A functional Landscape Complementation model with recommendations for the Farmer Clusters involved

Deliverable Number: D4.2 (D29)

Lead Author and Institution: Laura Mansier (UvA)

Date of Submission: March, 31st 2023

This Project has received funding from the European Union´s Horizon 2020
research and innovation programme under grant agreement No 862731

Deliverable Description & Contributors

- **Due date**: September, 30th 2022
- **Actual submission date**: March, 31st 2023
- **Project start date**: October, 1st 2020
- **Duration**: 60 months
- **Work package**: WP4 Agroecological Understanding
- **Work package leader**: Anna-Camilla MOONEN (SSSA)
- **Deliverable Title**: A functional Landscape Complementation model with recommendations for the Farmer Clusters involved
- **Nature of deliverable**: Other
- **Dissemination level**: Public

- **Deliverable description:** The presented models will indicate which habitats and resources in the studied area are limiting for the target populations. This will help to recommend management options for the involved Farmer Clusters based on predicted effectivity in enhancing target species and the related ecosystem services.

- **Contributors**
  - Laura Mansier (UvA)
  - Paul van Rijn (UvA)

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 862731

Contents

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.

1.2 Project Partners

No	Participant organisation name	Type	Country
1*	The James Hutton Institute (JHI)	Research Inst	UK
	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

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 862731

1.3 Purpose of the Deliverable

The purpose of this deliverable was to create a functional Landscape Complementation model with recommendations for the Farmer Clusters involved. This model aims to study how landscape composition and management techniques affect hoverfly population dynamics and natural pest control of aphids. The model indicates which landscape composition offers optimal hoverfly performance and natural pest control of aphids. Additionally, the model shows the possible impact of management strategies such as sowing and mowing of flower-rich field margins and pesticide applications on natural pest control. Based on this knowledge, recommendations are formulated for farmers and policy makers on the optimal composition of the agricultural landscape and on the optimal management of landscape elements, including the crop fields. 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. Please contact Laura Mansier (l.mansier@uva.nl) for further information.

This Project has received funding from the European Union´s Horizon 2020
research and innovation programme under grant agreement No 862731

2. Abstract

Pest-regulating insects are broadly considered to benefit from habitats other than agricultural fields. These other habitats can be important in providing hibernation sites, alternative prey, or floral resources. The relative importance of these different habitats to the performance of pest-regulating insects is difficult to study empirically. This is where landscape-based population-dynamical modelling can play an essential role. In this study, we modelled the dynamics of aphidophagous hoverflies (Diptera: Syrphidae) and investigated their effectiveness as control agents of aphids. Whilst larvae of these hoverflies feed on aphids, and enforce natural pest control, adult hoverflies require floral resources. Both types of resources are often spatially and temporally segregated in agricultural landscapes. Therefore, also in our model, hoverflies move between different habitats in the arable landscape. The model is designed and parameterised based on field observations of temporal and habitat-related availability of resources. The model indicates optimal hoverfly performance and aphid suppression when different habitats are present that can provide aphid and/or floral resources at different times of the year. Woody habitat can provide aphid and floral resources early and late in the year, and flower margins during the growing seasons of the crops. Arable crops, such as winter wheat and potato, can enhance each other's pest control when their aphid populations peak at different moments in time. Agricultural management techniques, such as mowing and planting of flower margins, can be optimised in such a way that resources are spatially and temporally complementary in the landscape. The model indicates optimal hoverfly performance and aphid suppression when flower mixtures produce many flowers suitable for hoverflies. Sowing flower margins early in the year next to an early crop provides hoverflies with floral resources at the time when aphid numbers increase in the early crop, which in turn, improves aphid suppression by hoverflies in that crop. Mowing and pesticide use reduce hoverfly performance and increase aphid abundance in the crops. Management of one field or habitat can have large effects on natural enemy populations at nearby crop fields. Therefore, we recommend that management should not be an individual effort by single farmers but should be orchestrated on a larger scale (for example in farmer clusters).

3. Introduction

Almost all organisms require a variety of non-substitutable and complementary resources for development and reproduction that are available at specific locations, such as sites for hibernation, roosting and breeding, predator-free refuges, and patches with food (Dunning et al., 1992; Ouin et al., 2004). These locations with complementary resources may occur spatially or temporally segregated. This forces the organism to focus on a select set of resources at a time, after which it needs to focus on a different set to meet all its vital needs. The organism is limited by its movement range when visiting the various locations with resources, which means that resource patches can only complement each other when they occur within the movement range of the organism. Thus, resource patches containing non-substitutable resources occurring in close proximity within a landscape can support more of these organisms than landscapes in which these patches are absent or far apart. This possible effect of the complementarity of resource patches is called the landscape complementation theory (Dunning et al., 1992).

Dunning's landscape complementation theory is linked to landscape heterogeneity, as the degree of landscape heterogeneity explains the number, proportions, and physical layout of different patches that can be found in a landscape (Dunning et al., 1992). Landscapes are naturally spatially heterogeneous and differ in landscape composition and physiognomy (Band et al., 2005; Dunning et al., 1992; Johnson et al., 1992). Landscape composition refers to the relative amount of each patch type present within the landscape, whereas landscape physiognomy has to do with the psychical layout of landscape elements (Dunning et al., 1992). With increasing compositional heterogeneity, more patches become available, that in general benefit organisms that rely on multiple patches for resource complementation. Therefore, higher levels of compositional heterogeneity are linked to higher levels of biodiversity.

Biodiversity in agricultural landscapes is not only important in itself but it also supplies many ecosystem services (ES), for example pollination and pest control (Zhang et al., 2007). These ES are threatened due to biodiversity loss. Food production is highly dependent on ES such as pollination and pest control. Therefore, loss of biodiversity and ES threatens our food security. This loss in biodiversity is to a large extent due to a decrease in landscape heterogeneity. Landscape heterogeneity decreased due to the increase of intensive agriculture, owing to the demand of greater volumes of cheaper food and with lower production costs (Benton et al., 2003; Fahrig et al., 2011). During the green revolution after World War II, intensely managed agricultural lands expanded, and many (semi)natural habitats were lost or fragmented in the process. Biodiversity and the related ES of agricultural lands have suffered from this process (Benton et al., 2003; Sirami et al., 2019). With increased homogeneity of habitats, many organisms find it difficult to find all the resources they need, resulting in a decrease of their densities, and in an overall loss of biodiversity.

Understanding how the agricultural landscape needs to change to restore agricultural biodiversity and ES is paramount but is difficult to study in the field. Empirical studies can be extremely time consuming, as new landscape elements sometimes need years to develop into suitable resource patches. Additionally, such empirical studies are often correlative, where the amount or diversity of landscape elements can be correlated with measured levels of ES or of ES providers (e.g., pollinators or natural enemies of pests). However, confounding factors are generally difficult to exclude. This is where landscape-based population-dynamical modelling plays an essential role. Such models can give insights into the relationship between a species and its different habitats and the necessity of these habitats for species survival and persistence. Landscape complementation models can serve to gain better understanding of the system and to identify bottlenecks for focal species and species groups. As a result, farmers and landscape managers can be advised on bottlenecks and on possible landscape alterations to tackle these.

Hoverflies (Diptera: Syrphidae) are one of many insect groups that provide important ES, such as pollination and natural pest control of aphids (Jauker et al., 2012; van Rijn et al., 2017). The zoophagous larvae of hoverflies are common natural enemies of aphids and, together with lacewings, make up 50% of all predators found on potato leaves (van Rijn, Wäckers, et al., 2010). Whilst larvae of these hoverflies feed on aphids, and enforce natural pest control, adult hoverflies require floral resources. Both types of resources are often spatially and temporally segregated in agricultural landscapes. Due to segregation of resources, hoverflies might not be optimally supported by the agricultural landscape, resulting in sub-optimal natural pest control of aphids.

The aim of this study is to model how landscape composition affects hoverfly population dynamics and natural pest control of aphids. The population-dynamical model created is based on earlier work by van Rijn et al. (2017) but is edited to better fit the Dutch agricultural landscape. Moreover, the model was used to more extensively study the impact of landscape alterations and management on hoverfly and aphid abundance than was done previously. The model shows which landscape composition offers optimal hoverfly performance and natural pest control of aphids. Additionally, the model shows the possible impact of management strategies such as sowing and mowing of flower-rich field margins and pesticide applications on natural pest control.

The population-dynamical model is framed in a set of ordinary (ODE) and delay differential equations (DDE), similar to models made by van Rijn (van Baalen et al., 2001; van Rijn et al., 2017; van Rijn et al., 2002) and others (Banks et al., 2017; Chattopadhyay et al., 2002; Cushing, 2013). The model distinguishes habitats that differ in the timing of essential resource availability. Simple optimal foraging rules for hoverflies connect the different habitats. The model combines this with the life history of hoverflies and aphids to show seasonal population dynamics of both hoverflies and aphids within the habitat-structured landscape. A primary three-habitat model was created and assumes that hoverflies need complementary habitats to acquire all necessary resources year-round. The three habitats considered are modelled on the dominant crops and semi-natural habitats present in the Dutch farmer cluster (Table 1).

Insights in the necessity of specific landscape elements for hoverfly performance and aphid suppression can be found by identifying landscape-level bottlenecks. Additionally, management options can be scrutinized for optimal hoverfly performance and natural pest control of aphids. Knowledge on both landscape and management bottlenecks can be used to

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 862731

advise farmers and landscape managers on possible landscape and management alterations in favour of natural pest control of aphids.

Table 1. Habitat structures present in the Dutch farmer cluster.

Habitat	Overview
Woods and shrubs	Habitat predominated by shrubs and trees
Early crop	Fields containing an early crop, for example winter wheat
Late crop	Fields containing a late crop, for example potato
Flower-rich field margins	Field margins adjacent to both early and late crop
Bird fields	Fields containing leguminous fodder crops, and strips with flowering herbs to serve as habitat for small farmland birds
Grassy habitats	Linear herbaceous habitats that are dominated by grasses, such as ditch banks and road verges

This Project has received funding from the European Union´s Horizon 2020
research and innovation programme under grant agreement No 862731

4. Recommendations

This study aims to gain more insight in the role of the agricultural landscape in the support of natural enemies and the pest control services they provide. The model discussed in this report focuses on hoverflies as the main predator of aphids in arable crops and is used to study which landscape elements are limiting the performance of this predator. Based on this knowledge, recommendations are formulated for farmers and policy makers on the optimal composition of the agricultural landscape and on the optimal management of landscape elements, including the crop fields. The recommendations should contribute to more reliable natural pest control, a reduction in the use of pesticides, and an increase of farmland biodiversity. Further, targeted, recommendations can be given following model updates to represent specific farmer clusters.

4.1 Landscape

In terms of landscape composition, the following advice are given.

- Investigate the composition of the landscape surrounding the crop fields in terms of the resources they provide for natural enemies (such as hoverflies).
- Woody landscape elements, such as hedgerows and woodlots, should be sufficiently present in the landscape (at the scale of 1-2 km). A minimum of 5 to 12% of the landscape should be made up by woody habitats, depending on the composition and on the availability of other landscape elements such as flower margins. Ideally, the woody plant species are selected on their ability to provide natural enemies with both suitable (and non-harmful) prey and with suitable floral resources, especially in spring when woody habitats are most essential. See table K2 of van Rossum et al. (2022) for information on suitable woody plant species for a variety of natural pest control agents.
- Herbaceous landscape elements that provide floral resources, such as flower margins, should preferably be present near all arable fields. The plant species sown should provide pollen and nectar that are attractive and accessible for the natural enemies, such as hoverflies (van Rijn and Wäckers, 2016). Additionally, these plant species should vary in flowering time to extend the period that floral resources are available. See table K1 of van Rossum et al. (2022) for suitable floral plant species for a variety of natural pest control agents.
- Crops that develop pests at different parts of the season, such as winter cereals and potato, are best grown close to each other. The combination of these crops can help to sustain the natural enemies throughout the season, and provide substantial support for natural pest control, especially in the late crop.

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 862731

4.2 Management

In terms of management of crops and flower margins, the following advice are given.

- Create and maintain flower strips (or other habitats) that produce a high level of floral resources suitable for natural enemies throughout the season. See table K1 of van Rossum et al. (2022) for information on suitable flower mixtures for a variety of natural pest control agents.
- Sow the flower margins next to early crops as early in the year as possible. Flower margins next to late crops can be sown later in the year. Different types of flower margins (e.g., annual, and perennial, or different mixtures of flower species) in your farm(cluster) can complement each other.
- Do not mow flower margins while the adjacent crop can contain aphids. If needed, mow the flower margin of an early crop late (i.e., at the start of September), and mow the flower margin of a late crop early (i.e., before July).
- Monitor pests and their natural enemies in and around your fields during critical periods. Do not apply pesticides when pest numbers are below damage thresholds and when sufficient numbers of natural enemies are present on your farm. Take into account that pesticide applications also compromise natural pest control in other fields and in later years.
- Management of one field can have large effects on natural enemy populations in nearby fields. Therefore, management should preferably not be an effort of an individual farmers but should be orchestrated on a larger spatial scale (for example in farmer clusters).

This Project has received funding from the European Union´s Horizon 2020
research and innovation programme under grant agreement No 862731

5. References

Band, L. E., Cadenasso, M. L., Grimmond, C. S., Grove, J. M., & Pickett, S. T. (2005). Heterogeneity in urban ecosystems: Patterns and process. Ecosystem function in heterogeneous landscapes (pp. 257–278). Springer.

Banks, H. T., Banks, J. E., Bommarco, R., Laubmeier, A., Myers, N., Rundlöf, M., & Tillman, K. (2017). Modeling bumble bee population dynamics with delay differential equations. Ecological Modelling, 351, 14–23.

Benton, T. G., Vickery, J. A., & Wilson, J. D. (2003). Farmland biodiversity: Is habitat heterogeneity the key? Trends in ecology & evolution, 18(4), 182–188.

Chattopadhyay, J., Sarkar, R. R., & El Abdllaoui, A. (2002). A delay differential equation model on harmful algal blooms in the presence of toxic substances. Mathematical Medicine and Biology: A Journal of the IMA, 19(2), 137–161.

Cushing, J. M. (2013). Integrodifferential equations and delay models in population dynamics (Vol. 20). Springer Science & Business Media.

Dunning, J. B., Danielson, B. J., & Pulliam, H. R. (1992). Ecological processes that affect populations in complex landscapes. Oikos, 169–175.

Fahrig, L., Baudry, J., Brotons, L., Burel, F. G., Crist, T. O., Fuller, R. J., Sirami, C., Siriwardena, G. M., & Martin, J.-L. (2011). Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. Ecology letters, 14(2), 101–112.

Jauker, F., Bondarenko, B., Becker, H. C., & Steffan-Dewenter, I. (2012). Pollination efficiency of wild bees and hoverflies provided to oilseed rape. Agricultural and Forest Entomology, 14(1), 81–87.

Johnson, A., Wiens, J., Milne, B., & Crist, T. (1992). Animal movements and population dynamics in heterogeneous landscapes. Landscape ecology, 7(1), 63–75.

Ouin, A., Aviron, S., Dover, J., & Burel, F. (2004). Complementation/supplementation of resources for butterflies in agricultural landscapes. Agriculture, Ecosystems & Environment, 103(3), 473–479.

Sirami, C., Gross, N., Baillod, A. B., Bertrand, C., Carrié, R., Hass, A., Henckel, L., Miguet, P., Vuillot, C., Alignier, A., et al. (2019). Increasing crop heterogeneity enhances multitrophic diversity across agricultural regions. Proceedings of the National Academy of Sciences, 116(33), 16442–16447.

van Baalen, M., Kˇrivan, V., van Rijn, P. C. J., & Sabelis, M. W. (2001). Alternative food, switching predators, and the persistence of predator-prey systems. The American Naturalist, 157(5), 512–524.

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 862731

van Rijn, P. C. J., van Houten, Y. M., & Sabelis, M. W. (2002). How plants benefit from providing food to predators even when it is also edible to herbivores. Ecology, 83(10), 2664–2679.

van Rijn, P. C. J., Wäckers, F. L. et al. (2010). The suitability of field margin flowers as food source for zoophagous hoverflies. IOBCwprs Bull, 56, 125–128.

van Rijn, P. C. J., & Wäckers, F. L. (2016). Nectar accessibility determines fitness, flower choice and abundance of hoverflies that provide natural pest control. Journal of Applied Ecology, 53(3), 925–933.

van Rijn, P. C. J. et al. (2017). Natural pest control requires a complete landscape. Dundee (Scotland, UK) March 29-31, 2017, 122, 107–111.

van Rossum, Z. A., Wäckers, F. L., Janssen, A., & van Rijn, P. C. J. (2022). Bevordering van nuttige organismen voor plaagbestrijding en bestuiving in open teelten Rapport+Nuttige+organismen_def2.pdf

Zhang, W., Ricketts, T. H., Kremen, C., Carney, K., & Swinton, S. M. (2007). Ecosystem services and dis-services to agriculture. Ecological economics, 64(2), 253–260.

6. Disclaimer

The information presented here has been thoroughly researched and is believed to be accurate and correct. However, the authors cannot be held legally responsible for any errors. There are no warranties, expressed or implied, made with respect to the information provided. The authors will not be liable for any direct, indirect, special, incidental, or consequential damages arising out of the use or inability to use the content of this publication.

7. Copyright

8. Citation

Please cite this report as follows:

Mansier, L. & Van Rijn, P. C. J. (2023). Deliverable D4.2 (D29) A functional Landscape Complementation model with recommendations for the Farmer Clusters involved for the EU-H2020 funded project FRAMEwork under Grant Agreement Number 862731. DOI: 10.5281/zenodo.7797526.