counts were all after sugar beet. These were 370 eggs/m^2 in organic soil in Cambridgeshire, 254 eggs/m^2 in mineral soil in Norfolk and 158 eggs/m^2 in mineral soil in Norfolk. The highest egg count not after sugar beet was in potatoes in mineral soil in North Yorkshire.

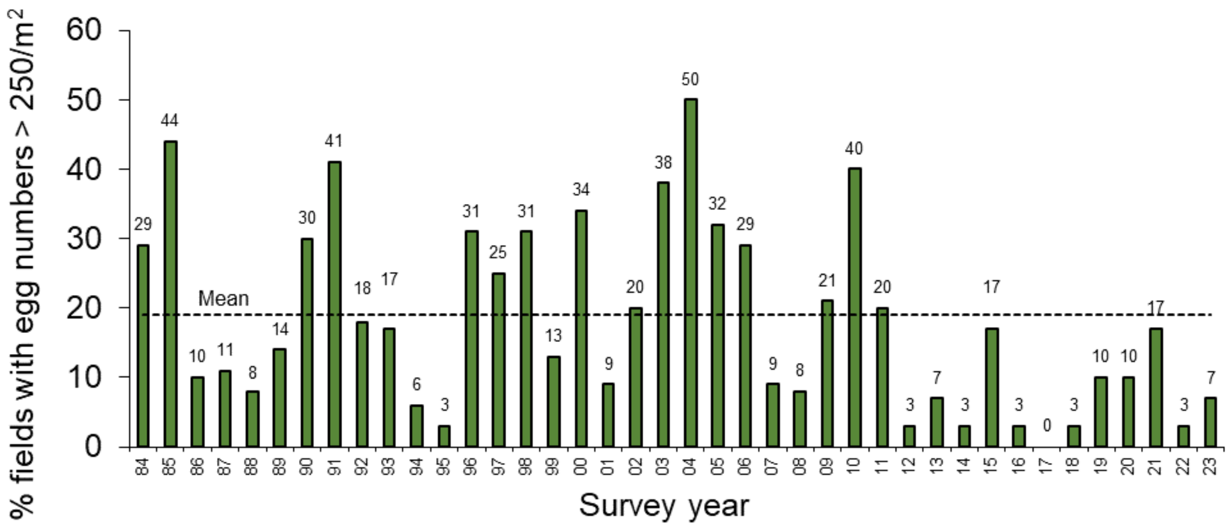

Figure 1. Wheat bulb fly annual risk levels between 1984–2023 with an overall mean represented by the dashed line.

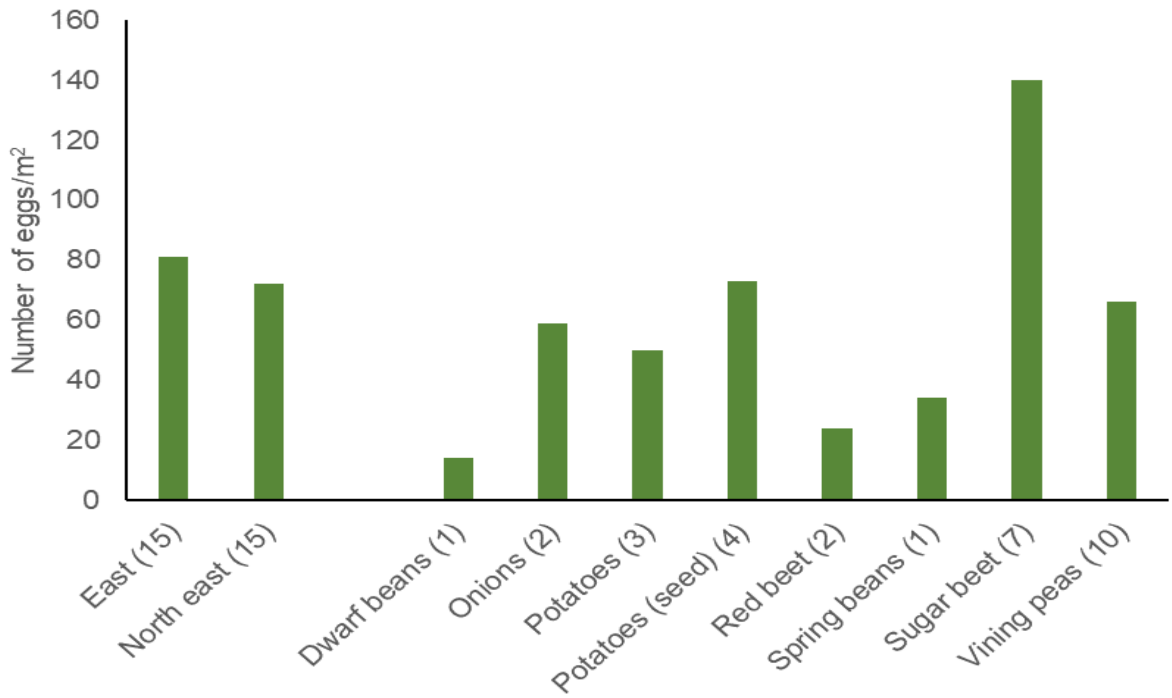

Figure 2. Average egg counts by region and previous crop in autumn 2023 (number of sites per region/crop in brackets).

4.1. East England

The mean egg number was 81 eggs/m² for sites sampled in 2023. Samples taken from organic soils had a slightly higher mean egg count (seven samples with a mean of 83/m^2) than those from mineral soils (eight samples with a mean of 80/m^2) . The potential for WBF damage in eastern England in organic soils is similar to mineral soils for 2023.

The three highest egg counts were all after sugar beet. These were 370 eggs/m^2 in Cambridgeshire in organic soil, 254 eggs/m^2 in Norfolk in mineral soil and 158 eggs/m^2 in Norfolk in mineral soil. Sugar beet had the highest mean number of eggs of all crops sampled (140 eggs/m^2, Table 3) Onions had the next highest count of 59 eggs/m^2 although only two sites were sampled.

Table 3. Mean eggs/m² and preceding crops in eastern England in autumn 2023 (range in brackets).

Preceding crop	Number of fields sampled	Mean number of eggs per m²
Dwarf beans	1	14
Onions	2	59
Potatoes (ware)	2	14
Red beet	2	24
Spring beans	1	34
Sugar beet	7	140
Mean egg count		81 (7–370)

Two of the sampled fields were in the high risk category (13%), three in the moderate category (20%) and 10 in the low category (67%, Table 4). Overall, five fields (33%) were in risk categories of moderate or above.

Table 4. Infestation categories and preceding crops in eastern England in autumn 2023.

	Number of fields by rotation and risk category			
Preceding crop	Low (<100 eggs/m²)	Moderate (100–249 eggs/m²)	High (250–499 eggs/m²)	Very high (>500 eggs/m²)
Dwarf beans	1	0	0	0
Onions	1	1	0	0
Potatoes (ware)	2	0	0	0
Red beet	2	0	0	0
Spring beans	1	0	0	0
Sugar beet	3	2	2	0
Total	10	3	2	0
% of fields by infestation category	67	20	13	0

4.2. North East England

The mean egg number was 72 eggs/m² for the north east of England (Table 5). The highest egg population of 123 eggs/m² was recorded in North Yorkshire after ware potatoes. This was followed by egg counts of 105/m² (twice, one in East and one in North Yorkshire) and 99/m² (twice, one in East and one in North Yorkshire). Ware potatoes also had the highest overall risk (123 eggs/m²) but only one site was sampled. This was followed by seed potatoes with 73 eggs/m². Sites with vining peas as the previous crop were the most abundantly sampled in north east England (10 sites) and had a mean of 66 eggs/m².

Table 5. Numbers of eggs/m² and preceding crops in north east of England in autumn 2023 (range in brackets).

Preceding crop	Number of fields sampled	Mean number of eggs per m²
Potatoes (ware)	1	123
Potatoes (seed)	4	73
Vining peas	10	66
Mean egg count		72 (19–123)

None of the sampled fields were in the very high or high risk category, four were in the moderate category (27%) and 11 in the low risk category (73%, Table 6).

Overall, four fields (27%) were in risk categories of moderate or above This represents a low risk to crops sown after November.

Table 6. Infestation categories and preceding crops in north east of England in autumn 2023.

Preceding crop	Number of fields by rotation and infestation category			
	Low (0–100 eggs/m²)	Moderate (100–250 eggs/m²)	High (250–500 eggs/m²)	Very high (>500 eggs/m²)
Potatoes	0	1	0	0
Potatoes (seed)	4	0	0	0
Vining peas	7	3	0	0
Total	11	4	0	0
% of fields by infestation category	73	27	0	0

4.3. Testing the model for prediction of WBF risk

Results are provided for model predictions for both 2022 and 2023 (Table 7). In the east of England predicted counts were almost 400% higher than soil counts. The difference between soil counts and predicted counts was less marked for the north east, although the latter were still about 160% higher than the former. Adding meteorological data and egg counts from 2019-2022 to the model calculations did little to improve predicted egg counts and predictions for the east and north east using data just from those regions were similarly poorly correlated with soil counts Both datasets did however produce similar predictions.

Table 7. Comparison of WBF egg counts (number/m^2) from soil sampling and those from predictive models in 2022 and 2023.

	2022			2023		
	East	North East	Mean	East	North East	Mean
Egg counts from soil samples	62	100	81	81	72	77
Predicted egg counts from the 2019 model (Leybourne *et al* 2022)[1]	111	38	75	323	114	219
Predicted egg counts from 2019 model (Leybourne et al 2022) [1]	118	45	82	320	123	222
Predicted egg counts from the east using the 2019 model and eastern met and egg count data (Leybourne et al 2022) [1]	–	–	–	369	–	–
Predicted east egg counts from updated model using only eastern met and egg count data [2]	–	–	–	392	-	–
Predicted egg counts from the north east using the 2019 model and north eastern met and egg count data (Leybourne et al 2022) [1]	–	–	–	–	107	–
Predicted north east egg counts from updated model using only north eastern met and egg count data [2]	-	-	-	-	118	-

[1] = using the egg counts and meteorological data up to 2019 to make predictions. [2] = adding the 2020, 2021, and 2022 meteorological data and egg counts into the model to make predictions

5. Discussion

Egg counts for 2023 indicate a relatively low risk year for WBF. Since 1984 the proportion of sites sampled with egg numbers above 250/m^2 (7%) has only been lower than in 2023 on eight occasions (in 1994, 1995, 2012, 2014, 2016, 2017, 2016 & 2022) and was equal to 2023 in 2013. Young & Cochrane (1993) suggest that the harvest date of the previous wheat crops has a significant effect on egg laying by WBF. The longer crops remain in the ground, the greater the number of eggs laid. Cereal harvest in the UK in 2023 started slowly and was initially hindered by wet weather (AHDB 2023). By the week ending 15th of August wheat harvest had progressed to 37% of the total, which was behind the five-year average of 56%. Over the next two weeks rainfall was slightly lower than the long-term average and by the 29th of August 89% of wheat had been harvested, which was above the five-year average of 82%. Over the next fortnight the weather was predominantly hot and dry so 99% of the wheat crop had been harvested which was just above the five-year average of 98%. It is possible that the despite the slow start harvest was ultimately sufficiently rapid to limit the development of saprophytic fungi in cereal ears, which resulted in limited food for adult WBF females and low numbers of eggs being laid.

5.1. East England

The mean egg number in east England was 81 eggs/m^2 for sites sampled in 2023. This is lower than in 2021 (143 eggs/m^2) but higher than in 2022 (62 eggs/m^2). In general, counts from individual sites in the east of England in 2023 were higher than in 2022 but lower than in 2021 with 10 sites in the low category compared to 12 in 2022, and nine in 2021. As in 2022, 2021 and 2020, samples taken in 2023 from organic soils had a higher mean egg count (seven samples with a, mean of 83/m^2) than those from mineral soils (eight samples with a, mean of 80/m^2), although the differences between the two soil types was much smaller than in 2022 (organic 81/m^2, mineral 23/m^2), 2021 (organic 236/m^2, mineral 36/m^2) or 2020 (organic 306/m^2, mineral 21/m^2) . The potential for WBF damage in eastern England in organic soils is similar to organic soils for 2023.

Overall, two sites (13%) had egg numbers above the 250 eggs/m^2 threshold for crops sown at the conventional timing (before November). The equivalent figure for 2022 was 7%, for 2021 it was 27% and for 2020 it was 20%. In total, 10 of the 15 sites sampled (67%) had egg numbers lower than 100 eggs/m^2. This compares with 80% in 2022, 60% in 2021 and 73% in 2020

5.2. North East England

The mean egg number was 72 eggs/m² for the north east of England. This is lower than in 2022 when there were 100 eggs/m^2, 2021 when there were 95 eggs/m^2 and 2020 when there were 111 eggs/m^2. Overall, 11 sites were in the low category, the same number of sites as in 2021 and 2020, but higher than in 2022, when nine sites were in the low category. No sites had egg numbers above the 250 eggs/m^2 threshold for crops sown at the conventional timing (before November), which was the same as in 2022 and 2020. In 2021 one site (7%) had egg numbers above this level. In total 11 of the 15 sites sampled (73%) had egg numbers lower than 100 eggs/m^2. This compares with 60% in 2022, 73% in 2021 and 80% in 2020.

5.3. Early sown crops (September/October)

In autumn 2023, two of the sampled fields were considered at high risk (egg numbers 250-500/m^2), seven at moderate risk (egg numbers 100-249/m^2) and 21 at low risk (egg numbers <100/m^2). This was equivalent to 7%, 23% and 70% of fields in the high, moderate and low risk infestation categories respectively. A total of 7% of sites had egg numbers above the 250 eggs/m^2 threshold for crops sown in September and October. Since 1984 the overall risk has been higher than 2023 on 30 occasions and lower than 2023 on eight occasions and equal to 2023 on one occasion.

5.4. Late-sown crops (November onwards)

Late-sown (November onwards) or slow developing crops are at greater risk from WBF attack than those that are early sown (September/October) due to slower tiller development. As a result, a lower threshold of 100 eggs/m^2 or 1 million eggs/ha is applicable for these crops. In the east of England 33% of monitored fields were above this level and in the north east 27% of fields were above this level. All fields in the moderate infestation category or above would benefit from a seed treatment if sown after November. Any field sown after January would benefit from a seed treatment if any WBF fly eggs are found. This would include all fields sampled in the survey. A summary of control strategies for WBF in relation to egg numbers and sowing date is given in Table 8.

Table 8. Wheat bulb fly egg numbers that would justify a seed treatment in crops sown between September and March.

Risk category	Sowing date		
	Sep–Oct	Nov–Dec	Jan–Mar
Low (<100 eggs/m^2)	Economic damage unlikely; no treatment	Economic damage unlikely; no treatment	Seed treatment
Moderate (100–249 eggs/m^2)	Economic damage unlikely; no treatment	Seed treatment	Seed treatment
High (250–500 eggs/m^2)	No available treatment	Seed treatment	Seed treatment
Very high (>500 eggs/m^2)	No available treatment	Seed treatment	Seed treatment

5.5. Chemical control

Seed treatment (Cypermethrin, Signal 300 ES) is effective on late-sown crops (November onwards) and is the recommended treatment for late autumn or winter sowings of wheat and barley made before the end of egg hatch in areas and rotations at risk from WBF. The label treatment claim for this product is for a 'reduction of wheat bulb fly'. Treated seed should be drilled at a recommended maximum depth of 4cm in a firm, even seedbed. The label also states that this product must only be applied to cereal seed sown in the autumn/winter. In practice CRD define this as any crop sown up until the end of January (Personal communication UPL Ltd). It is important to note that seed treatments may not be sufficiently persistent to fully protect crops sown in September or October. If plants are well-tillered by the time that WBF larvae hatch between January and March, it is possible that they will be able to tolerate some pest attack.

5.6. Non-chemical control

With the loss of chlorpyrifos egg hatch sprays non-chemical control of WBF is the only available option for those crops sown before November as seed treatments are insufficiently persistent. The impact of WBF can be reduced by sowing early and increasing the seed rate. This is likely to result in a more robust crop which is well tillered before the start of WBF egg hatch and so can tolerate and compensate for larval invasion.

5.6.1. WBF Threshold Scheme

Taking into account crop tolerance is fundamental to improving pest risk assessment and achieving a rational approach to pesticide use which is cost effective and minimises the impact on the environment and the potential for the development of resistance (Ellis *et al.*, 2009). This approach was the subject of an AHDB Cereals & Oilseeds funded project entitled 'Crop management guidelines for minimising wheat yield losses from wheat bulb fly' (21120032) (Storer *et al*., 2018). A WBF threshold scheme was developed that used information from the autumn survey of WBF incidence in September, egg viability, the maximum shoot number the crop could achieve by late winter, and the number of shoots that a single WBF larva could destroy. This model showed that typical variation in the maximum shoot number had a large effect on the chance of yield loss because well grown crops produce excess shoots which can be sacrificed without affecting yield. A model of shoot production was developed based on thermal time and plant population that was embedded within the WBF threshold scheme. This was done to allow a prediction of yield loss from WBF to be made in time for decisions about sowing date and seed rate. A review of literature showed that most WBF mortality occurs in the larval stage between egg hatch and plant invasion. The lowest level of mortality recorded was 56% and this value was used to help calculate the numbers of shoots likely to be lost to the pest. The literature also suggested that the number of shoots destroyed by an individual WBF larva was typically four. Independent tests showed the shoot production model performed reasonably well, but it should be recognised that it does not deal with site specific factors that may limit tillering (e.g., soil capping). The project has developed prototype guidelines summarising how sowing date and plant population should be adjusted, and insecticide seed treatments targeted, for different WBF risk situations.

In order for the threshold scheme described above to be adopted, a more reliable and up-to-date estimate of the minimum final ear number required for high yielding wheat crops was considered necessary. This was the subject of a desk study (Storer *et al*., 2019) which investigated whether the minimum final ear number changes in different regions and under different environmental conditions. A positive association between yield and final ear number was identified for UK wheat crops. For crops expected to yield up to 11 t/ha, a target final ear number of 500 ears/m^2 was deemed a conservative default value. For crops expected to exceed 11 t/ha, a higher target final ear number of 600 ears/m^2 was deemed appropriate. Although there was evidence that the ear number associated with specific yields may vary between varieties and geographic regions, it was not strong enough to recommend its inclusion in the threshold scheme. Before the scheme can be adopted, further research is necessary. In particular, it is important to quantify varietal differences in relation to shoot number at growth stage 31 and final ear number. Despite this significant steps have been made in developing a control strategy to help combat WBF in the absence of chemical control. There are plans to test the proposed threshold scheme in the field when suitable sites can be located. This will ideally be done in fields which show a range of WBF egg populations.

5.7. Predictive models

The primary method for risk determination for WBF is soil sampling, egg extraction, and egg counting. This process is labour-intensive and requires the use of bulky extraction equipment and taxonomic expertise for egg identification, and so can only be undertaken by a specialised laboratory.

Soil sampling is effective but laborious and often too late to influence decisions for winter wheat crops.

A revised WBF risk prediction model was developed based on the Young & Cochrane model (Young & Cochrane, 1993). The Young & Cochrane model used January air temperature, January soil temperature, July air temperature, and rainfall during the preceding October to predict wheat bulb fly egg density and had a reported predictive power (accuracy) of 59%. The revised risk prediction model incorporated air frost data in addition to the parameters used by Young & Cochrane (1993) and has a predictive power of 70% (Leybourne *et al.*, 2022), an 11% increase when compared with the original Young & Cochrane model.

Improving the predictive power of decision support models is likely to increase the confidence in their findings, and therefore uptake by farmers and agronomists. This revised risk prediction model will provide an additional component to a potential IPM strategy for the pest. In 2022, the revised predictive model was very accurate when compared to mean soil counts (east and north east regions combined) over all 30 sites sampled. However, in 2023 the predicted egg counts were much less precise and higher than the soil counts for both the east and north east. In the east, predicted counts were about four times higher than predicted counts. In both 2022 and 2023 predictions specifically for the east and north east regions showed relatively poor correlation with soil counts for those regions. The poor agreement between model predictions and soil counts are difficult to explain. It is possible that soil type has an influence on egg numbers and this is not accounted for in the model. This is particularly relevant to the east, where both mineral and organic soils are sampled. In both 2021 and 2022 egg counts in organic soil in the east of England were much higher in mineral soil. In 2022 the eastern soil count was driven by three high egg counts of 1000, 850 and 404 eggs/m^2 from three sites on organic soils.

6. Conclusions

The following conclusions can be drawn from the 2023 autumn survey of WBF:

- The overall risk from WBF is relatively low with only 7% of sites sampled with egg numbers above 250/m^2 . Thie risk has only been lower on eight occasions since 1984.

- In the east of England mean egg counts were 81 eggs/m^2. Sugar beet had the highest three egg counts and also the highest mean egg count of all crops sampled. Two of the sampled fields were in the high risk category (13%), three in the moderate category (20%) and 10 in the low category (67%, Table 4). Overall, five fields (33%) were in risk categories of moderate or above. There was little difference in egg counts between organic (83 eggs/m^2) and mineral soils (81 eggs/m^2).

- In the north east of England mean egg counts were 72/m^2. The highest egg population of 123 eggs/m^2 was recorded in North Yorkshire after ware potatoes and this crop had the highest mean egg count, although only one site was sampled. None of the sampled fields were in the very high or high risk category, four were in the moderate category (27%) and 11 in the low risk category (73%). Overall, four fields (27%) were in risk categories of moderate or above.

- There was poor correlation between model predicted egg counts and egg counts from soil sampling in 2023.

- Further development and refinement by inclusion of model moderators such as soil type, summer rainfall and possibly previous crop would allow the production of a more robust and dynamic model (Leybourne *et al.*, 2022). That the highest egg counts in 2020 in the east were all in organic soil suggests that soil type may influence the egg laying preferences of WBF. In 2021 and 2022 it was also noticeable that in the east the highest egg counts were recorded in organic soil. Interestingly, in 2023 there was little difference in egg counts from mineral and organic soil. Previous crop in the rotation also affects WBF egg laying as it is likely to affect the pests access to bare soil in which it likes to lay its eggs. Where crops are harvested early, such as vining peas or seed potatoes the entire field becomes available for egg laying. In row crops such as sugar beet and potatoes, which are harvested much later into the autumn, the flies can only gain access to bare ground between the rows. This in turn is influenced by the degree to which the crop has senesced at the time of egg laying (July until early September). Taking account of soil type and previous crop represents the next logical step in the development of the model to predict WBF egg number.

7. References

AHDB. 2023. Harvest progress in Great Britain.
Harvest progress across Great Britain, reports and interactive tool | AHDB

AHDB. 2014. AHDB Encyclopaedia of pests and natural enemies in field crops. 199 pp.

Ellis, S, Berry, P, Walters, K. 2009. A review of invertebrate pest thresholds. Home-Grown Cereals Authority Research Review No 73. HGCA, Stoneleigh, Warwickshire. 70pp.

HGCA. 2016. Wheat bulb fly. Information Sheet 51 Summer 2016.

Gratwick, M. **1992.** Crop pests in the UK. Collected edition of MAFF leaflets. Chapman & Hall, London. 490pp.

Gough, H C, Woods, A, Maskell F E, Towler, M J. 1961. Field experiments on the control of wheat bulb fly leptohylemia coarctata (Fall.). *Bulletin of Entomological Research.* **52**: 621-634.

Leybourne D J, Storer K, Ellis S, Berry P. 2020. Updating a wheat bulb fly risk prediction model. *AHDB interim report (P1906305).* 29pp. https://projectblue.blob.core.windows.net/media/Default/Research%20Papers/Cereals%20and%20Oilseed/2020/PR624%20interim%20report%202020%20(wheat%20bulb%20fly%20risk%20prediction%20model).pdf

Leybourne, D J, Storer, K E, Berry, P, & Ellis, S. 2022. Development of a pest threshold decision support system for minimising damage to winter wheat from wheat bulb fly, *Delia coarctata*. *Annals of Applied Biology***. 180**: 118-131.

Oakley J N, Young J E B. 2000. Economics of pest control in cereals in the UK. *The BCPC Conference – Pests and Diseases 2000.* 663-670.

Storer K, Ellis S, Berry P. 2018. Crop management guidelines for minimising wheat yield losses from wheat bulb fly. *Project Report No. 598*. 59pp. https://projectblue.blob.core.windows.net/media/Default/Research%20Papers/Cereals%20and%20Oilseed/pr598-final-project-report.pdf

Storer K E, Berry P M, Ellis S. 2019. Calibrating the wheat bulb fly threshold scheme using field data. Desk Study. *Project Report No. 607*. 16pp. https://projectblue.blob.core.windows.net/media/Default/Research%20Papers/Cereals%20and%20Oilseed/pr607-final-project-report.pdf

Young J E B. 1992. Control of wheat bulb fly in winter wheat. I. Chemical methods. II. Varietal susceptibility. *HGCA Project Report No. 67*.

Young J E B, Cochrane J. 1993. Changes in wheat bulb fly (*Delia coarctata*) populations in East Anglia in relation to crop rotations, climatic data and damage forecasting. *Annals of Applied Biology* **123**: 485-498.

Young J E B, Ellis S A. 1996. *Impact of changes in arable agriculture on the biology and control of wheat bulb fly.* Research Review No. 33, HGCA, London.

Appendix A

Egg populations ranked in descending order for 15 fields sampled in eastern England in autumn 2023

County	Previous crop	Number of eggs (number/m^2)	Soil type	Risk category
Cambridgeshire	Sugar beet	370	Organic	High
Norfolk	Sugar beet	254	Mineral	High
Norfolk	Sugar beet	158	Mineral	Moderate
Cambridgeshire	Onions	110	Organic	Moderate
Norfolk	Sugar beet	110	Organic	moderate
Norfolk	Sugar beet	34	Mineral	Low
Norfolk	Sugar beet	34	Organic	low
Cambridgeshire	Red beet	27	Organic	Low
Norfolk	Sugar beet	27	Mineral	Low
Norfolk	Sugar beet	27	Mineral	Low
Cambridgeshire	Red beet	21	Mineral	Low
Cambridgeshire	Potatoes	21	Organic	Low
Cambridgeshire	Dwarf beans	14	Organic	Low
Cambridgeshire	Onions	7	Mineral	Low
Norfolk	Potatoes	7	Organic	Low
Mean		81		

Appendix B

Egg populations ranked in descending order for 15 fields sampled in north eastern England in autumn 2023. All fields are mineral soil types.

County	Previous crop	Number of eggs (number/m²)	Risk category
North Yorkshire	Potatoes	123	Moderate
East Yorkshire	Vining peas	117	Moderate
East Yorkshire	Vining peas	105	moderate
North Yorkshire	Vining peas	105	Moderate
East Yorkshire	Seed potatoes	99	Low
North Yorkshire	Vining peas	99	Low
East Yorkshire	Seed potatoes	80	Low
North Yorkshire	Seed potatoes	62	Low
East Yorkshire	Vining peas	56	Low
East Yorkshire	Vining peas	49	Low
East Yorkshire	Seed potatoes	49	Low
East Yorkshire	Vining peas	43	Low
East Yorkshire	Vining peas	37	Low
East Yorkshire	Vining peas	31	Low
East Yorkshire	Vining peas	19	Low
Mean		72	