Report on landscape complementation modelling including validation and modification of the models in the Farmer Clusters involved

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- **Contributors**

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1. Background to the FRAMEwork project

1.1 FRAMEwork Project Executive Summary *(abbreviated)*

Biodiversity is essential for agroecosystem resilience, sustainability, and long-term food security. Traditionally, management for short-term economic returns has taken priority over management for the environment. Current mechanisms for compensating and encouraging farmers to apply biodiversity sensitive management strategies are often inefficient, being applied at individual farm rather than landscape level, and tend to be generic solutions, imposed from the top down at an EU or national level. Monitoring is rarely carried out and there is therefore little scope for evaluating the success of strategies in achieving improvements to farmland biodiversity.

The FRAMEwork project has been designed and develop a novel alternative to this called the **FRAMEwork System for Biodiversity Sensitive Farming** to enable the transition of EU farming systems to a position where they can conserve biodiversity and benefit from the enhancement of ecosystem services, while mitigating agronomic or economic risks. The FRAMEwork System combines the following elements:

- **Advanced Farmer Clusters** – local farmer groups working as a collective to deliver landscape scale management, supported by a Cluster Facilitator with expertise in agriculture and the environment, and linked to a local Cluster Stakeholder Group to inform and promote policy and practice, organised into regional, national, and international networks.
- **Technical Resource** – technical specialists associated with the regional, national, international networks to provide technical information, methods, and tools to support agrobiodiversity monitoring, management and policy including the dedicated DSTs – FRAMEselect and FRAMEtest.
- **Scientific Innovation** – researchers associated with regional, national, international networks to provide knowledge on the ecology, sociology and economics that underpins the functioning of sustainable agricultural systems.
- **Citizen Observatory and Information Hub** – an open access platform to support FRAMEwork networks, sharing activities, information, data and resources between farmers, scientists, policy makers, and citizens.

The FRAMEwork project will design, build, test, and deploy a prototype of the FRAMEwork System for Biodiversity Sensitive Farming and will work with 3 concepts important to the success and delivery of the project: (i) promoting collective landscape management; (ii) applying the approach across a diversity of European farming systems; and (iii) understanding and supporting the social and ecological change associated with a transition to biodiversity sensitive farming.

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1.2 Project Partners

No	Participant organisation name	Type	Country
1*	The James Hutton Institute (HUTTON)	Research Inst	UK
2	Game and Wildlife Conservation Trust (GWCT)	Non-profit	UK
3	Groupe de Recherche en Agriculture Biologique (GRAB)	Non-profit	FR
4	Universitaet fuer Bodenkultur Wien (BOKU)	University	AT
5	Eesti Maaulikool (EMU)	University	EE
6	Hoehere Bundeslehr- und Forschungsanstalt fuer Landwirtschaft Raumberg-Gumpenstein (AREC)	Research Inst	AT
7	Fundacion Artemisan (ARTEMISAN)	Non-profit	ES
8	Scuola Superiore di Studi Universitari e di Perfezionamento Sant'anna (SSSA)	University	IT
9	The University of Hertfordshire Higher Education Corporation (UNI OF HERTS)	University	UK
10	Centro de Investigacion Ecologica Yaplicaciones Forestales Consorcio (CREAF)	University	ES
11	Institut National de la Recherche Agronomique (INRA)	Research Inst	FR
12	Internationales Institut fuer Angewandte Systemanalyse (IIASA)	Research Inst	AT
13	Universiteit van Amsterdam (UvA)	University	NL
14	Luxembourg Institute of Science and Technology (LIST)	Research Inst	LU
15	Universitaet Osnabrueck (UOS)	University	DE
16	Taskscape Associates Limited (TAL)	SME	UK
17	Ceska Zemedelska Univerzita v Praze (CULS)	University	CZ
18	Nordisk Fond for Miljo og Udvikling (NORDECO)	SME	DK

*Coordinating institution

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1.3 Purpose of the Deliverable

The purpose of this deliverable was to create functional Landscape Complementation models with recommendations for the Farmer Clusters involved. During the project trajectory, two different models, a spatially implicit and a spatially explicit model, were created to study how landscape composition, management and configuration affect hoverfly population dynamics and natural pest control of aphids. In deliverable 4.2, the results and recommendations of the spatially implicit model were presented. Deliverable 4.2 showed which landscape composition offers optimal hoverfly performance and natural pest control of aphids and the possible impact of management strategies such as sowing and mowing of flower-rich field margins and pesticide applications on natural pest control. However, this spatially implicit model fails to capture key spatial processes when the arrangement and connectivity of habitats strongly influence ecological interactions. Therefore, we created a spatially explicit model to evaluate how natural enemies disperse through fragmented landscapes or how proximity to semi-natural habitats affects pest suppression in adjacent crop fields. In this deliverable, we will formulate recommendations, based on the spatially explicit model, for farmers and policy makers on the optimal composition and configuration of the agricultural landscape. The recommendations should contribute to a more reliable natural pest control, a reduction in the use of pesticides and an increase of farmland biodiversity.

A manuscript describing the model and model analysis underpinning the recommendations presented in this report will be openly accessible once submitted for publication. Contact Laura Mansier (lauramansier@gmail.com) for further information.

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2. Abstract

The effectiveness and abundance of natural enemies can be enhanced by a diverse landscape with a variety of habitat types as these provide complementary resources throughout the life cycles of natural enemies. However, less is known about how landscape configurations and connectivity affect natural pest control as it is difficult to assess with empirical studies. Spatially explicit models can help in evaluating how natural enemies disperse through fragmented landscapes or how proximity to semi-natural habitats affects pest suppression in adjacent crop fields.

With a spatially explicit model, we studied the dynamics of predatory hoverflies (Diptera: Syrphinae) and their aphid prey in a variety of landscapes with different habitat compositions, configurations and connectivity between habitats. All landscapes consisted of, at least, woody habitats, flower strips and an early (winter wheat) and a late (potato) crop. We show that pest control improves when flower strips and woody habitats increase in size, but increases in woody habitat are more beneficial than increases in flower strips. A crop field will experience better pest control when that field is smaller and in close proximity to a complementary crop. In terms of landscape configuration, flower strips should be adjacent to woody habitats and both crops. Woody habitats should especially be located close to the early crop and the early crop should be located close to the late crop.

Synthesis and applications

Our model shows that pest densities in crops can be strongly affected by landscape composition and configuration of both semi-natural habitats and crop fields. Complementary habitats should be arranged and scaled in such a way that allows for the continuity of resources to natural enemies throughout the year. Our results underscore the importance of tailored arable landscapes to maximize natural pest control and support sustainable agriculture.

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3. Introduction

Agricultural landscapes are often composed of large fields with single crops and a limited amount of (semi)natural areas, resulting in large scale agricultural landscapes with little diversity in habitats (Raven & Wagner, 2021). This is detrimental to all species that require more complex mosaics of croplands and semi-natural habitats (Bianchi et al., 2006; Schellhorn et al., 2015). This also includes species that provide ecosystem services, such as natural pest control. Previous studies have shown that diverse landscapes with a variety of habitat types can enhance the abundance and effectiveness of natural enemies by providing complementary resources throughout their life cycles (Bianchi & van der Werf, 2004; Gurr et al., 2017; Letourneau et al., 2011; Mansier & van Rijn, 2024; Rusch et al., 2016).

However, it is difficult to assess the influence of landscape configuration, and connectivity on natural pest control with empirical studies (Bianchi & van der Werf, 2004; Mansier & van Rijn, 2024). Modelling approaches may improve our understanding of the relationship between the landscape elements and the effectiveness of natural pest control (Bianchi & van der Werf, 2004). Previously, we have studied landscape complementation using a spatially implicit model, assuming that natural enemies can move freely across landscapes and have equal access to all resources, regardless of their actual spatial arrangement (Mansier & van Rijn, 2024). Alternatively, spatially explicit models can assess the importance of the spatial position of habitats. In these models, movement is represented as a reaction diffusion system or a discrete approximation of it (Durrett & Levin, 1994).

Both spatially implicit and explicit models have their own benefits and downsides and are used for different research objectives. Spatially implicit models, which do not account for distance or landscape configuration, are useful for exploring general population dynamics and they make population dynamics relatively easy to explore analytically because of their relative simplicity (DeAngelis & Yurek, 2017; Jongejans et al., 2008; Lopes et al., 2010; Pichancourt et al., 2006). However, these models may fail to capture key spatial processes when the arrangement and connectivity of habitats strongly influence ecological interactions. In such cases, spatially explicit models are more appropriate, as they incorporate the actual configuration of the landscape, including distances and barriers, and how these are overcome by organism movement behaviour (DeAngelis & Yurek, 2017; Pichancourt et al., 2006). For example, when evaluating how natural enemies disperse through fragmented landscapes or how proximity to semi-natural habitats affects pest suppression in adjacent crop fields, spatially explicit models offer crucial insights that implicit models cannot provide. A difficulty of spatially explicit models is that they are often harder to generalize, and their complexity trades off with the ability to explore the model dynamics analytically (DeAngelis & Yurek, 2017; Jongejans et al., 2008; Lopes et al., 2010; Pichancourt et al., 2006). However, these models are essential for understanding how specific landscape features, such as the connectivity of flower strips or the spatial distribution of woody elements, affect natural pest control outcomes at multiple scales.

A suitable spatial approach can be found by comparing models that differ in their level of detail. In this way, it is possible to learn how each level of spatial complexity contributes to the understanding of the spatial population dynamics (Loehle, 2004; Lopes et al., 2010). If spatially implicit and explicit models give very similar results, then it is better to choose the simpler spatially implicit one (Lopes et al., 2010). In this study, we want to compare the outcomes of our previous spatially implicit model with a new spatially explicit model to understand how the configuration and connectivity of habitats impact pest control at both local and landscape scales.

For that reason, we built a spatially explicit model incorporating most element from our spatially implicit model of predatory hoverflies (Diptera: Syrphinae) as natural enemies of aphids (Homoptera:Aphididae), an important pest in different arable crops (Dixon et al., 2007; Mansier & van Rijn, 2024; van Rijn & others, 2014). Juvenile hoverflies require aphid-rich areas for feeding, while adults need access to floral resources for nectar and pollen (van Rijn et al., 2013). Often these resources are found in different habitats and during different times of the year. Therefore, hoverflies will have to move between different habitats to obtain all the resources needed to complete their life-cycle. While hoverflies are relatively mobile, we expect that the movement, survival and effectiveness could be severely limited by spatially separated or poorly connected habitats. Thus, understanding whether the specific configuration of habitats affects pest control is crucial for designing landscapes that maximize ecosystem services.

With creating and analysing this model, we aim to address several key questions: (1) How do the proportions of different habitats affect the effectiveness of natural pest control? (2) How does the specific spatial arrangement of different habitats affect the effectiveness of natural pest control? We have studied this general question by formulating several sub-questions: (A) Do finer scale landscapes promote natural pest control more than larger scale landscapes?; (B) Does it matter for natural pest control where a habitat is located relative to the location of the other habitats?; (C) Does increased connectivity of habitats improve natural pest control?; (D) Do small-scale configuration, such as the proximity of flower strips to crops, have a larger impact on pest suppression than larger-scale landscape patterns, such as the proximity of woody habitats to crops or the proximity of one crop to another? (3) What are the basic differences in outcomes between our spatially implicit and spatially explicit models?

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4. Recommendations

For effective natural pest control, natural enemies need continuous access to resources throughout the growing season. Our model identifies when and where these resources are most critical and shows how both the amount and spatial arrangement of habitats influence pest suppression.

- Increasing the area of semi-natural habitats, both flower strips and woody habitats, improves pest control across crops. These habitats provide complementary resources: woody habitats supply floral resources and aphid prey early in the season, while flower strips extend floral resource availability later in the year.
- Our results indicate that to maximise natural pest suppression, woody habitats should make up a larger part of the available semi-natural habitats area than herbaceous (flower) habitat.
- Pest control in one crop can benefit from the presence of another crop that complements it temporally, for example, by providing prey at different times of the season. Mainly close proximity of that other crop will improve pest control in the focal crop.
- Proximity between woody habitats and the early crop enhances early-season control, as hoverflies and other natural enemies can exploit early resources without needing to travel far.
- Positioning flower strips adjacent and parallel to both crop fields and woody habitats further supports natural enemies by bridging resource gaps throughout the season.

While overall pest suppression improves with increasing habitat area, our results show that even highly mobile species such as hoverflies benefit from spatial proximity between complementary elements. This challenges the common assumption that configuration is less relevant for mobile natural enemies. Moreover, although the gains from improved configuration may be smaller than those from increasing habitat area, they are particularly relevant early in the season, when crops are most vulnerable, and pest pressure is high.

These findings suggest that both the amount and placement of semi-natural habitats should be considered in landscape planning. For farmers, this means that targeted habitat placement, such as aligning flower strips and woody habitats along crop edges, can enhance the benefits of natural pest control, especially early in the season.

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