The sustainable management of insect pests: from decision support systems to natural biocontrol

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NIAB Seminar, 19th May 2021

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Alexander von Humboldt Stiftung/Foundation

AHDB

BRITISH ECOLOGICAL SOCIETY







Overview

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1) Developing (the foundations for) a decision support system for wheat bulb fly control

1) Use the pest level prediction model to estimate seasonal pest levels



2) Use pest tolerance levels to estimate the number of shoots required to tolerate pest damage

Delia coarcata eggs (m^{-2})	Minimum shoot number needed to tolerate damage (m^{-2})
125	720
250	940
500	1380
750	1820

3) Use the shoot number prediction model to predict the maximum number of shoots a crop will produce using the planned sowing date and seed rate



4) Subtract the minimum number of shoots needed to tolerate the predicted level of pest pressure from the predicted maximum shoot number

5) If the result is positive, there is a high chance that the pest can be tolerated naturally. If the result is negative, consider one of the following IPM strategies

A) Adjust the planned sowing date or/and seed rate to achieve the minimum shoot number needed to tolerate damage



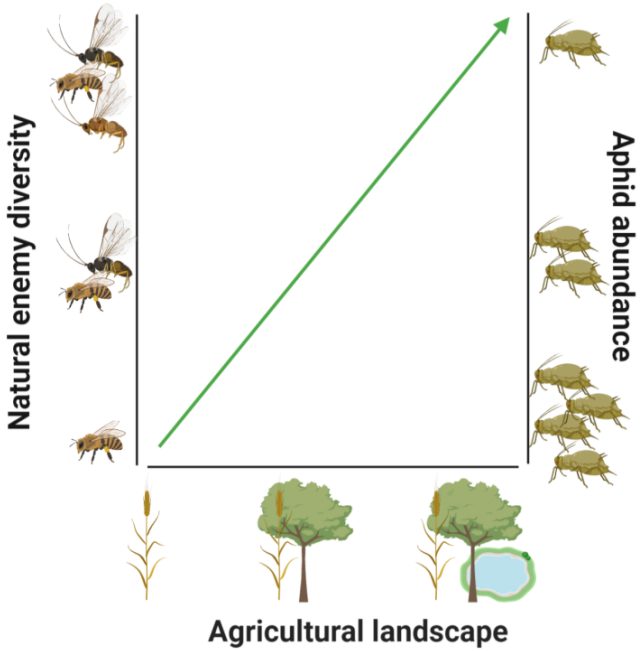
B) If the crop cannot be sown before November then consider using an insecticide seed treatment



C) Change rotation and grow an alternative crop



2) Natural biocontrol – ecological drivers of variable success



Graphics created with BioRender.com

Wheat bulb fly

- Major pest of winter cereals along Eastern coast of the UK
- Larval stage of agricultural importance: stem-borers that cause “deadhearts”
- Chemical control limited to seed treatment
- Non-chemical control methods reported but not robustly tested



Cereal aphids

- Major pests of cereals
- Primary vectors of plant viruses
  - *R. padi* & *S. avenae* vectors of *BYDV*
- Infestation can cause significant yield loss
  - ~ 20% through direct feeding damage
  - > 80% if plant viruses transmitted
- Insecticide resistant populations increasing



Cabbage stem flea beetle

- Major pest of oilseed rape and other field Brassicas
- Significant adult infestation after crop planting can devastate yields through defoliation
- High larval numbers can weaken stems
- Insecticide resistant populations are widespread across Europe
- Pest biology significantly understudied





Part 1

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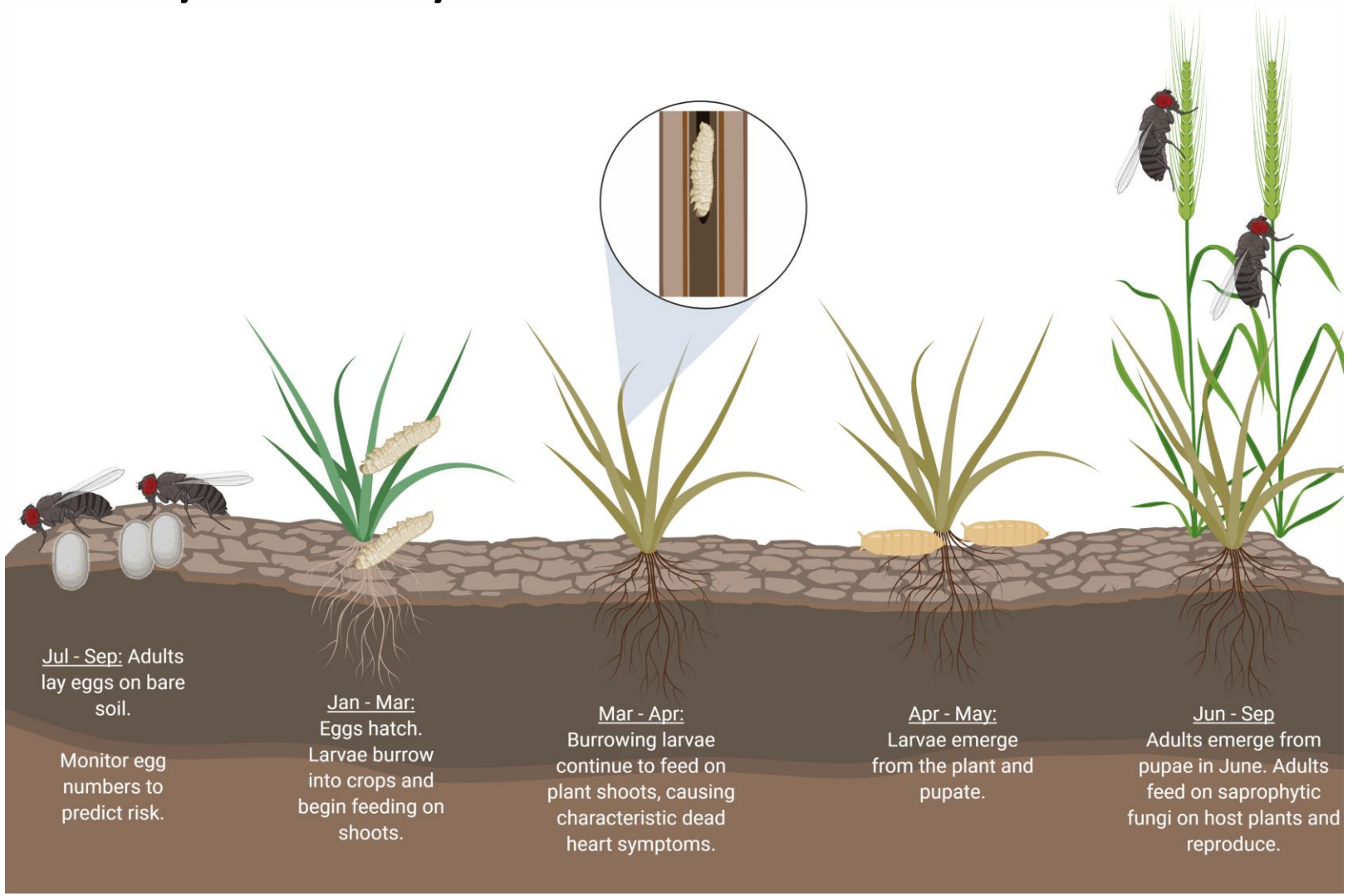
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2) Natural biocontrol – ecological drivers of variable success

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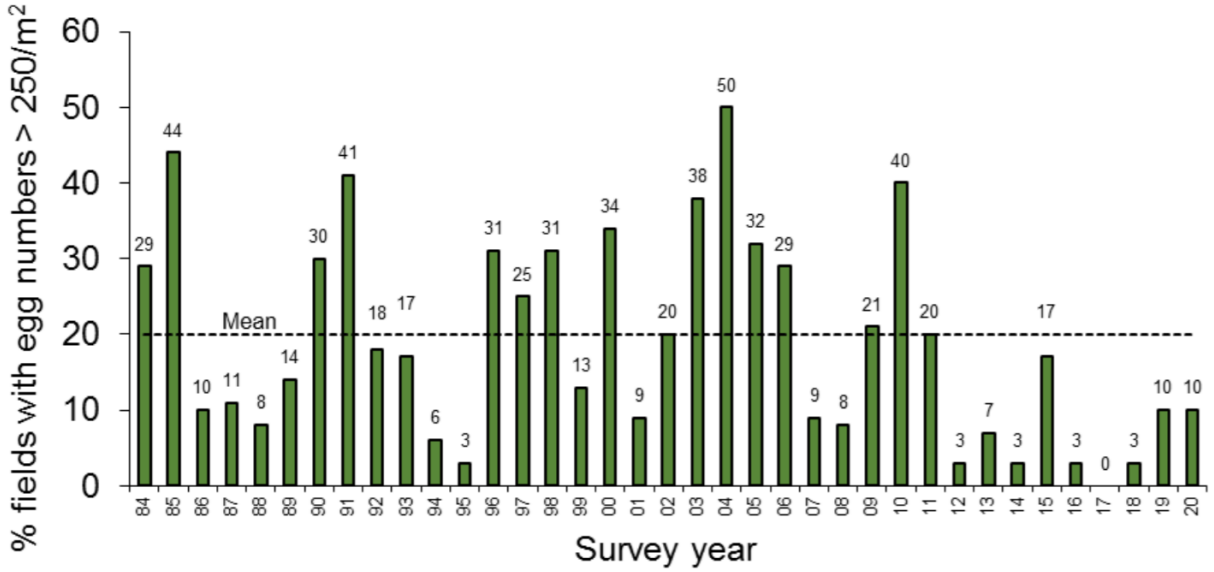
Wheat bulb fly life-cycle



Leybourne, Storer *et al., in-revision.* Graphic created with BioRender.com

Wheat bulb fly management

- Accepted wheat bulb fly thresholds – 250 eggs m^2
- AHDB commission seasonal wheat bulb fly surveys
- Chemical control options? One seed treatment
- Alternative control options? Understudied



Ellis, 2020. Autumn survey of wheat bulb fly incidence.

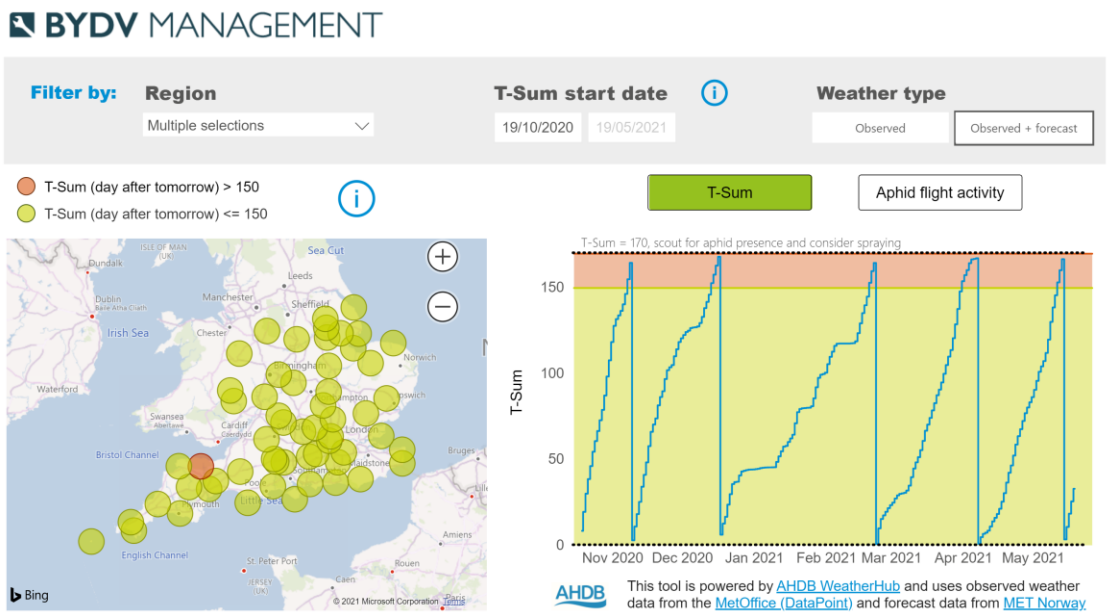
Wheat bulb fly management

Challenge 1: How can we better estimate seasonal wheat bulb fly risk?



Decision support systems and pest management

- Decision support systems are used to help growers make agronomic decisions
- Decision support systems for pest management fall into two categories
  1. Predict a phenological event of importance where the event increases crop risk
  2. Pre-season prediction of pest pressure
- Various predictors can be used in the decision support system models



Developing models to predict annual risk

Aim: Develop a model for the seasonal prediction of wheat bulb fly risk

Input:

- Open-access meteorological data (departure from ten year long-term averages)

Sources of data:

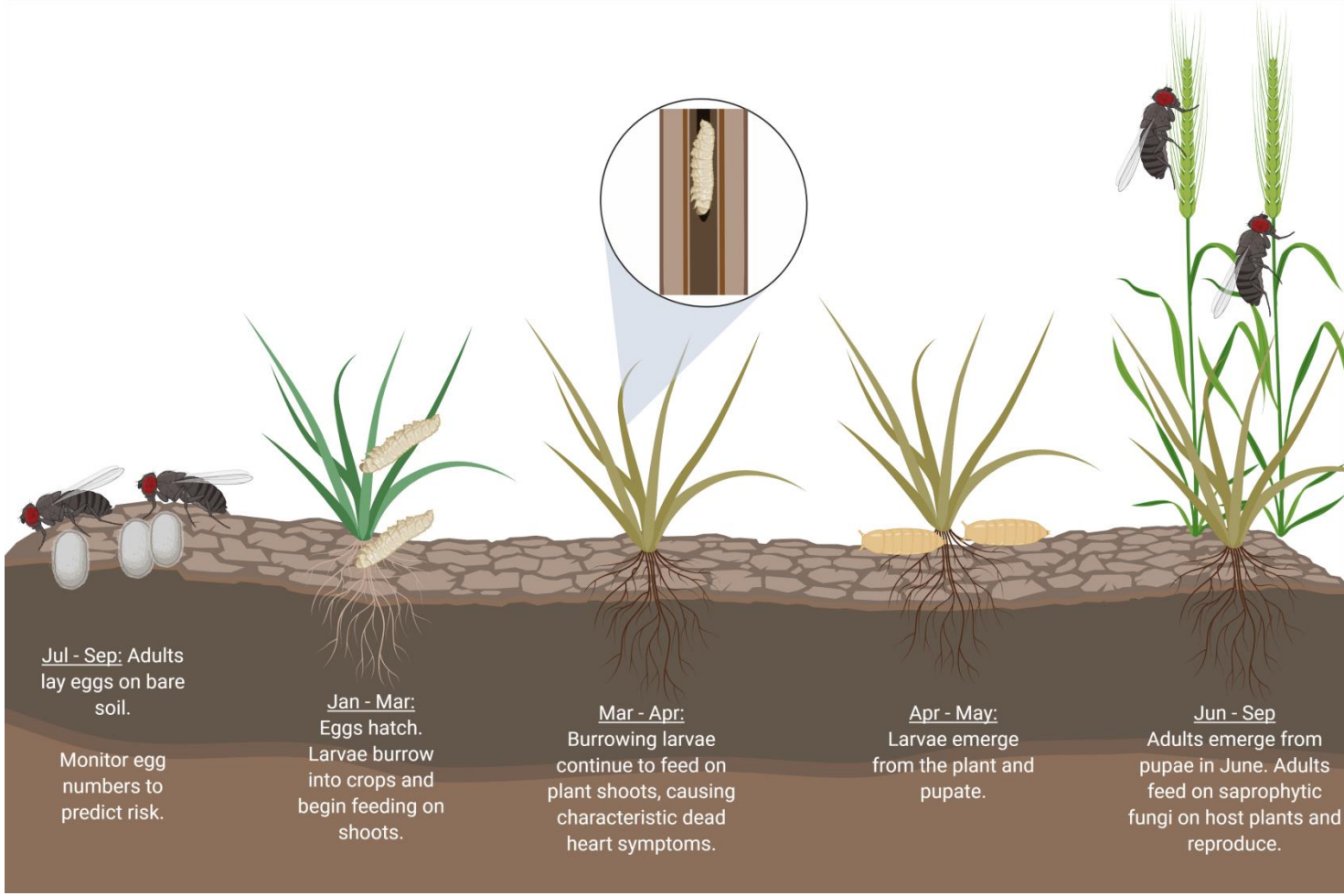
- Meteorological office
- AHDB wheat bulb fly survey
  - 1952 – 1991: East Anglia
  - 2005 – 2019: East Anglia and Northern England



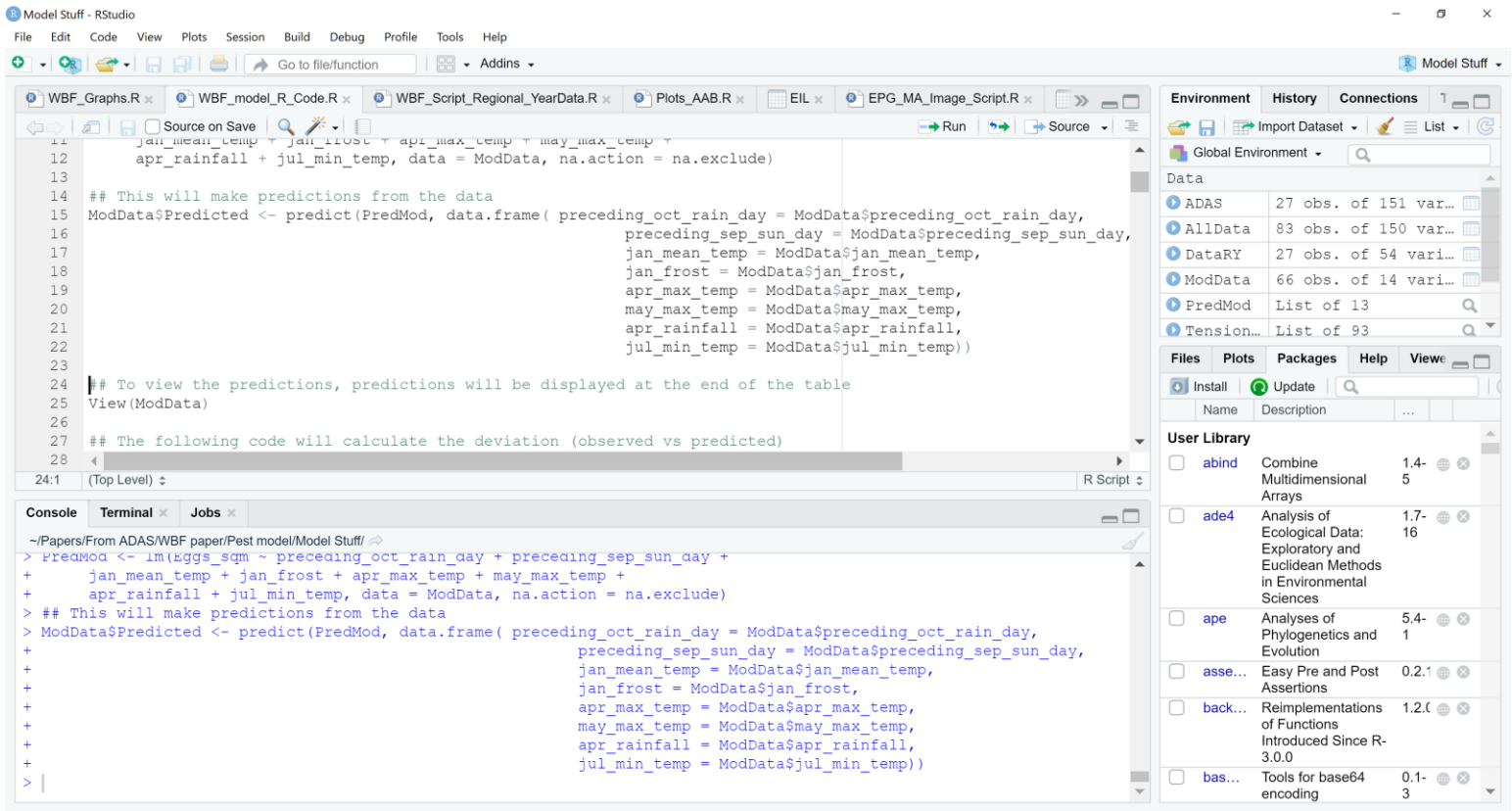
Developing models to predict annual risk

Input: Open-access meteorological data (departure from ten year long-term averages)

- Max / Min / Mean temperature
- Rainfall (ml)
- Number of rain days
- Sunshine days
- Number of frost days

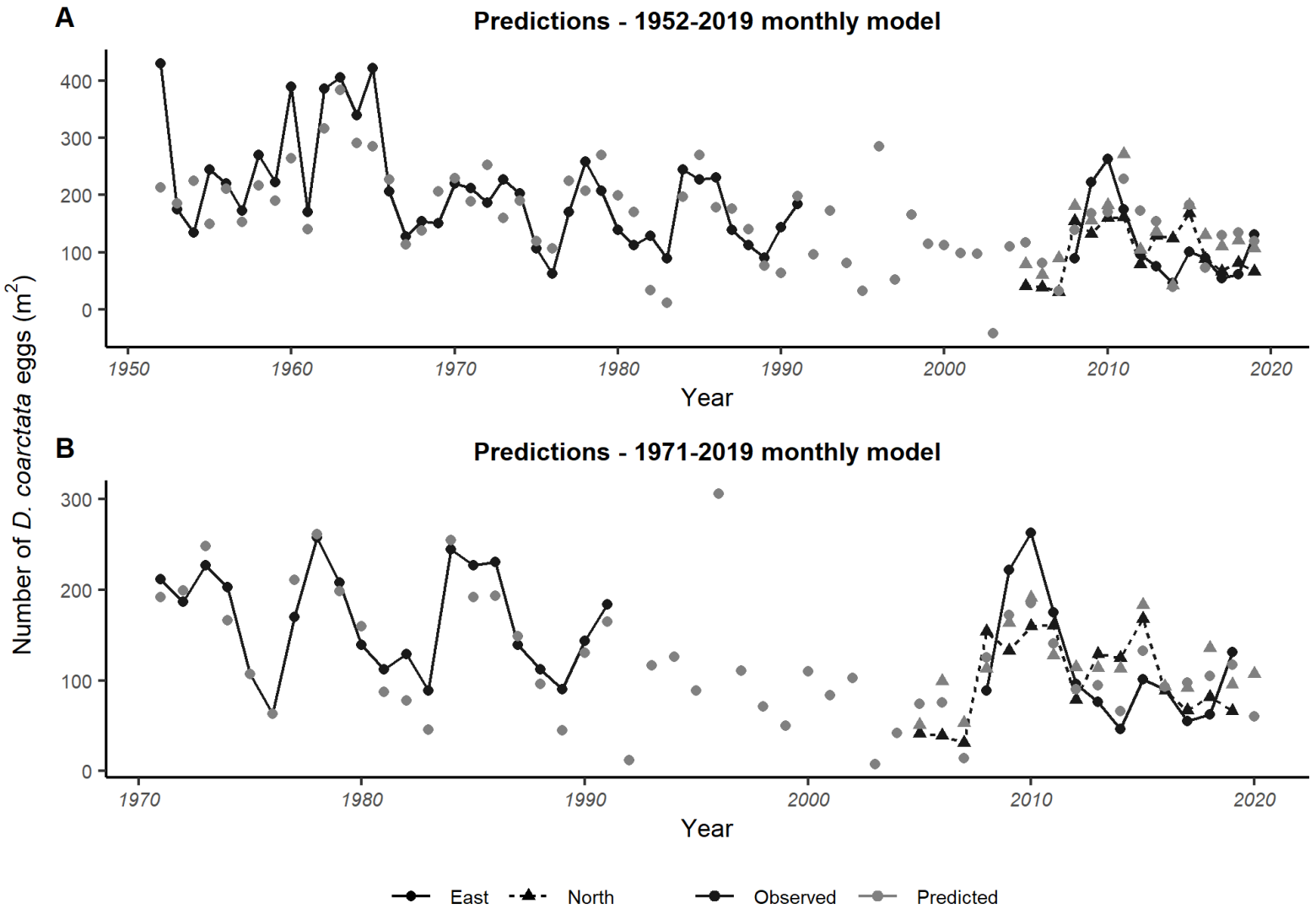


Developing models to predict annual risk



- Simple predictive model: linear model
- Developed in R
- Two-stage model development process
  - Seasonal model
  - Monthly model
- Model simplification through backward stepwise model selection

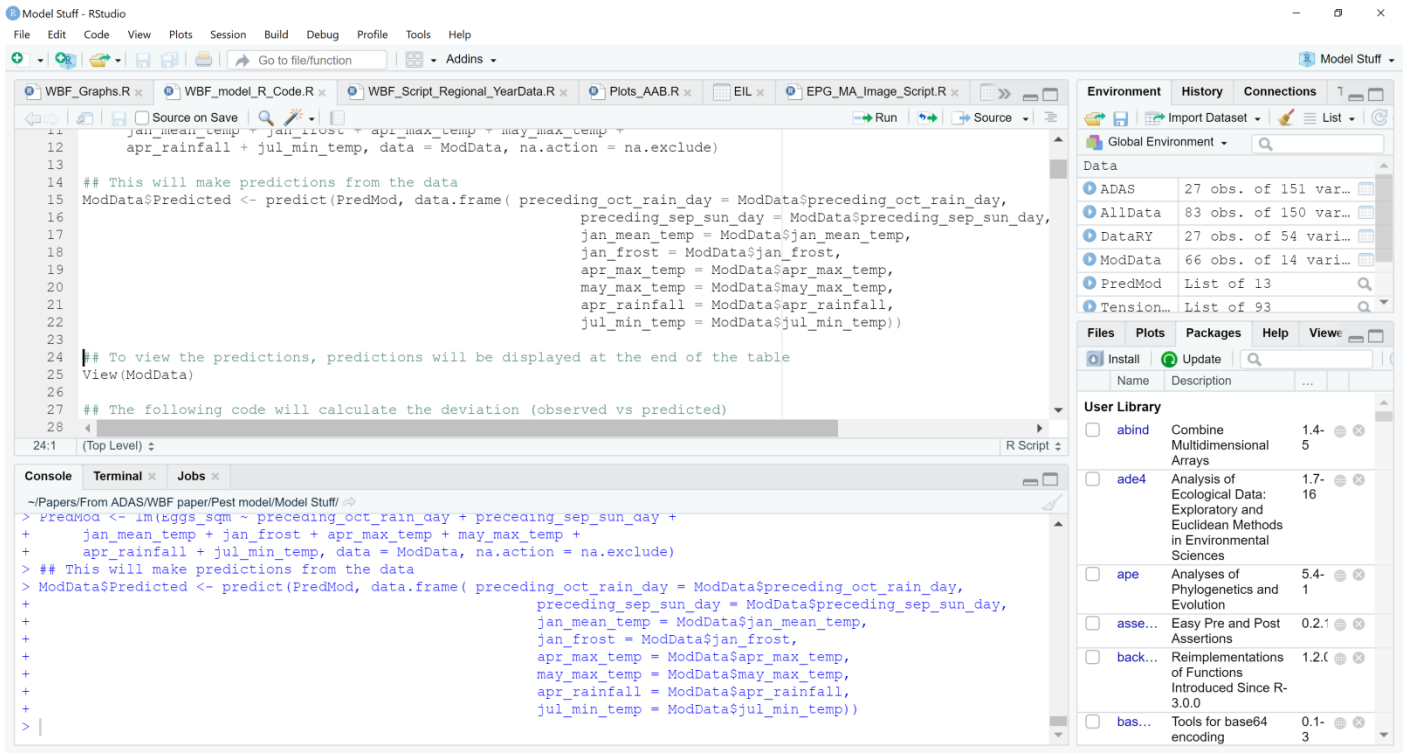
Developing models to predict annual risk



- Model A monthly: adj-R^2 = 0.59
- Model B "reduced" monthly: adj-R^2 = 0.70

Leybourne, Storer *et al., in-revision*

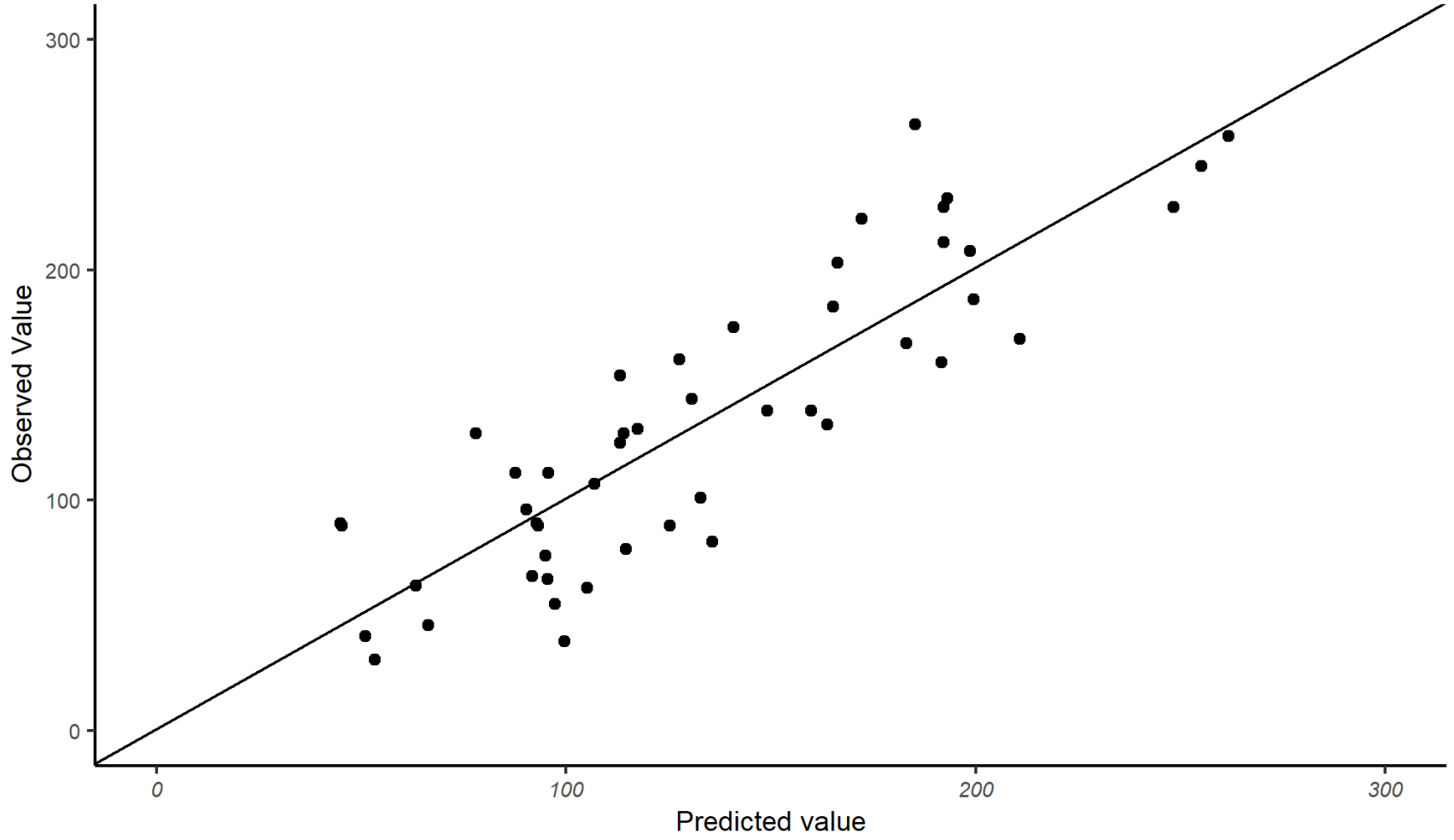
Developing models to predict annual risk



Final model parameters:

- Preceding September sunshine days
- Preceding October rain days
- January mean temperature
- January air frost days
- April max temperature
- April rainfall
- May max temperature
- July min temperature

Predictive model validation and testing



Leybourne, Storer *et al., in-revision*

Testing the predictive model

Region	Observed Average	Predicted Average	Deviation
North	111 eggs m^2	107 eggs m^2	- 4 eggs m^2

- Prediction for North – very good!



Leybourne, Storer *et al., in-revision*

Wheat bulb fly management

Challenge 2: We can better predict annual wheat bulb fly risk, but with a lack of chemical control what can we do with this information?



Updating wheat bulb fly thresholds

Current wheat bulb fly threshold (Economic Injury Level): 250 eggs m^2

Factors that can influence the Economic Injury Level:

1. The number of shoots a larva can destroy
2. The minimum number of shoots required to achieve yield potential
3. The maximum number of shoots a crop is expected to produce in winter

$$EIL = \frac{(SN - SN_{MIN})/SN_{KILL}}{Egg\ Viability\ x\ 100}$$



Leybourne, Storer *et al., in-revision*

Updating wheat bulb fly thresholds

$$EIL = \frac{(SN - SN_{MIN})/SN_{KILL}}{Egg\ Viability\ x\ 100}$$

Values estimated from literature:

- Shoot number (SN) = 1,000
- Minimum shoots for yield (SN_{MIN}) = 500
- Shoots killed per larva (SN_{KILL}) = 4
- Egg viability = 0.56



Leybourne, Storer *et al., in-revision*

Updating wheat bulb fly thresholds

Wheat bulb fly egg count (eggs m^2)	Shoot numbers required to tolerate expected damage (shoots m^2)
125	720
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Wheat bulb fly management

Challenge 3: How can we ensure we can produce a crop capable of tolerating the predicted natural levels of wheat bulb fly?



Sustainable pest management through pest tolerance

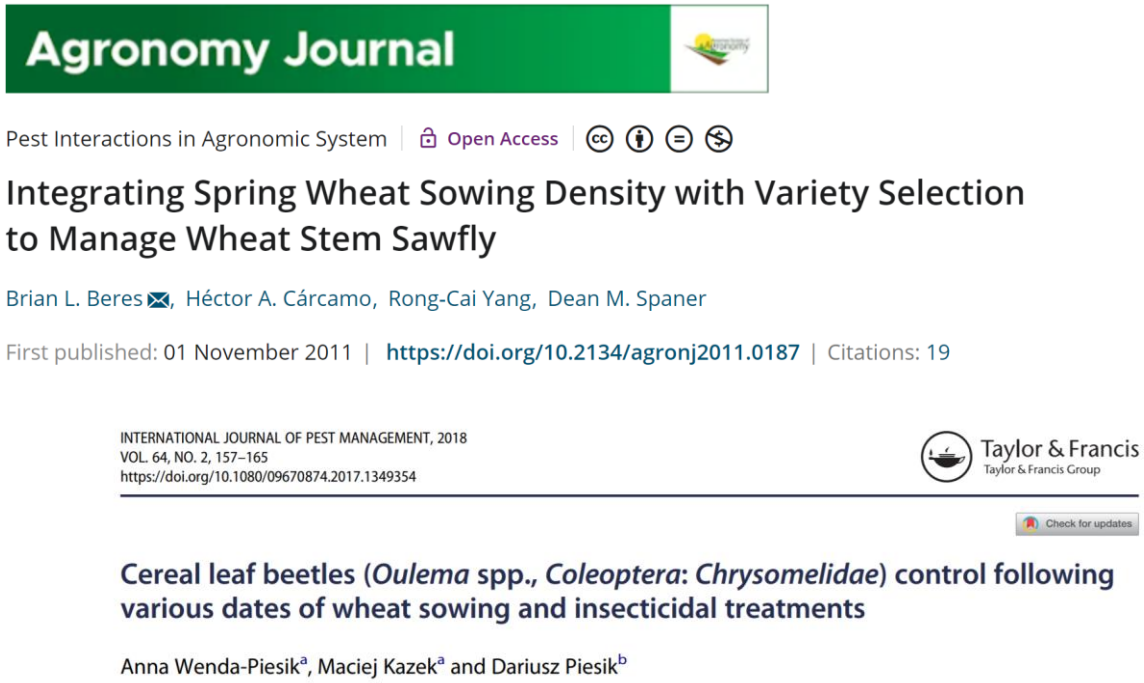
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Sustainable pest management through pest tolerance

- Wheat stem sawfly: *Cephus cinctus*
- Gout fly: *Chlorops pumilionis*
- Cereal leaf beetles: *Oulema spp*



Agronomy Journal

Pest Interactions in Agronomic System | Open Access

Integrating Spring Wheat Sowing Density with Variety Selection to Manage Wheat Stem Sawfly

Brian L. Beres, Héctor A. Cárcamo, Rong-Cai Yang, Dean M. Spaner

First published: 01 November 2011 | https://doi.org/10.2134/agronj2011.0187 | Citations: 19

INTERNATIONAL JOURNAL OF PEST MANAGEMENT, 2018
VOL. 64, NO. 2, 157–165
https://doi.org/10.1080/09670874.2017.1349354

Taylor & Francis
Taylor & Francis Group

Check for updates

Cereal leaf beetles (*Oulema* spp., *Coleoptera*: *Chrysomelidae*) control following various dates of wheat sowing and insecticidal treatments

Anna Wenda-Piesik[a], Maciej Kazek[a] and Dariusz Piesik[b]

Predicting shoot number to achieve pest tolerance

Aim: Develop a model to predict shoot number at terminal spikelet stage

Input:

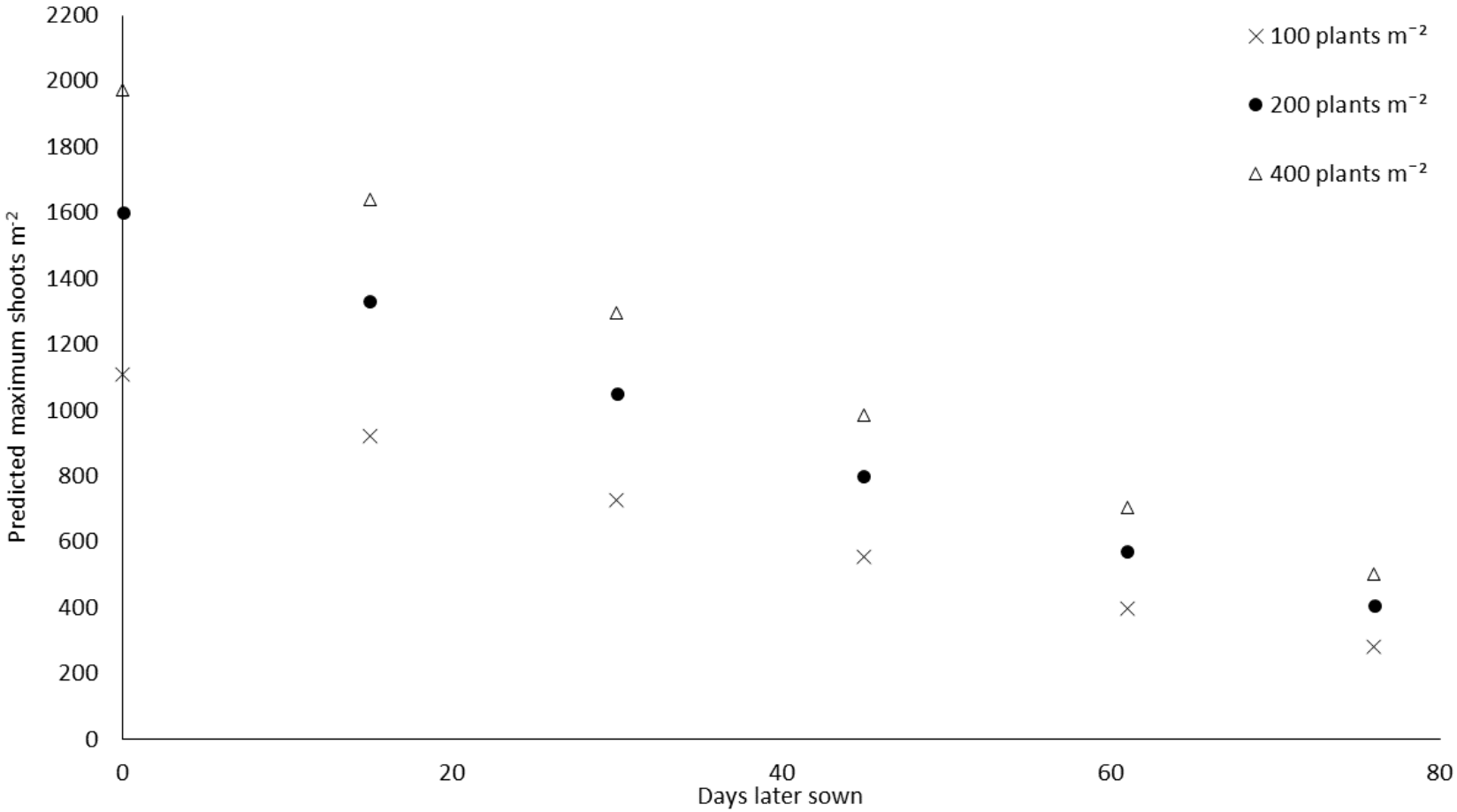
- Thermal time from plant emergence
- Leaf phyllochron length
- Target plant population (sowing rate)
- Sowing date (early, conventional, late)

Sources of data:

- ADAS field trials
- Published studies

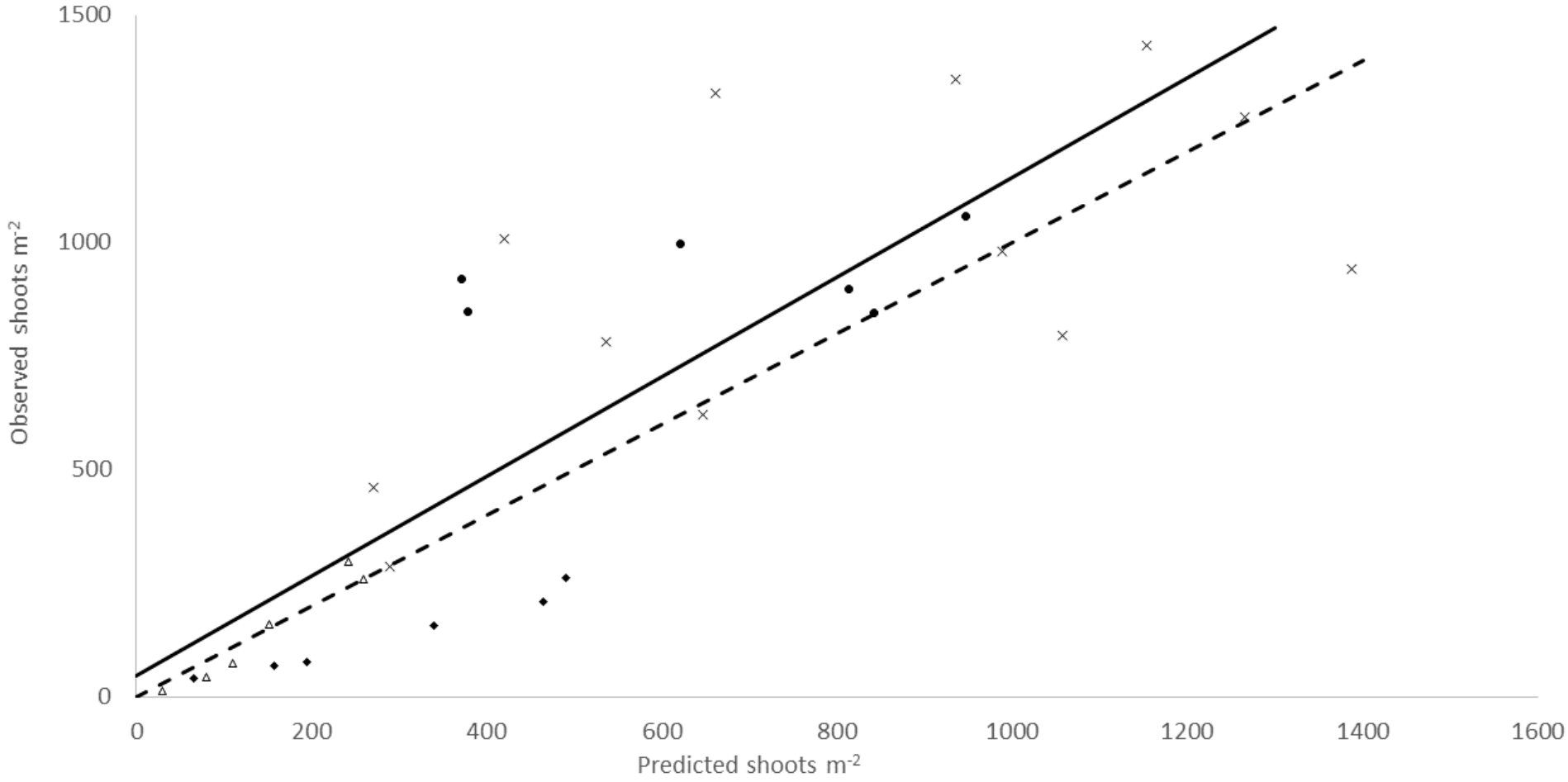


Predicting shoot number to achieve pest tolerance



Leybourne, Storer *et al., in-revision*

Predicting shoot number to achieve pest tolerance



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Towards a decision support system for wheat bulb fly management

Pest level prediction + updated thresholds + tolerance prediction = DSS?



Towards a decision support system for wheat bulb fly management

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Leybourne, Storer *et al., in-revision.* Graphic created with BioRender.com

Towards a decision support system for wheat bulb fly management: next steps

Improving the pest prediction model

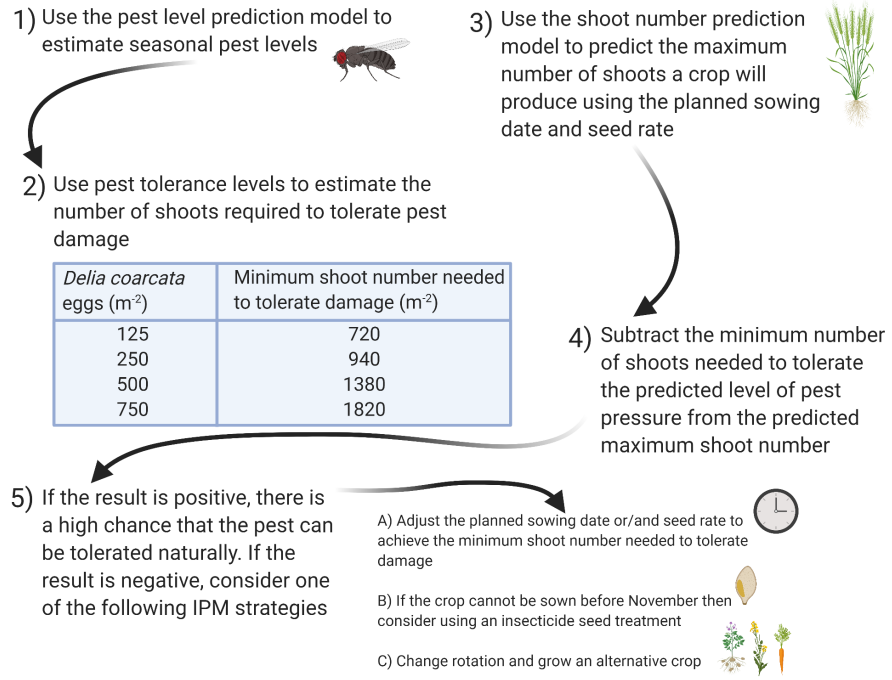
- Can we include crop history and soil metrics to improve predictions?
- Include data from other risk areas (East Scotland)
- Can we be more precise than large regional areas?

Improving the shoot prediction model

- Include more crop varieties
- Extensive field testing (starting this year)

Gaining confidence in the DSS

- Experimental testing and validation of the DSS



Part 2

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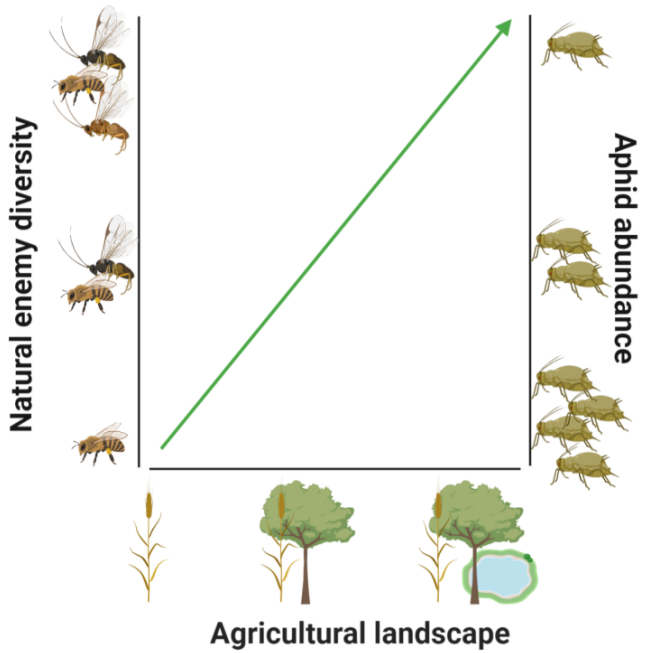
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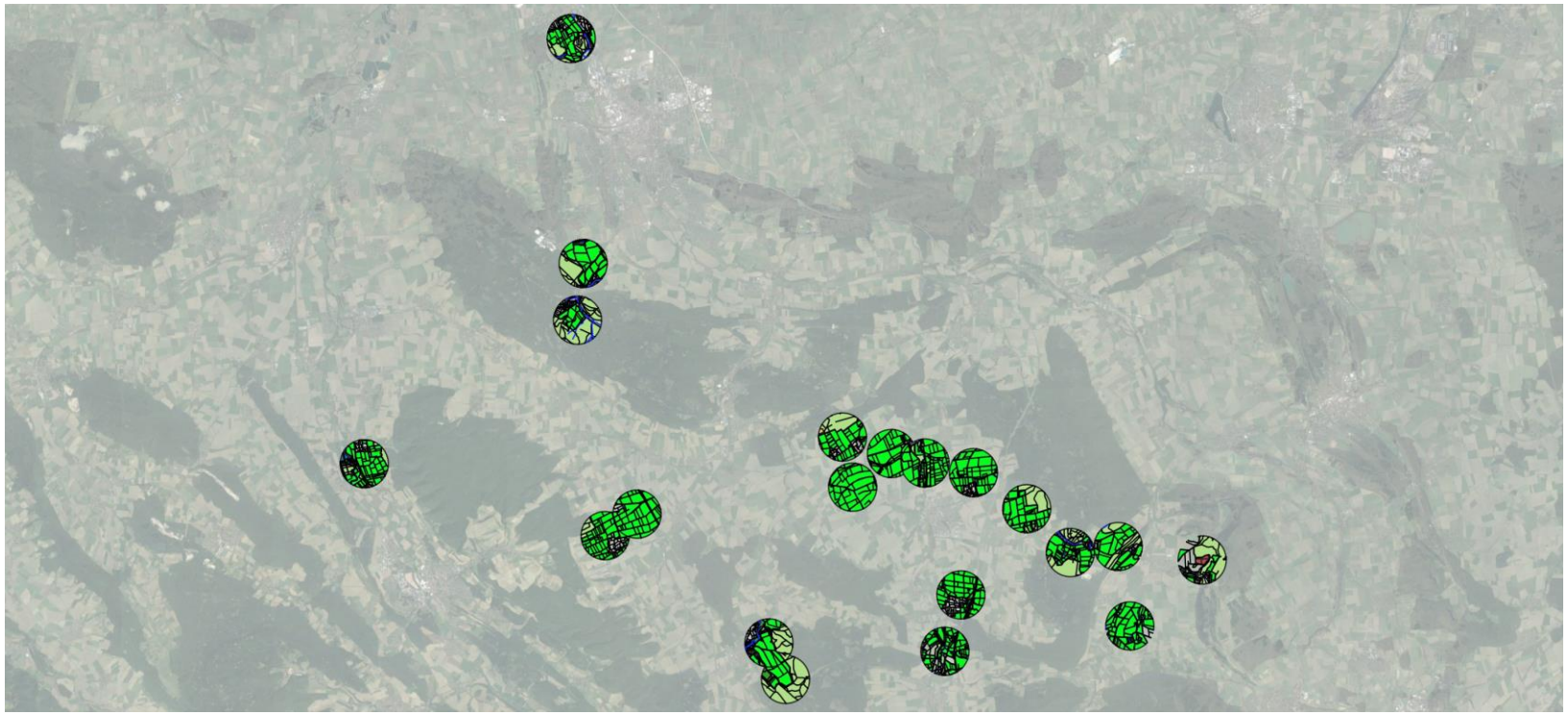
C) Change rotation and grow an alternative crop

2) Natural biocontrol – ecological drivers of variable success



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Pest management via natural biocontrol



Two levels of diversity influence natural biocontrol success:

1. Diversity within a field
2. Landscape diversity surrounding a field

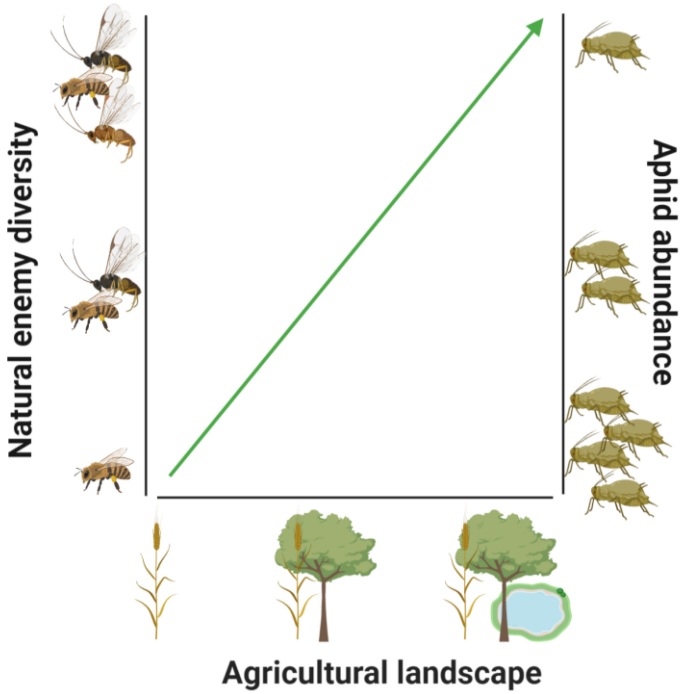
- % of farmland
- % of semi-natural habitat
- % of crop (host) cover
- Current season or previous seasons

Pest management via natural biocontrol

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Increasing the biodiversity surrounding a field can enhance biocontrol ecosystem services and promote pest management



ECOLOGICAL APPLICATIONS
ECOLOGICAL SOCIETY OF AMERICA

Article | Free Access

Landscape diversity enhances biological control of an introduced crop pest in the north-central USA

M. M. Gardiner, D. A. Landis, C. Gratton, C. D. DiFonzo, M. O'Neal, J. M. Chacon, M. T. Wayo, N. P. Schmidt, E. E. Mueller, G. E. Heimpel

First published: 01 January 2009 | https://doi.org/10.1890/07-1265.1 | Citations: 266

PeerJ

Pest control of aphids depends on landscape complexity and natural enemy interactions

Research article | Agricultural Science | Biodiversity | Ecology | Natural Resource Management

Emily A. Martin[1], Björn Reineking[2,3,4], Bumsuk Seo[4,5], Ingolf Steffan-Dewenter[1]

ELSEVIER

Basic and Applied Ecology
Volume 9, Issue 6, 6 October 2008, Pages 682-690

Insect pests in winter oilseed rape affected by field and landscape characteristics

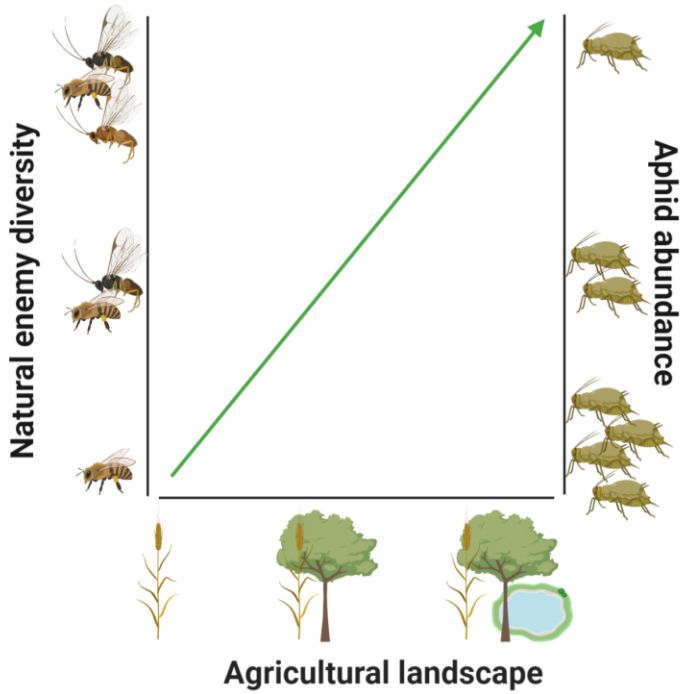
Johann G. Zaller, Dietmar Moser, Thomas Drapela, Claudia Schmöger, Thomas Frank

Pest management via natural biocontrol

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More landscape diversity = more biological control agents = greater pest suppression?



What is intra-species diversity?

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Aphid species
e.g. *R. padi*

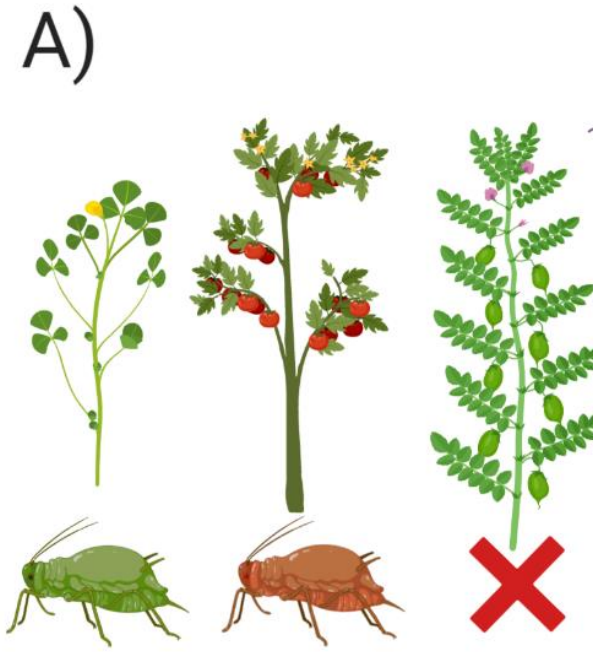


Graphic created with BioRender.com

Why is the intra-species diversity of herbivorous insects important?

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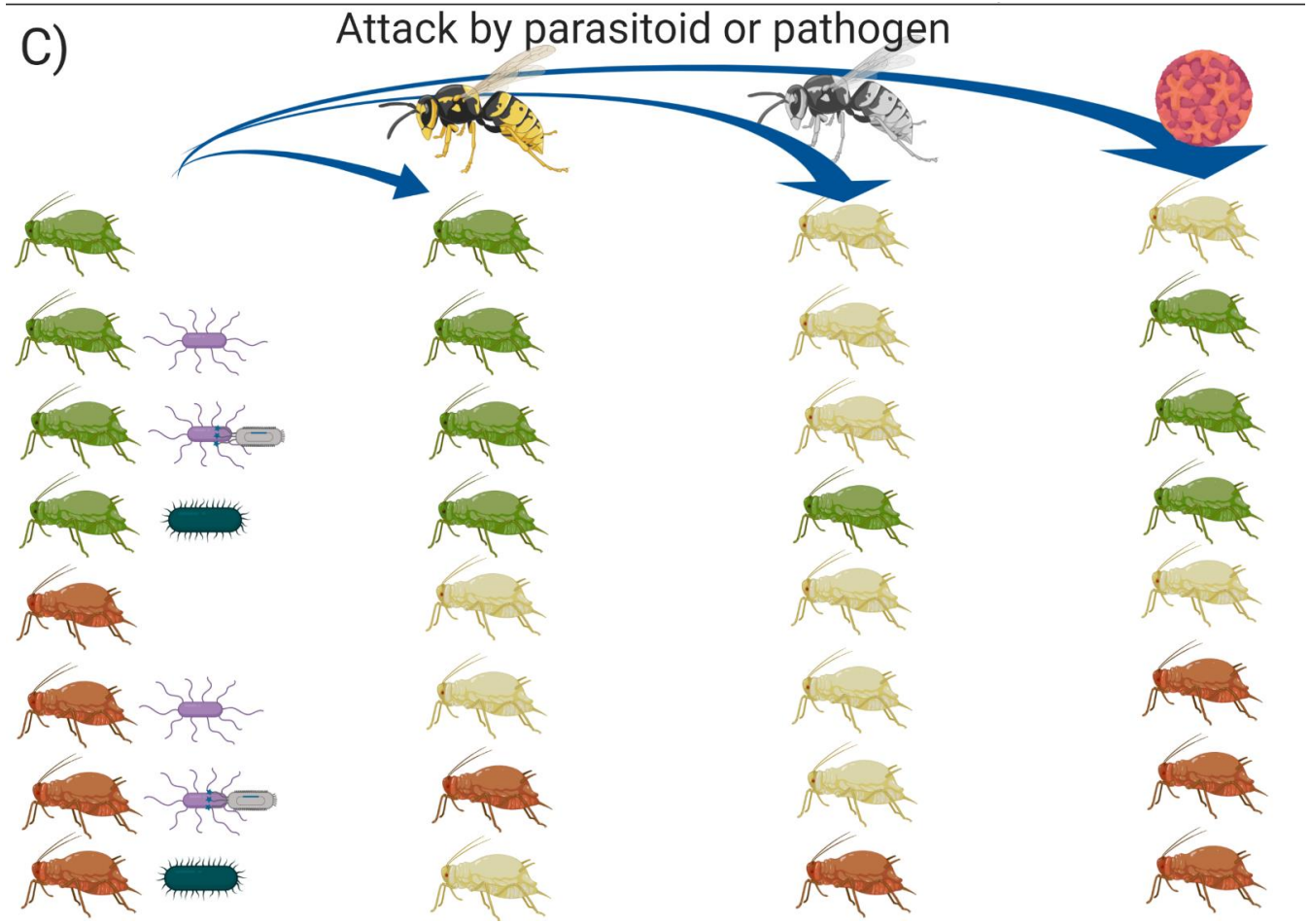
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Graphic created with BioRender.com

Why is the intra-species diversity of herbivorous insects important?

- Influence insect virulence
- Confer resistance
  - Natural enemies (parasitoid wasps)
  - Insecticides
- Influence interactions with environment
- Determine host range



Graphic created with BioRender.com

Two herbivorous insect systems, two connected projects

1. Cereal aphids - The Agricultural Landscape and Arthropod biodiversity Nexus (ALAN)

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2. Cabbage stem flea beetle - Landscape effects on the diversity of the Cabbage stem flea beetle *Psylliodes chrysocephala*

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ALAN – Project overview

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- Intra-species variation of cereal aphids has been well characterised
- Success of natural biocontrol is variable

Is there an ecological interaction between intra-species diversity and natural biocontrol success?

Aims:

1. Determine whether agricultural landscape diversity affects aphid abundance, aphid species diversity, aphid intra-species diversity, natural enemy diversity, and natural enemy success
2. Examine these at different scales in the field: field edge and in-crop
3. Identify any phenotypic traits associated with changes in intra-species diversity



ALAN – Experimental Approach

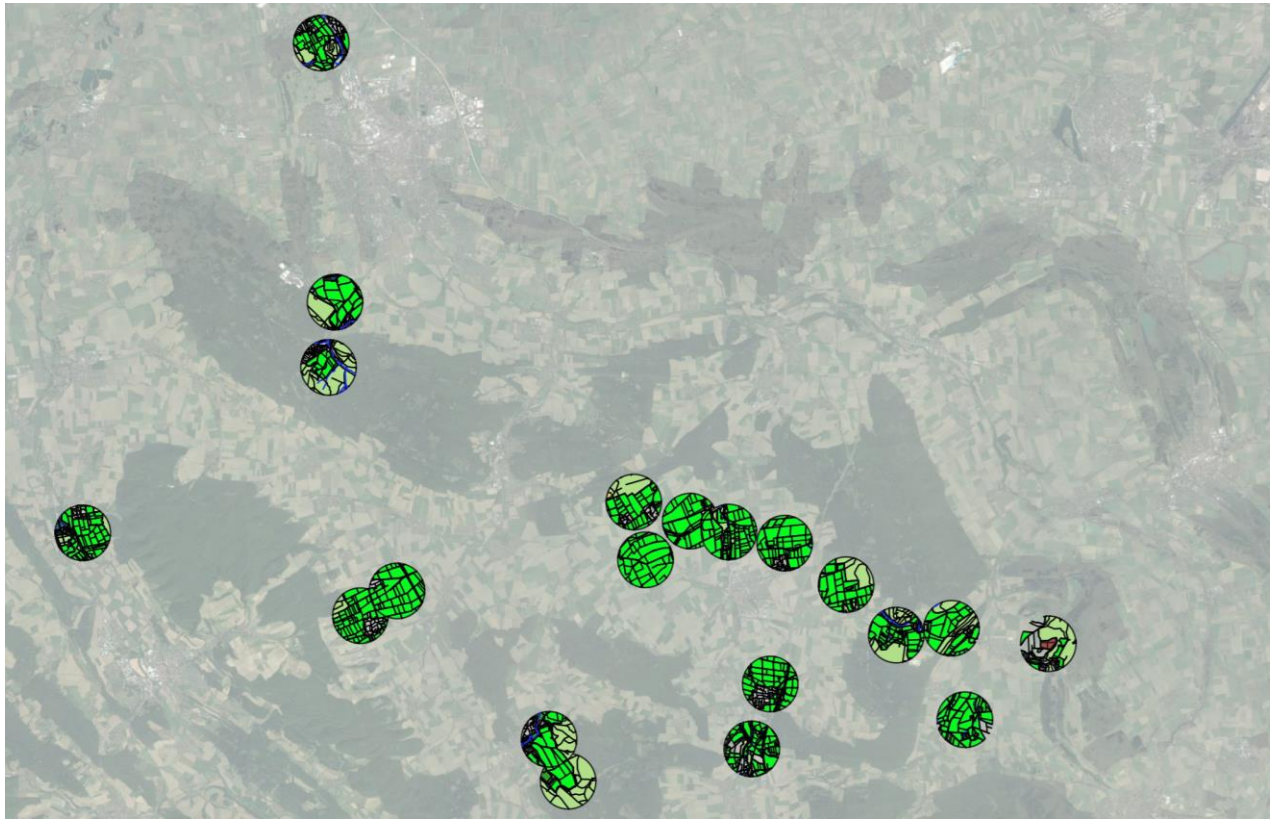
Alexander von Humboldt
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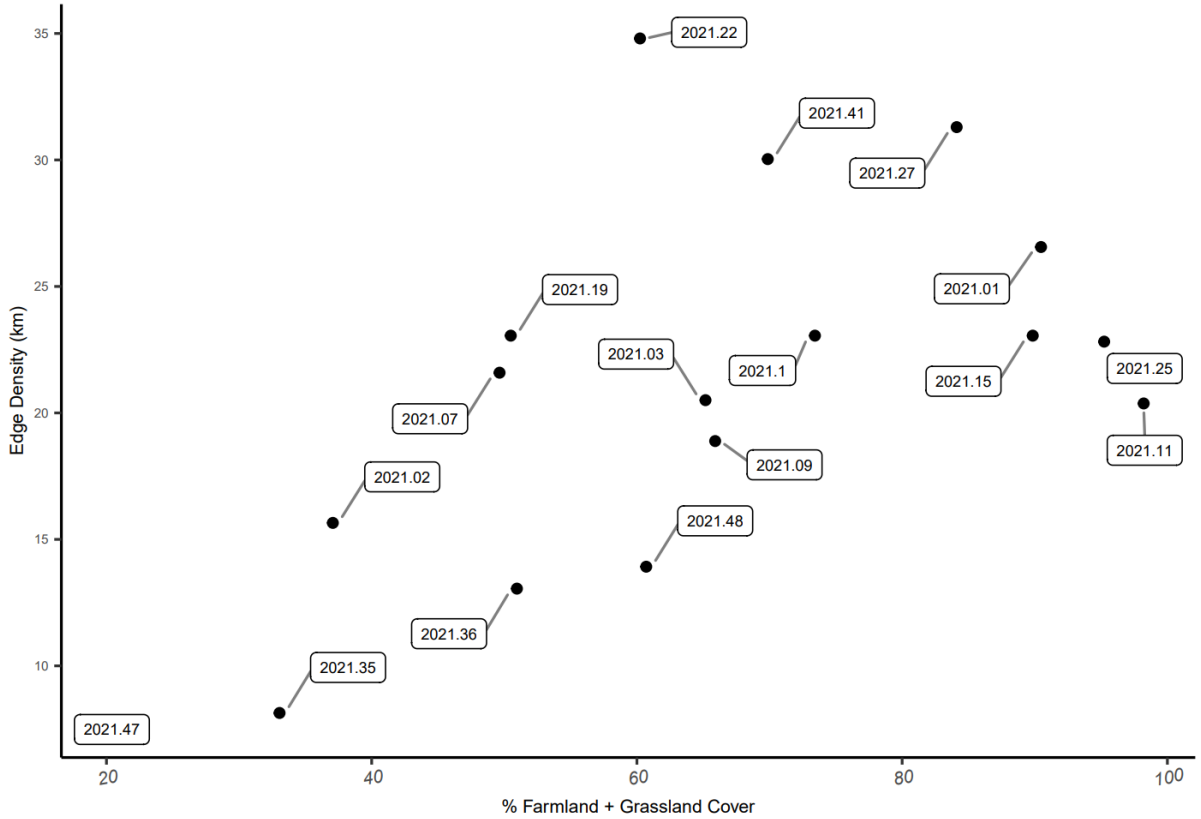
- 20 field sites each year (40 total)
- Heterogeneity and diversity of landscape surrounding each field mapped
- Sites visited on three occasions
  - Natural enemy diversity monitored (pan and pitfall traps)
  - Aphid, mummies, parasitoids counted
  - Aphids, mummies, parasitoids sampled for molecular diagnosis of intra-species diversity
- Live aphid samples collected and lab cultures established
- Statistical modelling
- Controlled environment experiments for insect bio-assays



ALAN – Experimental Approach

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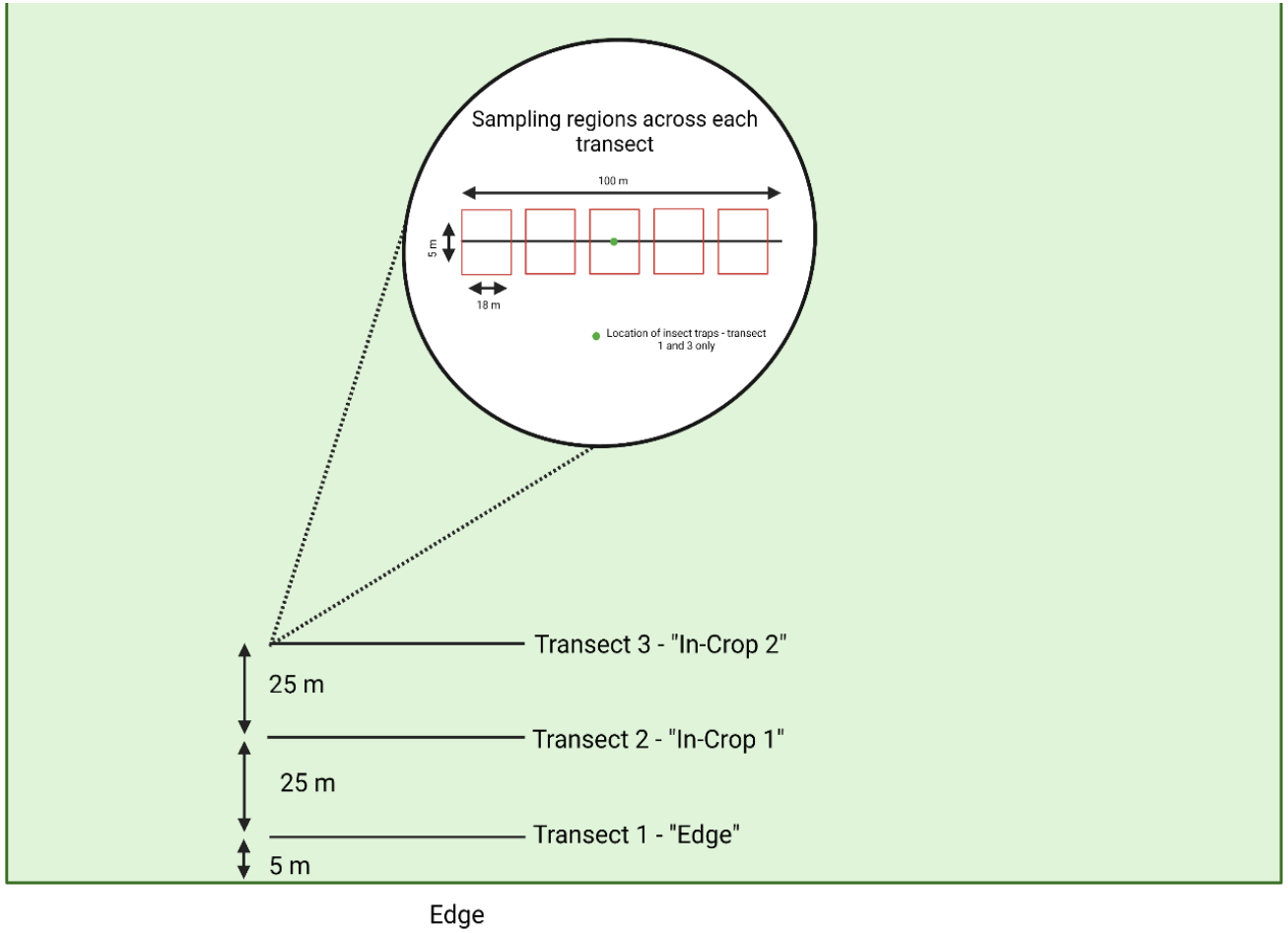






ALAN – Experimental Approach

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Sites visited on three occasions

- Natural enemy diversity monitored (pan and pitfall traps)
- Aphid, mummies, parasitoids counted at five locations per transect
- Aphids, mummies, parasitoids sampled for molecular diagnosis of intra-species diversity



Diversity in *Psylliodes chrysocephala* – Project overview

- Endosymbiont communities of *P. chrysocephala* have not been examined in great detail
- Pest biology is significantly understudied

Is there an ecological interaction between landscape diversity, intra-species diversity, and pest success?

Aims:

1. Characterise the endosymbiotic community and genetic diversity of cabbage stem flea beetle populations
2. Determine if agricultural diversity affects this diversity
3. Identify any phenotypic traits associated with insect diversity



Diversity in *Psylliodes chrysocephala* – Experimental approach

- 24 field sites (12 in Germany, 12 in UK)
- Diversity of landscape surrounding each field mapped
- Live cabbage stem flea beetle samples collected (four sampling locations per site)
- Beetle microbiome characterised by Illumina MiSeq (bacterial and fungal symbionts to be identified)
- Genotyping by sequencing approach to characterise genetic diversity of beetle populations
- Diagnostic PCR assay to determine symbiont progression through life-stages
- Insect bioassays to identify phenotypes associated with different intra-species traits



Summary

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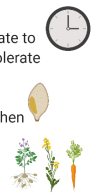
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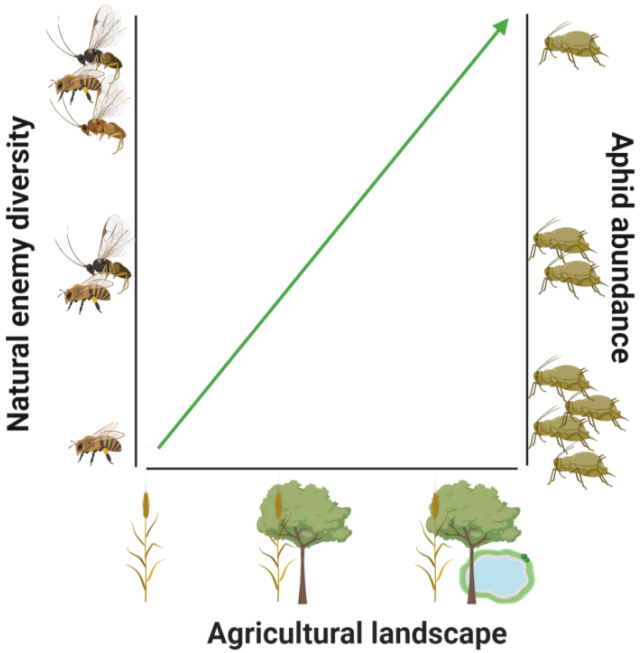
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2) Natural biocontrol – ecological drivers of variable success



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Acknowledgements

Dr Kate Storer (ADAS, UK)

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Dr Steve Ellis (ADAS, UK)

David Lunn (ADAS, UK)

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Tom Whiteside (ADAS, UK)

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Dr Emily Martin (Leibniz University Hannover, Germany)

Dr Sharon Zytynska (Liverpool University, UK)

Dr Antonino Malacrinò (University of Münster, Germany)

Dr Pilar Morera-Margarait (The James Hutton Institute, UK)

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