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Opportunities and challenges for weed detection and precision management

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BBSRC bioscience for the future

Lawes Agricultural Trust

Weed detection and precision herbicide application

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Current Management Paradigm

Weeds are predominantly managed by herbicides, which are costly and have perceived environmental consequences. Weeds often look different to crops (though not always).

Precision Weed Management Premise

Weed recognition allows precision targeting, applying herbicides or non-chemical management directly where needed.



Steininger et al. (2023). The CropAndWeed Dataset: a multi-modal learning approach for efficient crop and weed manipulation. Proc. IEEE/CVF Winter Conference on Applications of Computer Vision (WACV), 3729–3738.

Three questions for precision weed management

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1

Implementation

What are the benefits of precision management and how would it be used?

- What: types of precision application
- Why: potential benefits of adoption
- How: practical approaches to implementation

2

Detection and mapping

How reliably can we detect and manage weeds in a precise way?

- Are weeds patchy, and can we map them?
- Can last season's map help this season?
- Can we detect weeds earlier?

3

Longer-term implications

What are the longer-term implications of this technology?

- Herbicide resistance evolution
- Evolution of crop mimicry

Types of precision application

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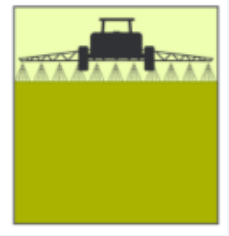
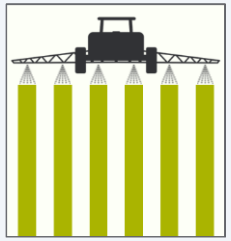
Broadcast



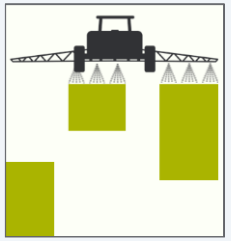
Uniform application across full field area

Banded



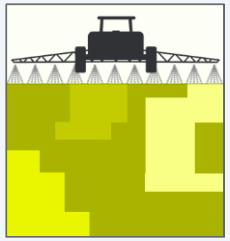
Targeted strips aligned with crop rows

Patch



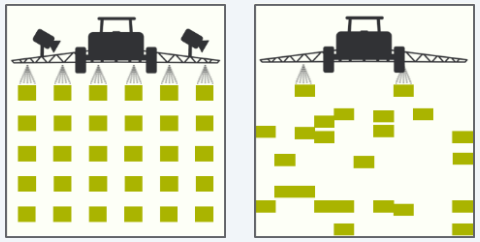
Defined weed treatment zones

Variable rate



Spatially variable number or dose of actives

Regular / Irregular spot



Grid-based or dynamic spraying of small areas

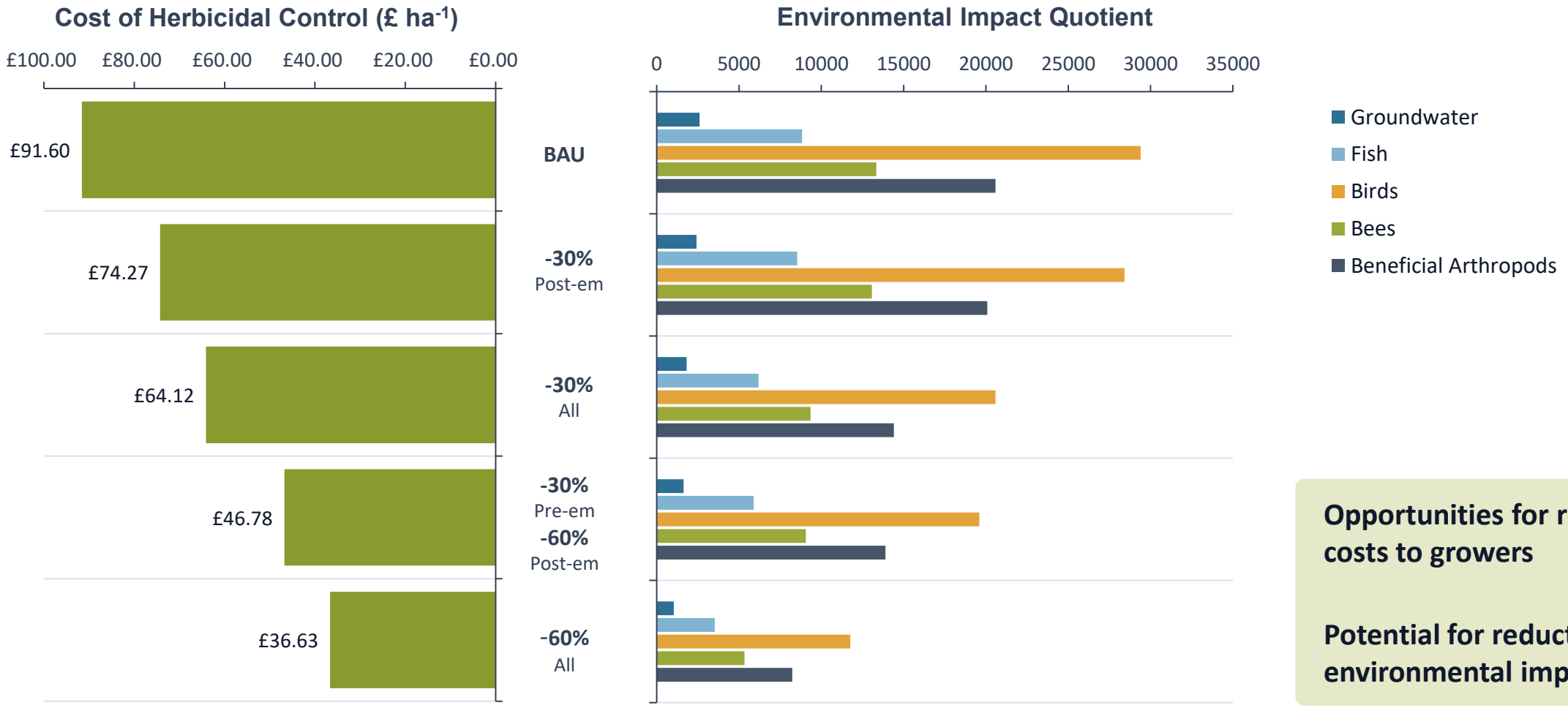
Single plant



Targeted spraying to individual weed plants

"European Precision Application Task Force" (EUPAF): *TG1 – Precision application equipment inventory, use, categories, terminology, and use reduction classification system*

Potential savings in cost and environmental impact



Opportunities for reduced costs to growers

Potential for reductions in environmental impact

BAU = business as usual. Costs: 2021 retail prices (Nix, 2021). EIQ: Environmental Impact Quotient (Kovach et al., 1992).

Two routes: prescription maps or real-time detection

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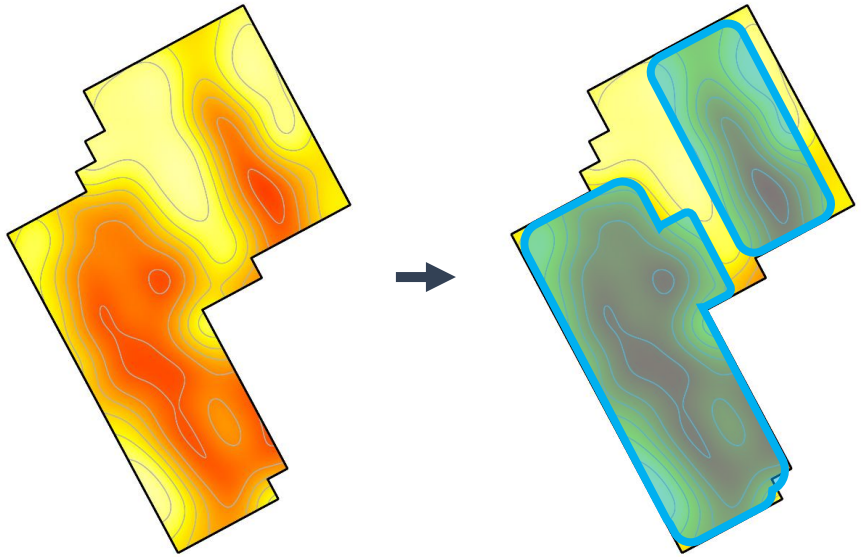
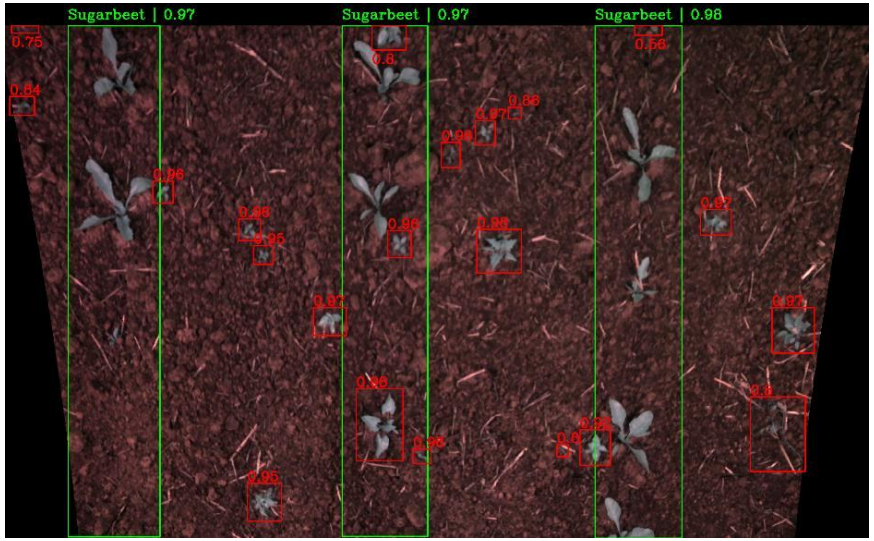
Mapping and prescription application

Mapping weed distributions first, generating prescription files, and applying later.



Real-time detection and control

Detecting and spraying weeds simultaneously in one pass using on-boom camera systems and rapid nozzle control.



Both Approaches Rely On:

Spatial Heterogeneity

Weed distributions must be spatially heterogeneous across the field

Detection Capability

The capacity to accurately detect and classify where weeds are located.

Targeting Hardware

The physical technology to accurately spray only where directed.

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Part 2 · Detection and mapping

Are weeds spatially heterogeneous? And can we map them from imagery?

Focus on grassweeds in cereals

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A Considerable Issue

Grassweeds represent a major economic and environmental challenge across arable agricultural systems.

A ‘Tricky’ Problem

Morphological similarities between cereal crops and grassweed species present a complex challenge for precision detection





Weed distributions are not homogeneous

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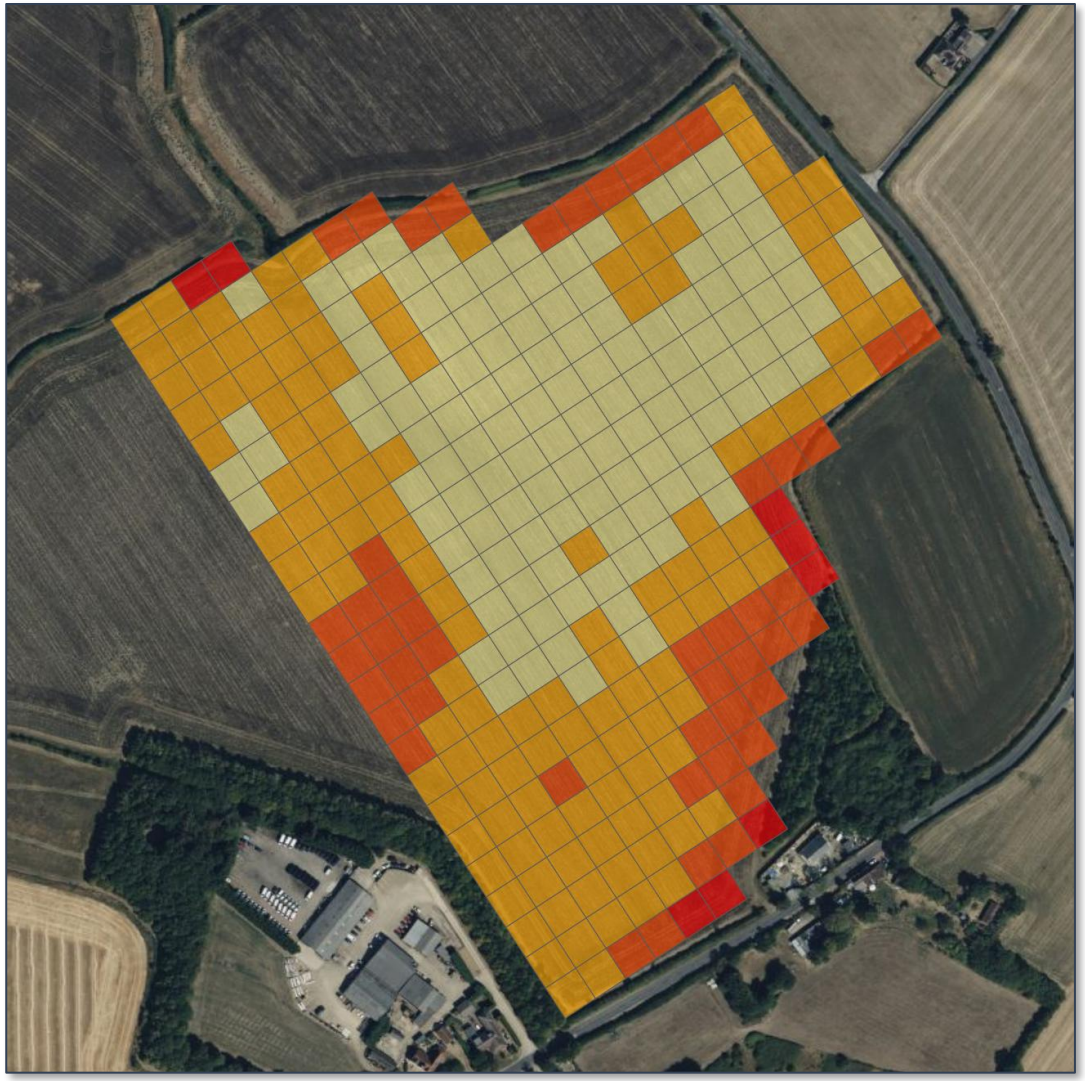



Black-grass is patchy, but patchiness varies widely

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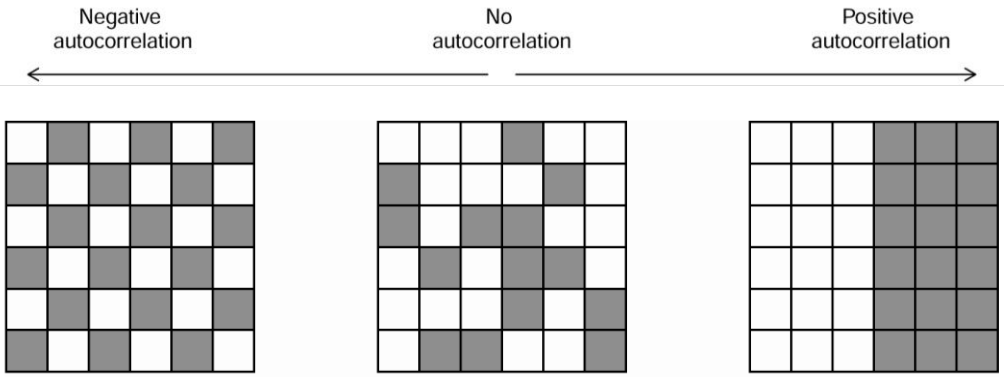

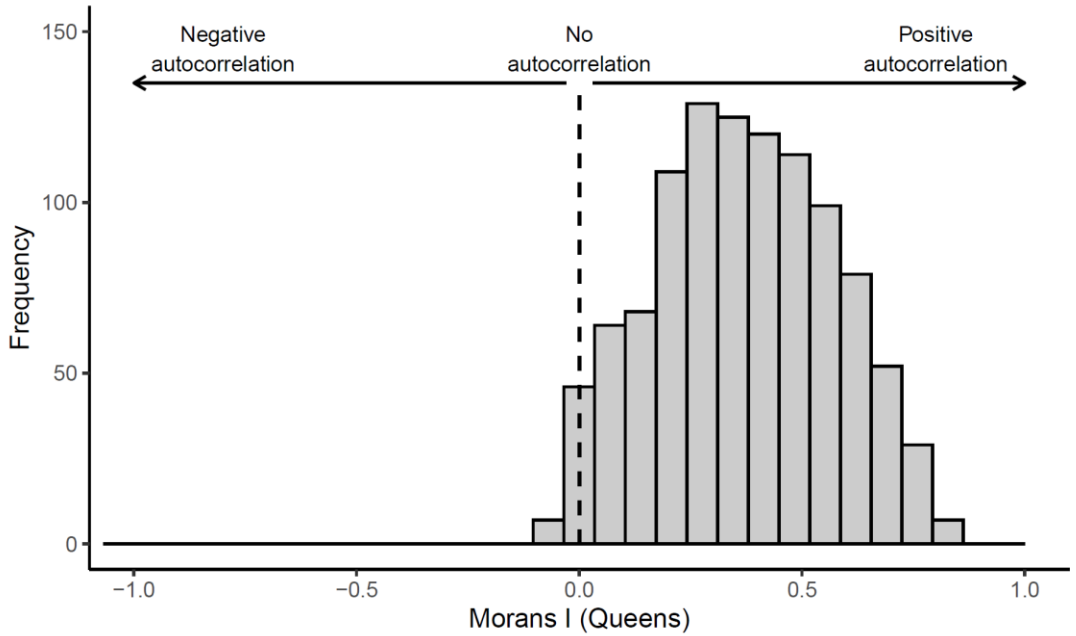

Large-scale data:

- **from 472 fields,**
- **>2,000 field × years**

Black-grass shows positive spatial autocorrelation, i.e. forming distinct patches within a field.

However, this is going to vary considerably amongst weed species and from field to field.

Any benefit from precision spraying is going to be strongly situation-specific.

Comont et al. (in press). Untangling the spatial and temporal dynamics of arable weed patchiness. Weed Research.

Mapping black-grass from UAVs

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Attempted to map black-grass at flowering using drones

- Created high quality dataset of 34 wheat fields in 2021
- Images at 1cm resolution using a DJI M210 UAV, with X7 sensors







The University Of Sheffield. IBM Hummingbird Technologies Precision Decisions DRIVING FARMING FORWARDS

AI picks out black-grass in UAV imagery

IBM

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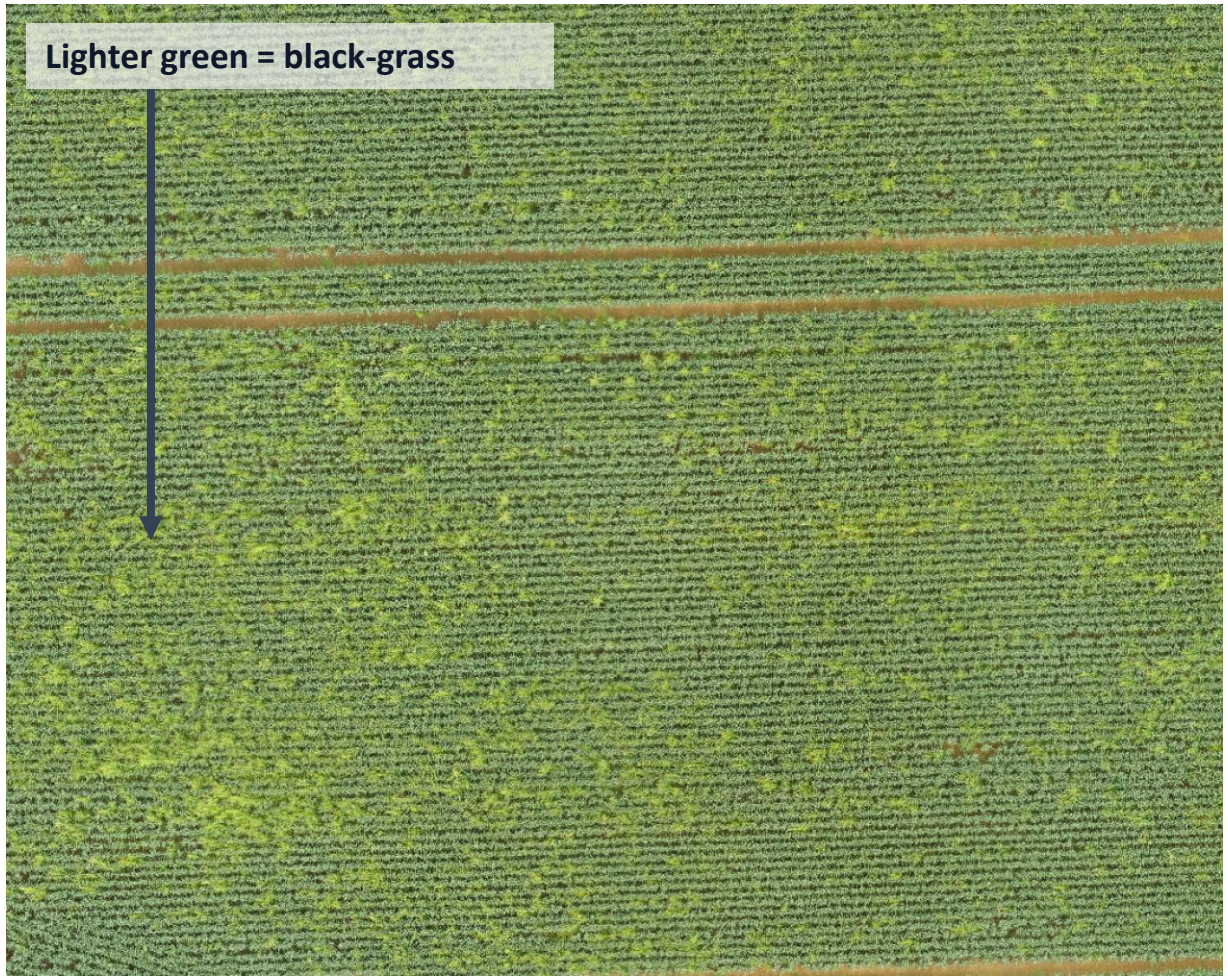
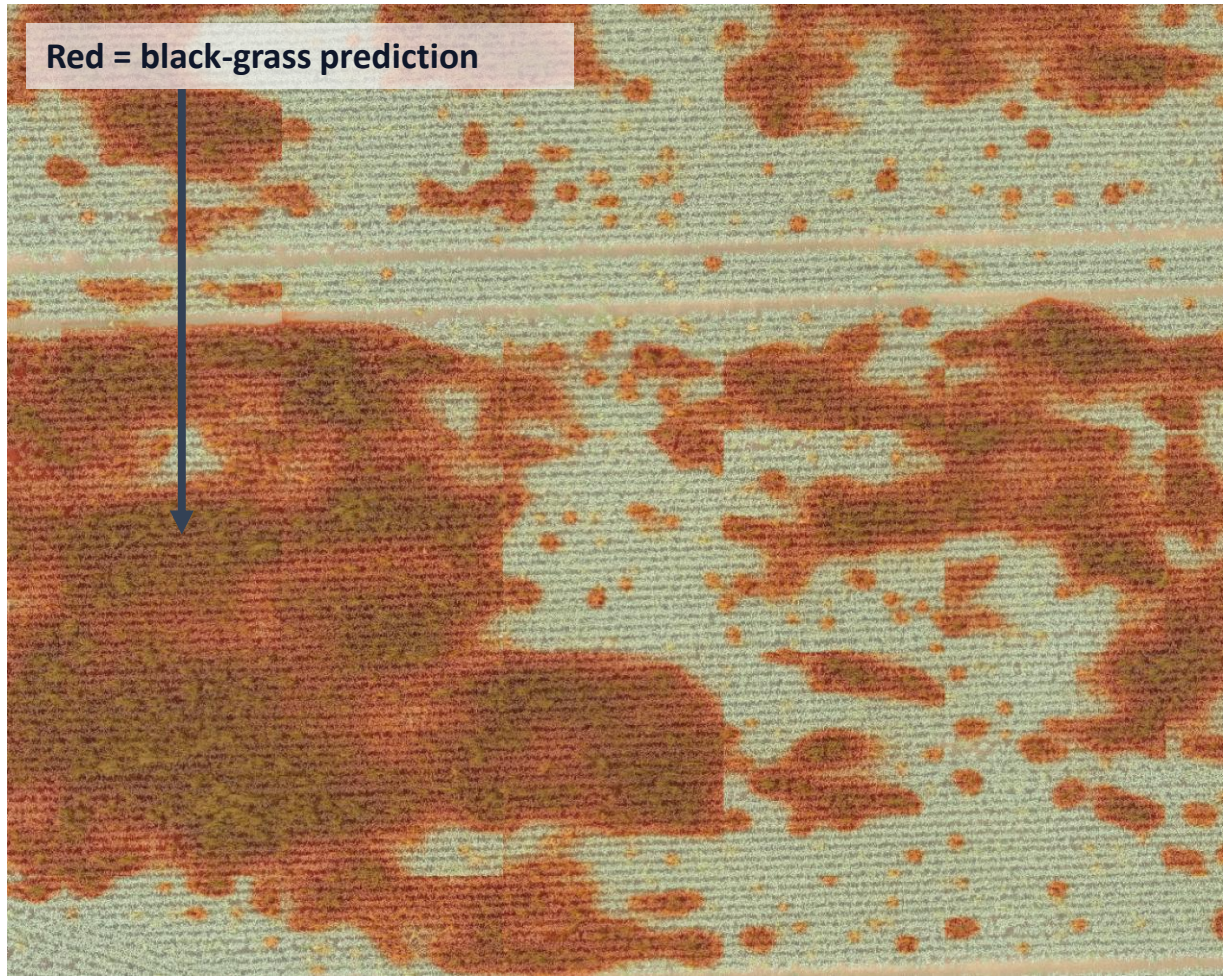
RGB UAV Image



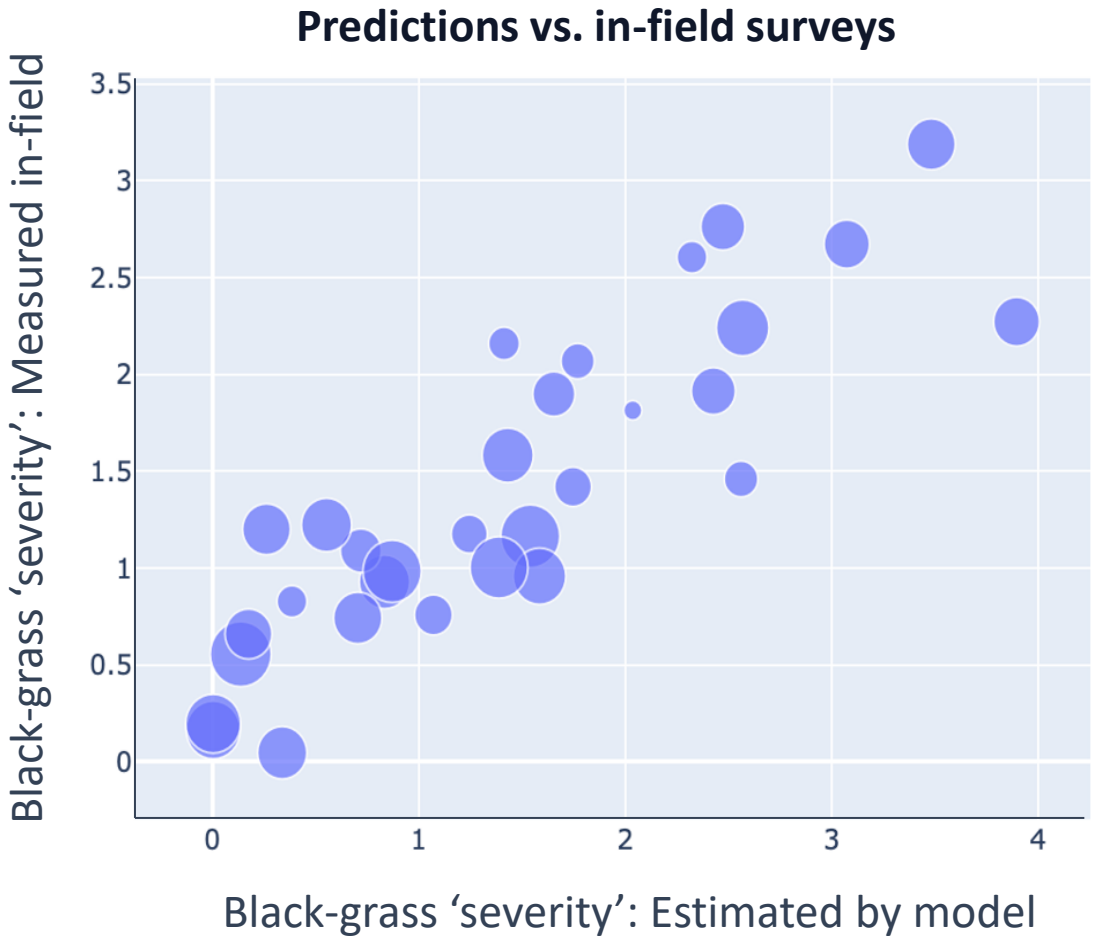
AI model prediction



UAV predictions match in-field surveys

The model predictions were converted to a format equivalent to our in-field weed survey data:

- **Spatial arrangement of black-grass patches conforms well with in-field mapping**
- **Strong positive correlation between model predictions and actual measured abundance**



Fraccaro et al. (2022). A deep learning application to map weed spatial extent from unmanned aerial vehicles imagery. Remote Sensing 14(17), 4197. https://doi.org/10.3390/rs14174197

UAV maps arrive too late for most management

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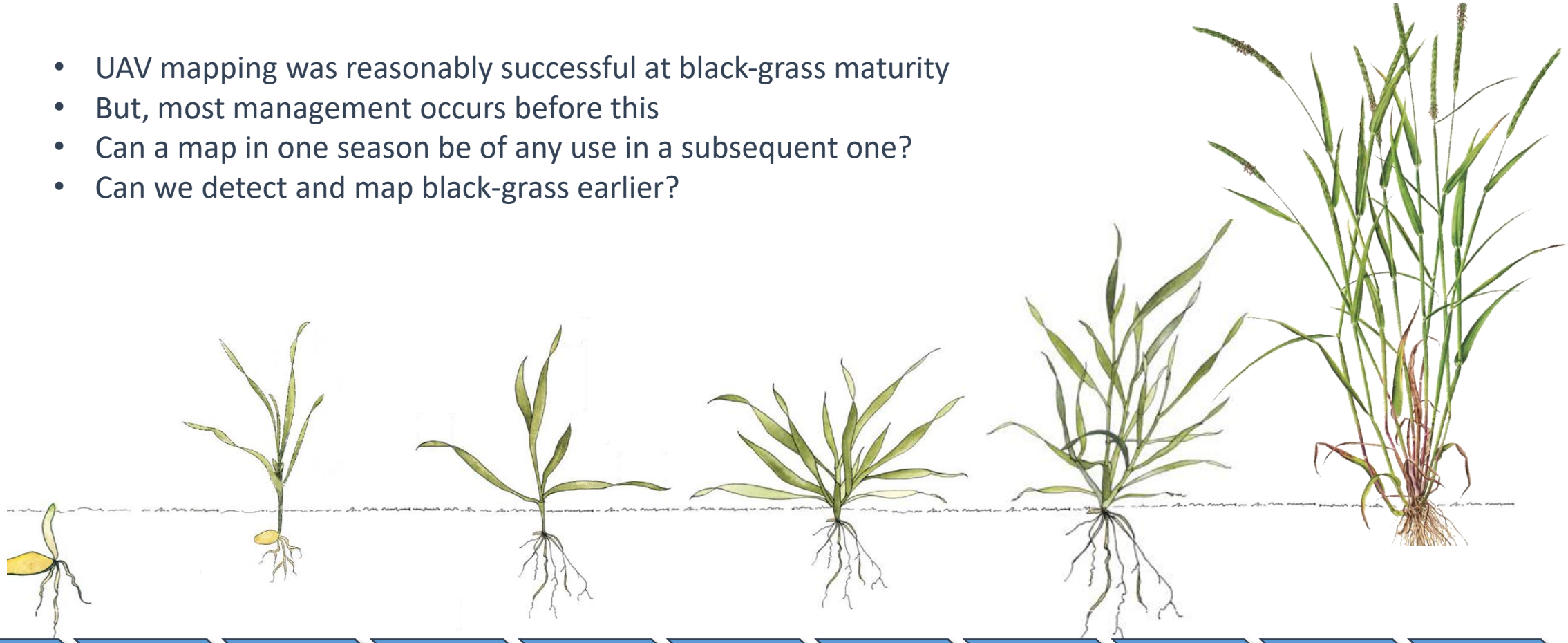
Black-grass management

UAV mapping

- UAV mapping was reasonably successful at black-grass maturity
- But, most management occurs before this
- Can a map in one season be of any use in a subsequent one?
- Can we detect and map black-grass earlier?



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Part 2 · Detection and mapping

Can a map from a previous season help with application in the next?

How might we use maps from a previous season?

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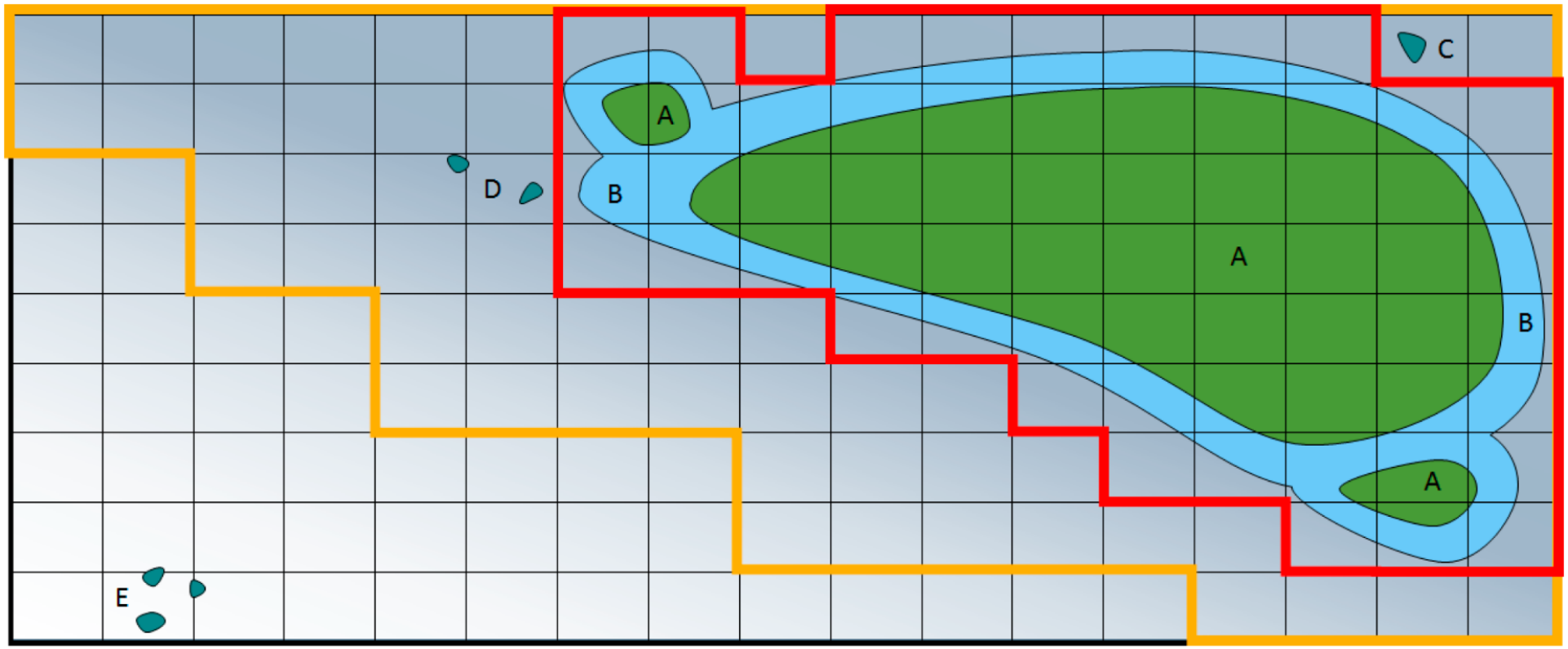
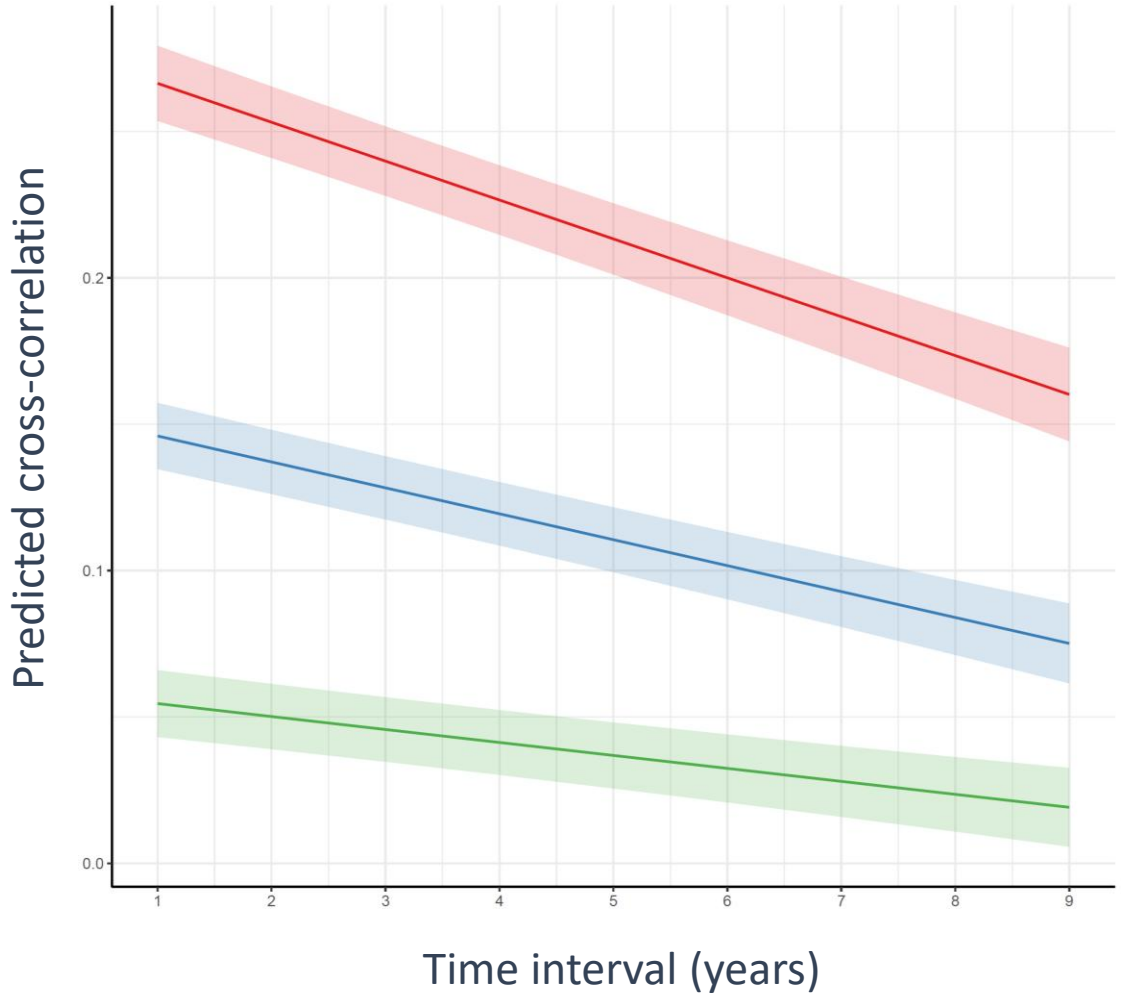
- Targeted pre-emergence herbicide: can't see the plants as they haven't germinated.
- Have to use previous seasons' maps *and* data on habitat suitability.
- Still relies on weed patches remaining stable over time…



Detected weeds
Buffer zone
Conventional spray zone
Weed vulnerable zone

Somerville et al. (2020). Spatial modelling of within-field weed populations; a review. Agronomy 10(7), 1044. https://doi.org/10.3390/agronomy10071044

Weed patches are modestly stable year to year



Answer: Sort of. There is some modest temporal persistence over short intervals. This declines as the interval between mapping increases.

This also varies from species to species, site to site.

Whilst informative, it's unlikely to be good enough to base a full herbicide programme on.

Comont et al. (in press). Untangling the spatial and temporal dynamics of arable weed patchiness. Weed Research.

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Part 2 · Detection and mapping

Can we detect weeds earlier in the season, and either map for prescription or control in one go?

Mapping black-grass: cameras on a sprayer boom

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Approximately 9,000,000 images, across 15 fields, at multiple time points:

- Stubbles + stale seedbeds
- Broadleaf weeds in cereals
- Grassweeds in broadleaf crops
- Grassweeds in cereals

Chafer · BASF We create chemistry · BOSCH · xarvio™ Digital Farming Solutions

Detection accuracy improved with more training data

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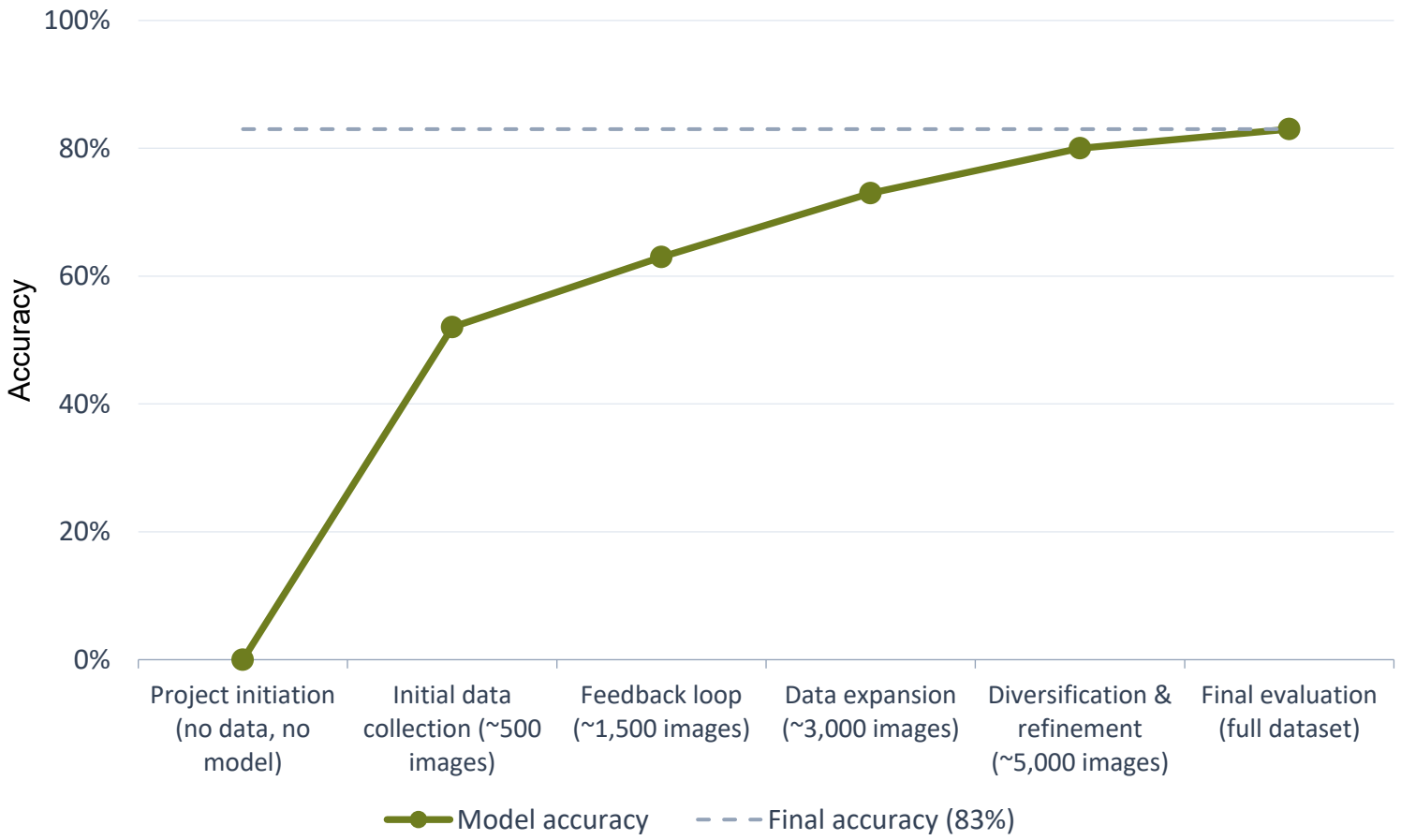
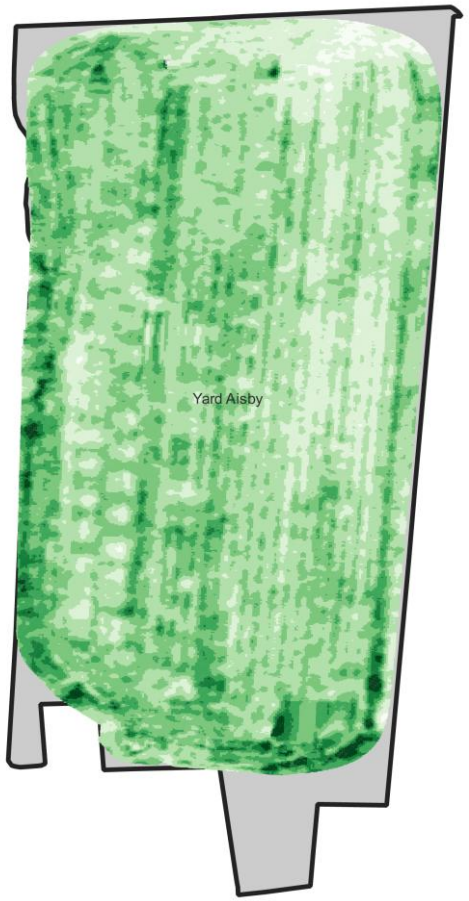
Models for Real-time detection and control



Mapping for prescription application



Accuracy falls as crop-weed similarity increases

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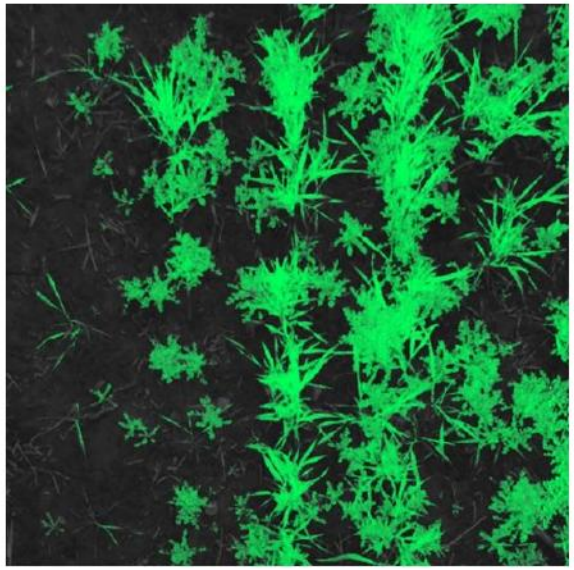
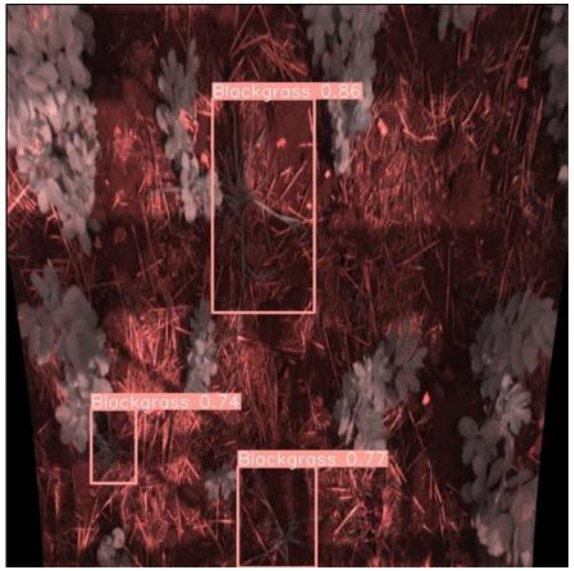
- Model performance remains situation-specific
- More accurate models will need more data…

Weeds on bare soil (stale seedbed)



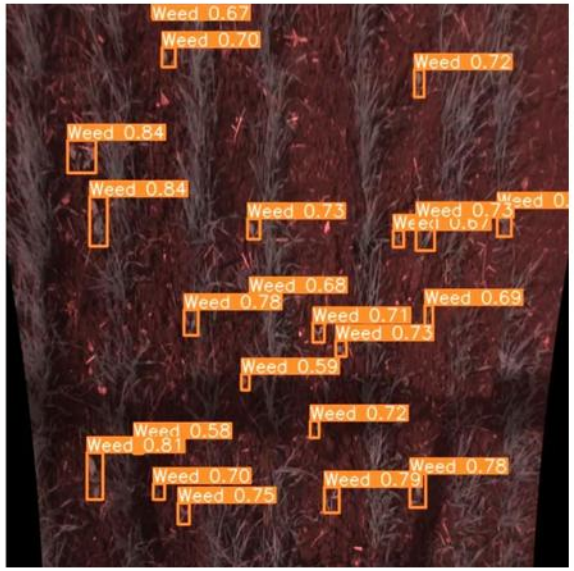
No model needed

Black-grass in beans



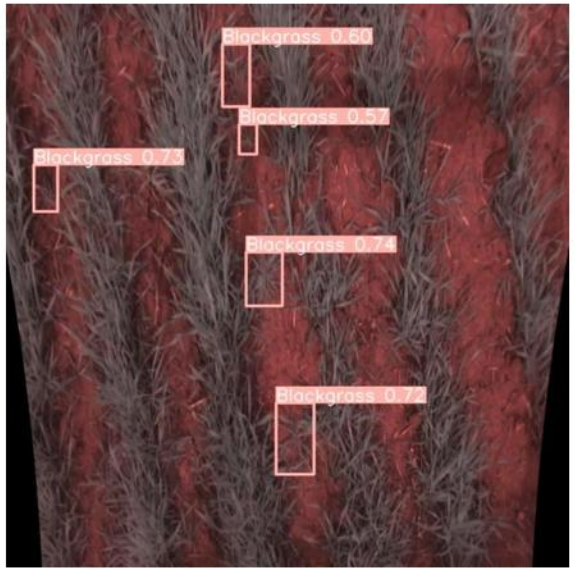
mAP50 = 0.90

Broadleaf weeds in wheat



mAP50 = 0.87

Black-grass in wheat



mAP50 = 0.36

Increasing crop–weed visual similarity

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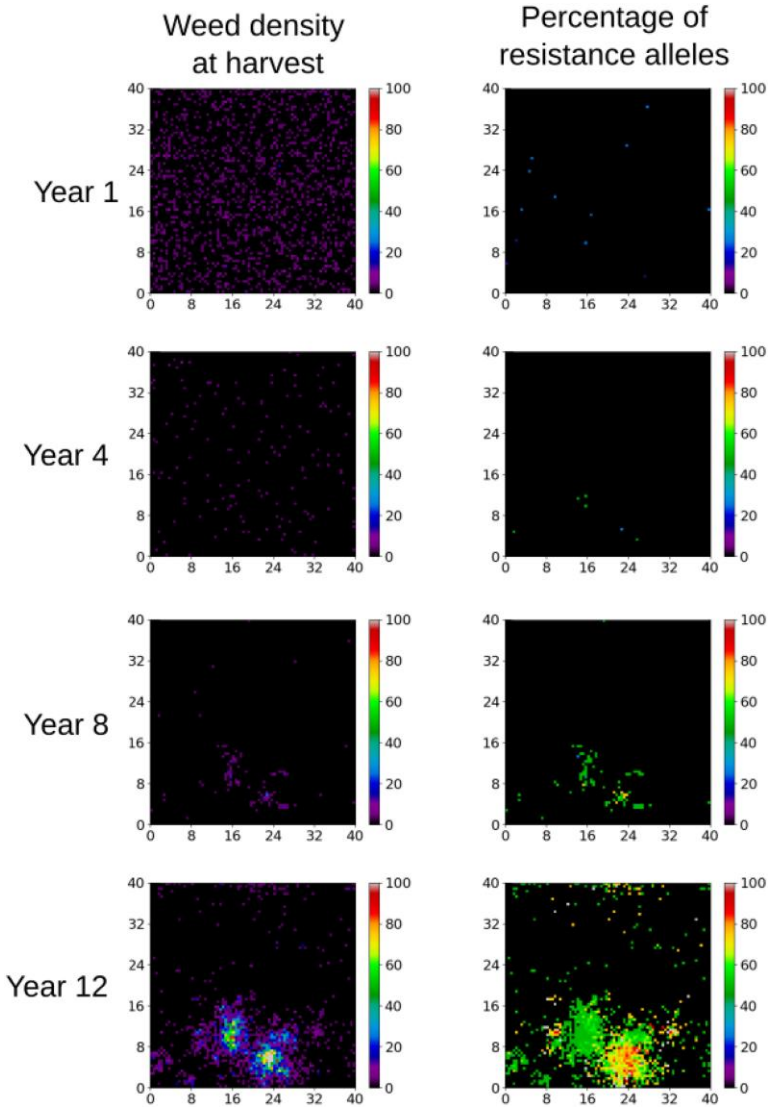
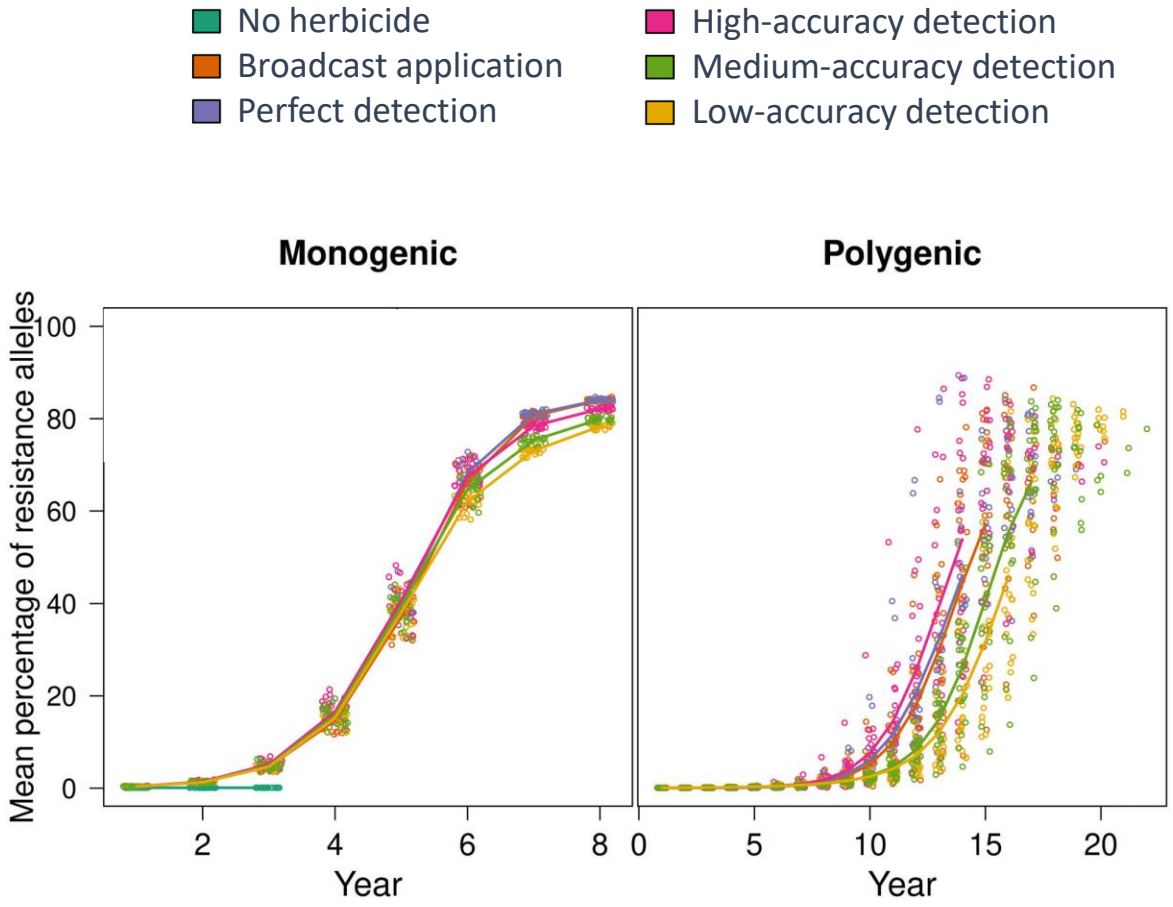
Part 3 · Longer-term implications

What are the longer-term evolutionary implications?

What might this do for resistance evolution?





Salinas et al. (2026). Do spatially targeted weed management strategies increase risk of herbicide resistance evolution? Pest Management Science. https://doi.org/10.1002/ps.71330

For the UK: Updating a spatially explicit weed model

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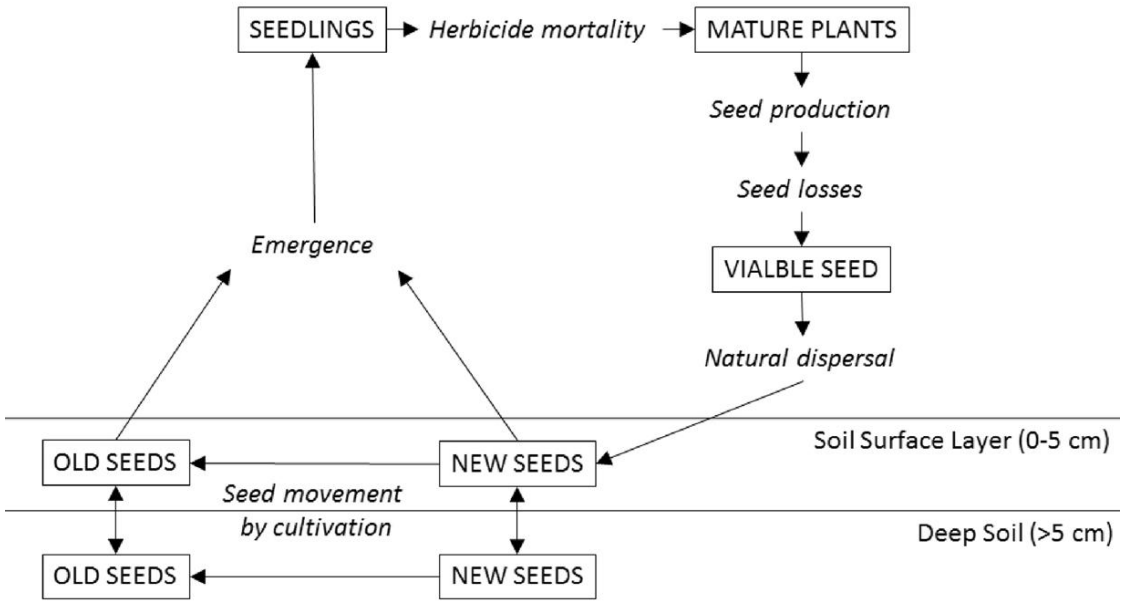
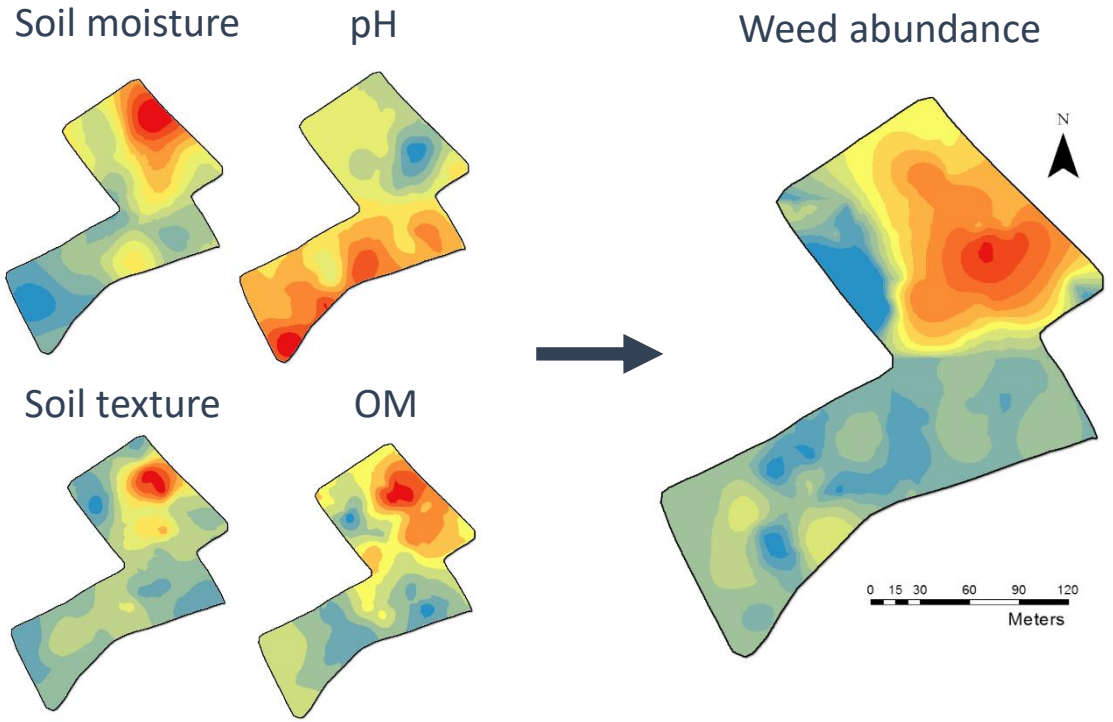
Weed life-history



Soil habitat suitability



Metcalfe et al. (2019). Modelling the effect of spatially variable soil properties on the distribution of weeds. Ecological Modelling 396, 1–11. https://doi.org/10.1016/j.ecolmodel.2018.11.002

Inclusion of spatially explicit resistance evolution

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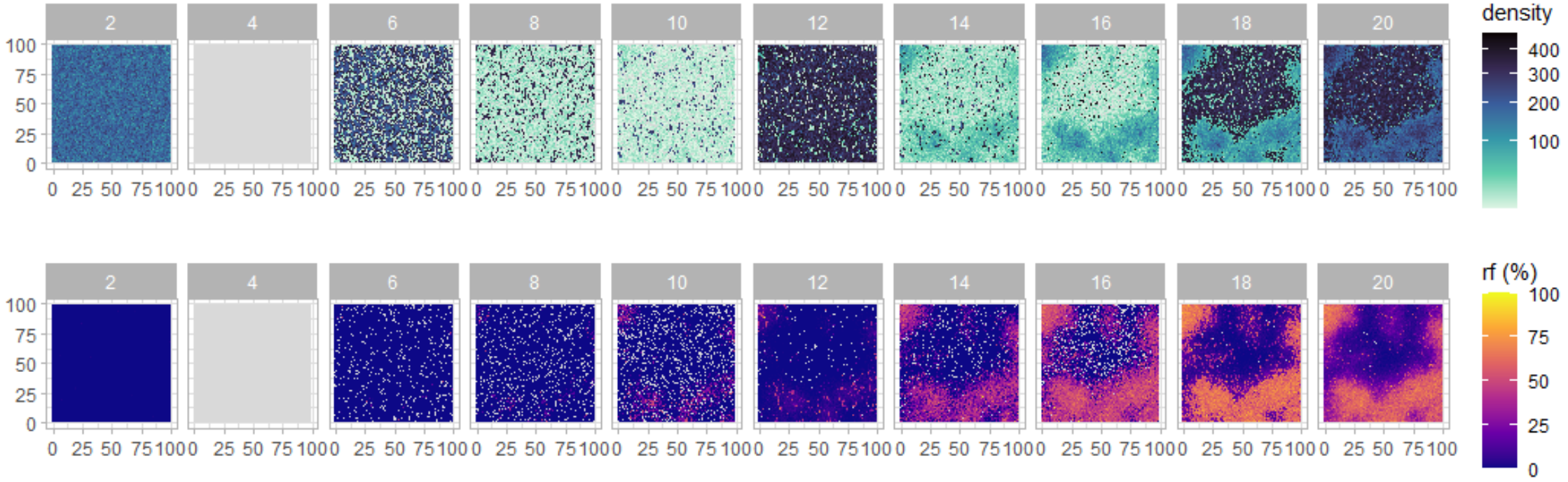
- Including resistance alleles into the spatially explicit model
- Allows simulation of different precision management scenarios
- Identify the potential implications for evolution of resistance at sub-field scales

We need to model the impact of precision spraying on herbicide resistance evolution, so that we can appropriately safeguard against the risk.

Top row: weed density **Bottom row:** resistance frequency, rf (%)



And further evolution to counter weed detection?

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Crop (rice) | **Weed -** *Echinochloa crus-galli* **(crop mimic)** | **(wild-type)**





Recurrent selection for 'crop-like' morphology leads to evolution

How soon before evolution poses a threat to image-based recognition?

Coleman et al. (2023). Image-based weed recognition and control: can it select for crop mimicry? Weed Research. https://doi.org/10.1111/wre.12566

Conclusions

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- Weed detection and precision management are already in use in some areas
- In the UK, some weed populations *are* spatially heterogeneous and show modest temporal persistence
- But the potential opportunity for precision management is going to be variable: Species, field, situation, detection capacity and technology.

We need to use robust data-driven approaches to evaluate this technology now, and identify future use-cases and risks.

Thanks for listening

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Any Questions?

Funding and partners:

BBSRC bioscience for the future

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UKRI Innovate UK

Chafer

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