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SAFEGUARD

Recommendations on optimal implementation of collaborative approaches implementing multiple measures at the landscape-level

Deliverable D4.8

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Safeguard
Safeguarding European wild pollinators

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Summary

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Task Description: Assessing the key benefits of a long-term, multi-actor conservation approach at the landscape scale for wild pollinators.

Results: We found that collaborative, multi-actor conservation at the landscape scale overall had positive effects on wild bee population trends, both in terms of their abundance and species richness. However, the effectiveness of bee-friendly management varied considerably between the five habitat types that were targeted in this collaborative conservation initiative with bee-friendly management in field margins having the most pronounced effects and bee-friendly hedge management being least effective. This was partly driven by the extent to which bee-friendly management succeeded in enhancing flower cover and partly by implementation success of the planned management. While flower cover was stable over time in sites with bee-friendly management, flower cover declined significantly in control sites. Significant increases in floral resources relative to controls were only found in field margins and pastures. Based on the results as well as the process of interacting in a collaborative, multi-actor conservation approach, we recommend that collaborative approaches can best be implemented using actors managing different parts of the landscape as this offers the highest chance for ecological synergies. It is furthermore essential to monitor whether the agreed wildlife-friendly management has actually been implemented to make sure the planned efforts of actors does not get lost in business as usual. Finally, monitoring the ecological outcomes of collaborative approaches is key because (i) it is motivating for actors and can inspire them to implement additional wildlife-friendly measures and (ii) it improves the odds that efforts made by actors actually result in biodiversity benefits (as this cannot be taken for granted).

1. Introduction

Despite valiant efforts to bend the curve of biodiversity decline, historical biodiversity losses due to land use change are expected to continue into the 21st century (Pereira et al., 2024), and climate change in conjunction with land use change is expected to intensify declines. Conservation strategies that have been implemented thus far, such as protected areas and agri-environment schemes, have failed to stop biodiversity loss (Batáry et al., 2010; Hallmann et al., 2017; Kleijn et al., 2006; Rada et al., 2019). These "traditional" conservation approaches often have a top-down approach that does not involve the local community, which may weaken support for conservation (Kleijn et al., 2020). Further, these conservation approaches are generally implemented in isolation of one-another, despite the potential for synergy if implemented together (Smart et al., 2014). Collaborative, multi-actor approaches may address these weaknesses and have been heralded as a more effective conservation solution, especially in the European Union (Hermoso et al., 2022). The term "stakeholder" is often used interchangeably with "actor", however for the sake of consistency we use "actor" throughout the text to refer to individuals, groups, or organisations with the capacity to influence the conservation effort (i.e., act) (Avelino & Wittmayer, 2016).

Such collaborative conservation approaches stimulate buy-in and allow actors to feel a sense of ownership over the conservation initiative (Kleijn et al., 2020; Reed et al., 2016; Zscheischler et al., 2019). Multi-actor conservation approaches can be particularly effective when implemented at the landscape level. Focusing on a specific landscape makes it potentially possible to consider the ecological requirements of the targeted species or species group and complement conservation actions in protected areas with tailored actions on farmland and public land. Particularly in Europe, protected areas are generally small in size, with more than 60% being less than 1 km^2 (Romão, 2012), making them highly susceptible to pressures from the intensively used surrounding landscape (Kleijn et al., 2020). Coherent action by a range of different actors (Doyle-Capitman et al., 2018), such as the local municipality, water boards, nature conservation organisations, and private landholders, makes it possible to cover a larger proportion of the landscape and target a wider range of habitats that the focal species groups may use during their life cycle. Though measures applied to different habitat types might have varying levels of effectiveness, the expectation is that there is synergistic effect of collaborative management on biodiversity (Ros-Tonen et al., 2018). The result can be a network of high-quality habitat that provides ample resources to target species and increases connectivity between potentially isolated protected areas.

Though popular in theory, there is little evidence of the actual implementation (Reed et al., 2016) or the effectiveness (Koontz et al., 2020) of such integrated landscape approaches. This may be because collaborative actions rarely result in the implementation of conservation measures in a way that meets the requirements of the traditional study designs used to evaluate conservation effectiveness. In a collaborative approach, the individual actors generally decide where to implement which type of conservation measure. As a result, different conservation measures can be located near one another and consequently, may no longer be statistically independent. This makes the use of common space-for time study designs more challenging (Christie et al., 2019; Westgate et al., 2013). Additionally, the ultimate goal of a landscape-level initiative is to enhance biodiversity at the level of the landscape. Given the time and cost involved in landscape-level multi-actor conservation, there is typically only a single landscape involved, meaning there is no independent replication of the study unit in question (Kleijn et al., 2020). Lastly, it is more difficult to ensure the quality of an intervention when the actors themselves are responsible for implementation. How and when a conservation measure is implemented can vary considerably between actors, for whom this is not their core business and who must balance optimal implementation with other socioeconomic priorities. Yet despite these difficulties, establishing proof of concept is vital if collaborative landscape-scale conservation is to become a widely adopted and effective approach to conservation (Sayer et al., 2017).

Here, we use an evaluation approach presented by Kleijn et al. (2020) to evaluate the landscape-level collaborative conservation initiative “Boshommellandschap” (i.e. Shrill carder bee landscape) in the Netherlands. The initiative targets wild bees that provide key pollination services to both wild plant and crop species (Potts et al., 2016; Rader et al., 2016), but whose populations are in serious decline due to land use change, agricultural intensification, and pesticide use (Dicks et al., 2021; Rader et al., 2014). Despite the current wealth of knowledge on targeted conservation interventions for wild bees (Duque-Trujillo et al., 2023), many wild bee species are still in decline. While some species are “winners” and are expanding their ranges or increasing in abundance, many more species are “losers” with shrinking ranges and populations (Bartomeus et al., 2013; Powney et al., 2019; Scheper et al., 2014). To achieve positive trends, a more cohesive conservation framework may be necessary, where both protected nature and the landscape surrounding it are conserved in cooperation with local actors (Stout & Dicks, 2022)—such as in the Boshommellandschap.

In the Boshommellandschap, 11 actors are collaborating by implementing, monitoring and evaluating codesigned bee-friendly management in five different habitat types to promote flower availability and thereby wild bee abundance and diversity. The five habitat types involved in this conservation initiative are hedgerows and field margins on farmland, road verges and water retention sites in public space and extensively managed grasslands in protected areas. Bee-friendly management was tailored for each habitat type and actor, but all aimed to enhance the spatiotemporal availability of floral resources. The initiative started in 2018 with the collection of two years of baseline data, after which the effects of four years of bee-friendly management implementation was monitored. The study design includes not only conventionally managed control sites within the landscape boundaries, but also outside the landscape in the surrounding agricultural matrix. Using data from this initiative, we sought to answer the following general questions: 1) how does collaborative, landscape-scale conservation affect wild pollinator abundance and diversity? and 2) What are the key benefits of this conservation approach for wild pollinators? We first broadly compared resource and population trends between sites with and without bee-friendly management, and then more specifically between the five different habitat types. We expected that, even though the specific management interventions would show variable effectiveness between habitat types, the effects of bee-friendly management would add up across habitats to overall positive trends in wild bee abundances and species richness at the landscape-level. We used the results to discuss the key benefits and drawbacks of collaborative multi-actor conservation for wild bees and to formulate recommendations for optimal implementation.

2. Methods

2.1. Study design

The data for this study was collected in the Boshommellandschap, located in the valley of the river Geul, Zuid-Limburg, the Netherlands (Figure 1). The Boshommellandschap is a landscape-level conservation initiative that began in 2018, with the aim of improving existing semi-natural habitat for wild bees (see www.boshommlellandschap-geuldal.nl for details). The Boshommellandschap exists as a partnership with multiple stakeholders that includes two municipal governments, the water board and water company, three nature conservation organisations, a farmer collective, a foundation implementing wildflower strips on farmland, the provincial council of Limburg, and Wageningen University & Research. See Kleijn et al. (2020) for a detailed overview of the conservation approach. The area of the Boshommellandschap is characterised by a hilly landscape on limestone soils, which also support protected species-rich calcareous grasslands. Intensive arable farming, orchards, and dairy farming dominate this region's agricultural landscape.

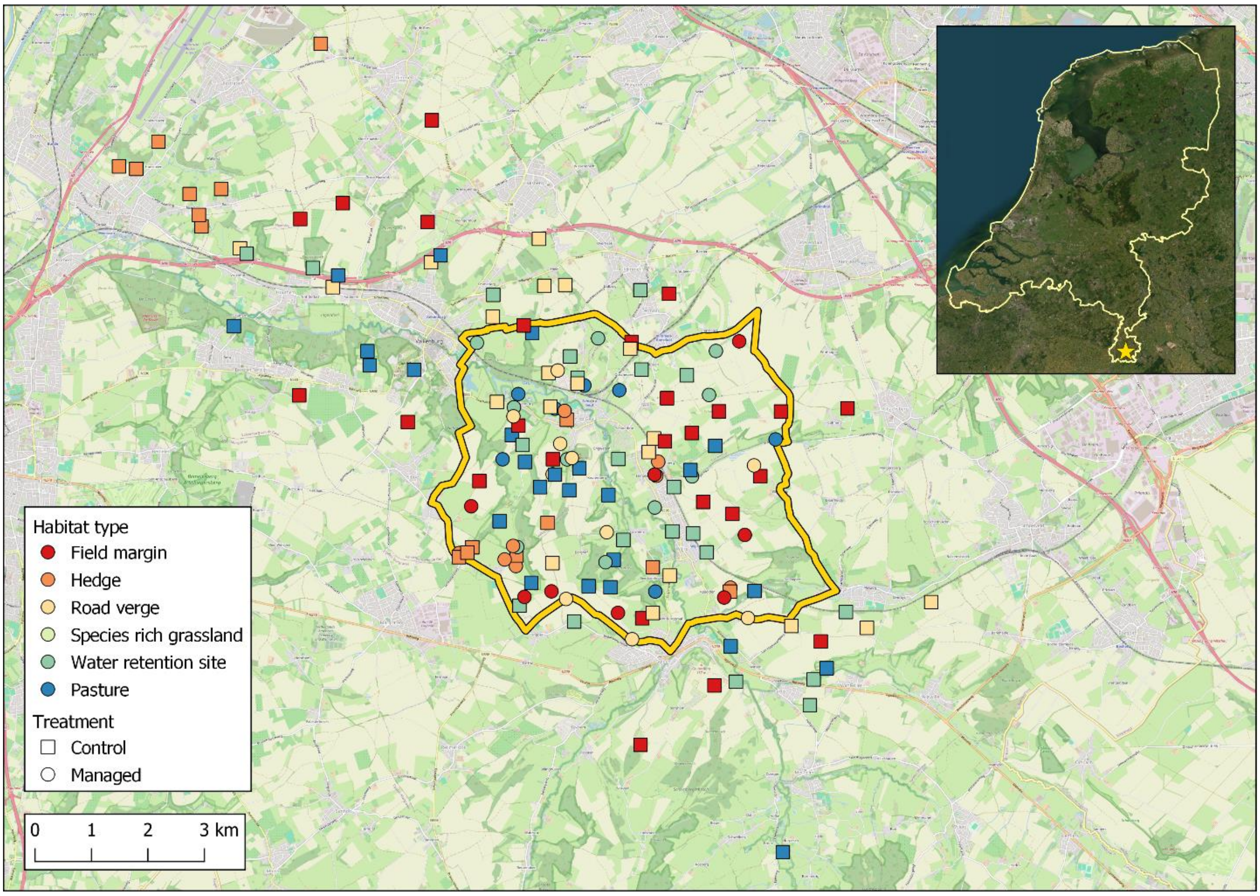


Figure 1. All transect locations of the Boshommellandschap (landscape delineated by yellow border). Transect colours denote their habitat type and shapes denote their treatment type. Control transects outside the yellow border are considered "outside landscape" (COL) and transects inside are considered "inside landscape" (CIL). The location of the Boshommellandschap in the Netherlands is indicated in the inset with a yellow star.

The initiative targets five habitat types: field margins, road verges, water retention sites, pastures and hedgerows. The five habitat types are split between three treatments: controls within the landscape (CIL), controls outside the landscape (COL), and sites with bee-friendly management (MA) (Figure 1; Table 1). Initial suggestions for effective bee-friendly management were proposed for each habitat type by conservation scientists. These management options were discussed with the partners responsible for implementing and maintaining them, which usually resulted in modifications to make them easier to implement while still being ecologically effective. Most non-farming partners subsequently contracted out the actual management to third parties. Partners subsequently contracted out the actual management to third parties. Bee-friendly conservation management was first applied in 2020 and includes a variety of interventions targeted to each habitat type (Table 2). We used six years of data (2018-2023) in this analysis.

Table 1. Number of transects sampled per habitat type and treatment as of 2023.

Habitat type	Treatment	No. transects
Field margin	Control in Landscape	13
	Control outside Landscape	12
	Bee-friendly Management	9
Hedge	Control in Landscape	8
	Control outside Landscape	8
	Bee-friendly Management	8
Pasture	Control in Landscape	13
	Control outside Landscape	9
	Bee-friendly Management	10
Road verge	Control in Landscape	10
	Control outside Landscape	10
	Bee-friendly Management	10
Water retention site	Control in Landscape	12
	Control outside Landscape	9
	Bee-friendly Management	10

2.2. Wild bee sampling

Wild bees were collected in three sampling rounds per year, for a total of 18 sampling periods between 2018 and 2023. The sampling protocol followed Scheper et al. (2015). 150 m^2 transects were sampled by net in 50 m^2 increments for 5 minutes each, totaling 15 minutes of pure sampling time. Sampling only occurred during good weather conditions: temperature at or exceeding 15 °C, no rain, and wind levels less than Beaufort 5. Individuals that could not be identified to the species level in the field were collected for further identification.

2.3. Floral resource survey

Forb flower diversity and cover were estimated for each transect by counting the number of flower units per species. Flower area was calculated per species by multiplying the number of floral units by average floral unit area. Transect-level flower cover was the sum of species-specific flower area divided by the total area of the transect (Scheper et al., 2015). Per-species average floral unit areas were taken from a database maintained by the Plant Ecology and

Nature Conservation group (Wageningen University and Research). Additionally, during each visit we recorded for all sites with bee-friendly management whether the observed management was in line with stakeholder agreements.

2.4. Data analysis

Honeybees were removed from the dataset prior to analysis. Solitary bees and bumblebees were analysed together. Sampling date was converted to time since the beginning of the conservation initiative (January 1st, 2018), measured in days (hereon referred to as Days Since Start, DSS).

Effectiveness of collaborative conservation

We assessed both the overall and habitat type-specific effectiveness of bee-friendly management for wild bee abundance and species richness and flower cover and species richness using (generalised) linear mixed-effects models. Wild bee abundance and species richness were modelled with negative binomial distributions. Flower species richness was modelled with a Poisson distribution. Flower cover was modelled with a zero-inflated Gamma model with a log link, with the zero-inflation parameter applied to all observations. DSS was standardised by centering and dividing by two standard deviations to aid with model convergence. All models included Treatment and DSS as interacting fixed factors. We assumed a linear effect of DSS, based on the observed relationship between all response variables and DSS. A second set of models, which additionally included the variable Habitat Type, were initially run with the main effects of Habitat Type, Treatment, and DSS, as well as the three-way interaction of Habitat Type, Treatment, and DSS to explore how the effect of treatment over time differs across habitat types. Transect ID was included as a random effect in all models to account for repeated measurements. The significance of interactions were assessed using likelihood-ratio tests, and non-significant interactions, and subsequently non-significant main effects, were dropped from the models. Temporal autocorrelation was detected for all flower cover and flower species richness models. We included Ornstein-Uhlenbeck covariance structures, which can handle irregular time points, in each model to correct for this. We defined the time variable as the sampling date and the group as a single dummy variable, as there was only one time series. Spatial autocorrelation was detected for the DSS * Treatment flower species richness model and was corrected for by including longitude and latitude as fixed factors, both standardised by centering and dividing by two standard deviations. Post-hoc testing to determine the pairwise differences in levels of Treatment, plus Treatment and Habitat Type, as a function of DSS, were done using emmeans (Lenth, 2024). Multiple comparisons were corrected for using the Tukey method.

Species richness by habitat type

Wild bee species richness, irrespective of treatment, was compared between habitat types using a generalised linear mixed-effects model, with species richness as the response, habitat type as a fixed factor, transect ID as a random effect, and using a negative binomial distribution. Pairwise comparisons between habitat type were done using emmeans (Lenth, 2024) and multiple comparisons were corrected for using the Tukey method.

All statistical analyses were done in R version 4.4.1 (R Core Team, 2024). Data was handled using tidyverse (Wickham, 2023), sf (Pebesma, 2023), sp (Pebesma & Bivand, 2005), and lubridate (Spinu et al., 2023). Models were created using glmmTMB (Brooks et al., 2024). Model fit and spatial and temporal autocorrelation were checked using R package DHARMa (Hartig, 2022) and multicollinearity was tested for using performance (Lüdecke et al., 2021). Figures were created using ggplot2 (Wickham et al., 2024), ggpubr (Kassambara, 2023), ggmin (Jessa, 2024), cowplot (Wilke, 2024), and NatParksPalettes (Blake, 2022).

3. Results

The dataset used for this analysis contains six years of sampling data from five habitat types: field margins, road verges, water retention sites, pastures, and hedgerows. These habitat types, the actors responsible for them, and the agreed-upon management are outlined in Table 2. The success of implementing bee-friendly management in these habitats was variable (Table 3). For example, eight out of nine field margins had issues in 2020, including several transects which had to be moved, sometimes more than once, due to farmer preferences or difficulties with implementing management. All of the pastures with bee-friendly management failed to successfully establish it in 2020, as staggered grazing or mowing were not correctly implemented. However, for these to habitat types management improved steadily over time, and by 2023 only one pasture and one field margin had failed management. Bee-friendly management in all eight hedges failed between 2020 and 2023, primarily due to over-pruning that prevented the hedges from growing in a pollinator-friendly manner. All water retention sites were managed successfully in 2020 and 2021, however in 2022 and 2023, management failed in two and three sites, respectively. Half of the road verges had failed management in 2020 and 2021, however all issues with mowing were resolved in 2022 and 2023.

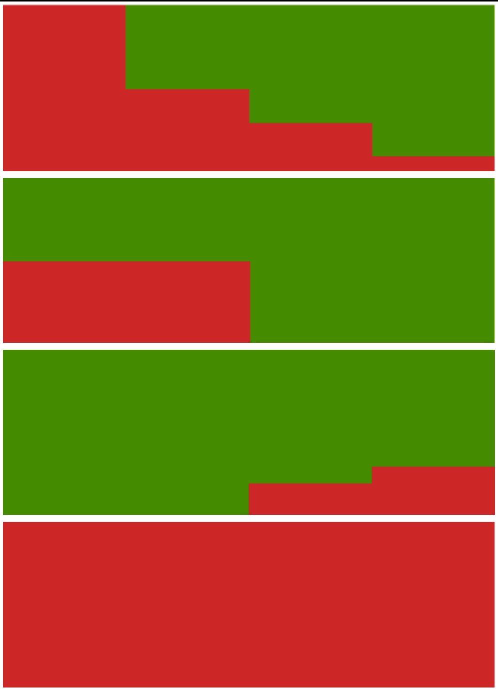
Over these six years, 21,679 specimens were sampled, or 197 species total. The most common wild bee species by frequency of occurrence over all years were *Bombus lapidarius* (20.8%), *Bombus pascuorum* (13.8%), *Bombus terrestris/lucorum* (9.1%), and *Lasioglossum pauxillum* (8.8%). 329 flower species were observed, of which the most common by total percent cover were *Papaver rhoeas* (16.6%), *Taraxacum officinale* (9.0%), and *Leucanthemum vulgare* (7.8%). See Table S18–S19 for an overview of wild bee and flower species.

Table 2. Proposed and realised bee-friendly management between 2020 and 2023.

Habitat type	Actor	Proposed management
Pasture	Natuurmonumenten	Staggered mowing without grazing Staggered mowing with grazing
	Staatsbosbeheer	Rotational grazing in place of seasonal grazing, as well as staggered mowing
Water retention site	Waterboard Limburg	No mowing or grazing before July 1st (one site before June 1st)

Road verge	Municipality Valkenburg a/d Geul	Alternately mow and remove cuttings or do not mow every 50 meters. After four weeks, mow and remove cuttings in the reverse order. Left side of the road mown completely and cuttings removed, in the second half of May (between 15 and 31 May); Four weeks later, in the second half of June (between 15 and 30 June, right side of the road mown completely and cuttings removed; Both sides of the road mown again and cuttings removed after 15 September.
	Municipality Gulpen-Wittem	From May 15th, the first meter of one side will be mowed and cuttings removed along all roads. At least five weeks later, the first meter along the other half of the road is mown. At the end of the year, the entire roadside is mown and cuttings removed. One site should be additionally mown in June/July, also alternating sides.
Field margin	Natuurrijk Limburg Stichting Limburg Bloeit Op	Sowing with various seed mixtures (Table S1) Depending on the site, sowing done in the spring, summer, or fall. Some sites may need to be resown after several years.
Hedge	Natuurrijk Limburg	Instead of pruning every year, (parts of) the hedges are allowed to grow out and are pruned every three to five years.

Table 3. Timeline of successful and failed management from 2020 to 2023. Red = failed transects, green = successful transects.



	2020	2021	2022	2023	Causes for failure
Pastures (n = 10)					Pasture completely mown or grazed; flooding
Road verges (n = 10)					Road verge mown again too soon after first mowing period
Water retention sites (n = 10)					Grazing occurred before agreed date
Hedgerows (n = 8)					Transect was intended to be a control, but allowed to grow out; over-pruning resulted in failed management

Field margins (n = 9)		Transect needed to be moved; flowers not sown; flowers sown, but wrong mixture used; flowers sown, but grazing impacted their effectiveness; flowers sown, but did not establish

3.1. The effect multi-actor conservation at the landscape level on floral resources

Here we present the results on flower cover and wild bee abundance, as the results for flower and wild bee species richness were similar (Figures S1−S4, Tables S10−S17).

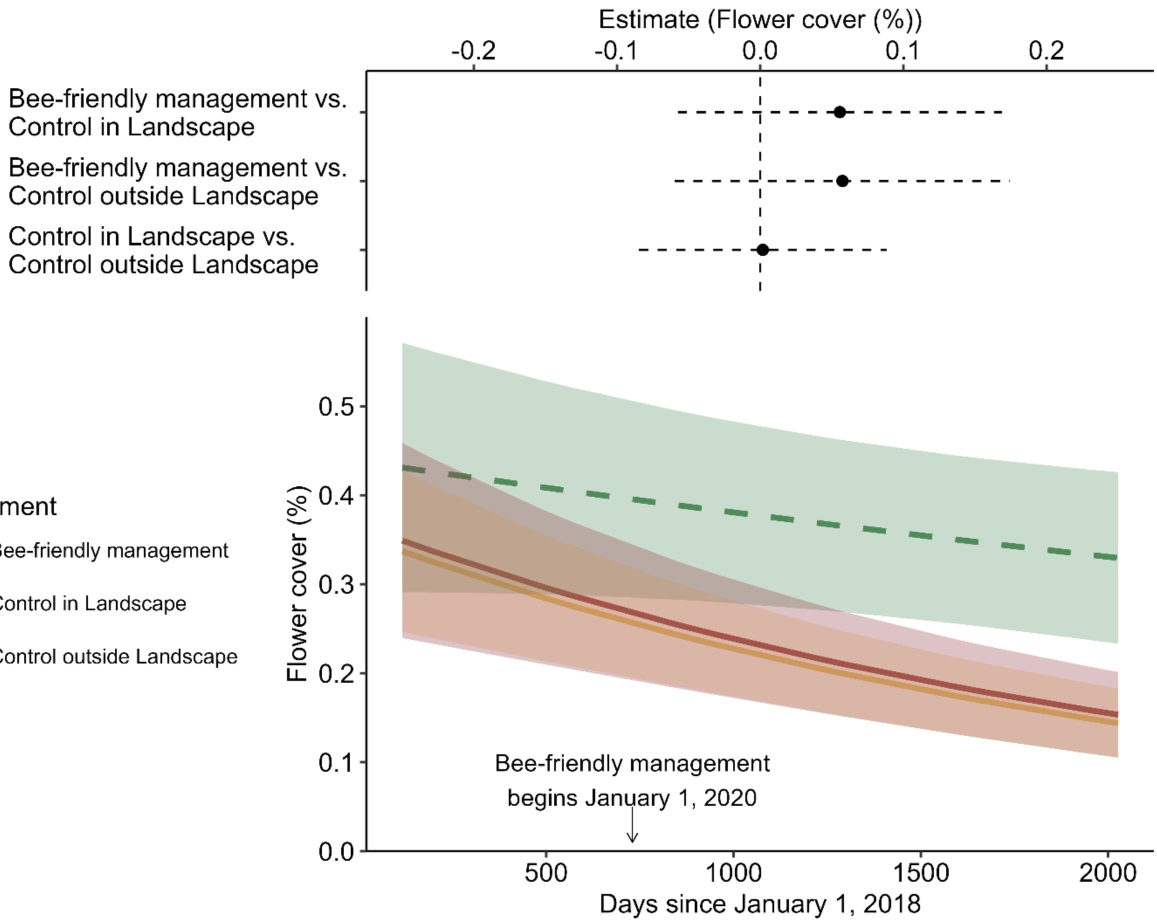


Figure 2. Upper panel: Pairwise comparisons of the rate of change in flower cover (%) by treatment type. Points represent the difference in slope and lines are the 95% confidence interval. A solid line indicates a significant difference between treatment types (p < 0.05). Lower panel: Estimated marginal means of the linear trend in wild bee abundance, as a function of time (Days) and treatment type. A solid line indicates a significant trend (p < 0.05).

We found significant negative trends over time (DSS) in flower cover in control sites within the landscape (slope = -0.001, SE = 0.0004, z = -4.21, p < 0.0001) and outside the landscape (slope = -0.001, SE = 0.0002, z = -4.06, p < 0.0001), and a non-significant negative trend in sites with bee-friendly management (slope = -0.0005, SE = 0.0003, z = -1.51, *p* = 0.13) (Figure 2: lower panel). The trend in flower cover in sites with bee-friendly management was not different from control sites within or outside the landscape (MA−CIL: β = 0.0006, SE = 0.0005, z = 1.15, p = 0.482; MA−COL: β = 0.0006, SE = 0.0005, z = 1.15, p = 0.484) (Figure 2: upper panel). Full model results and all pairwise comparisons can be found in the supplement (Table S2–S3).

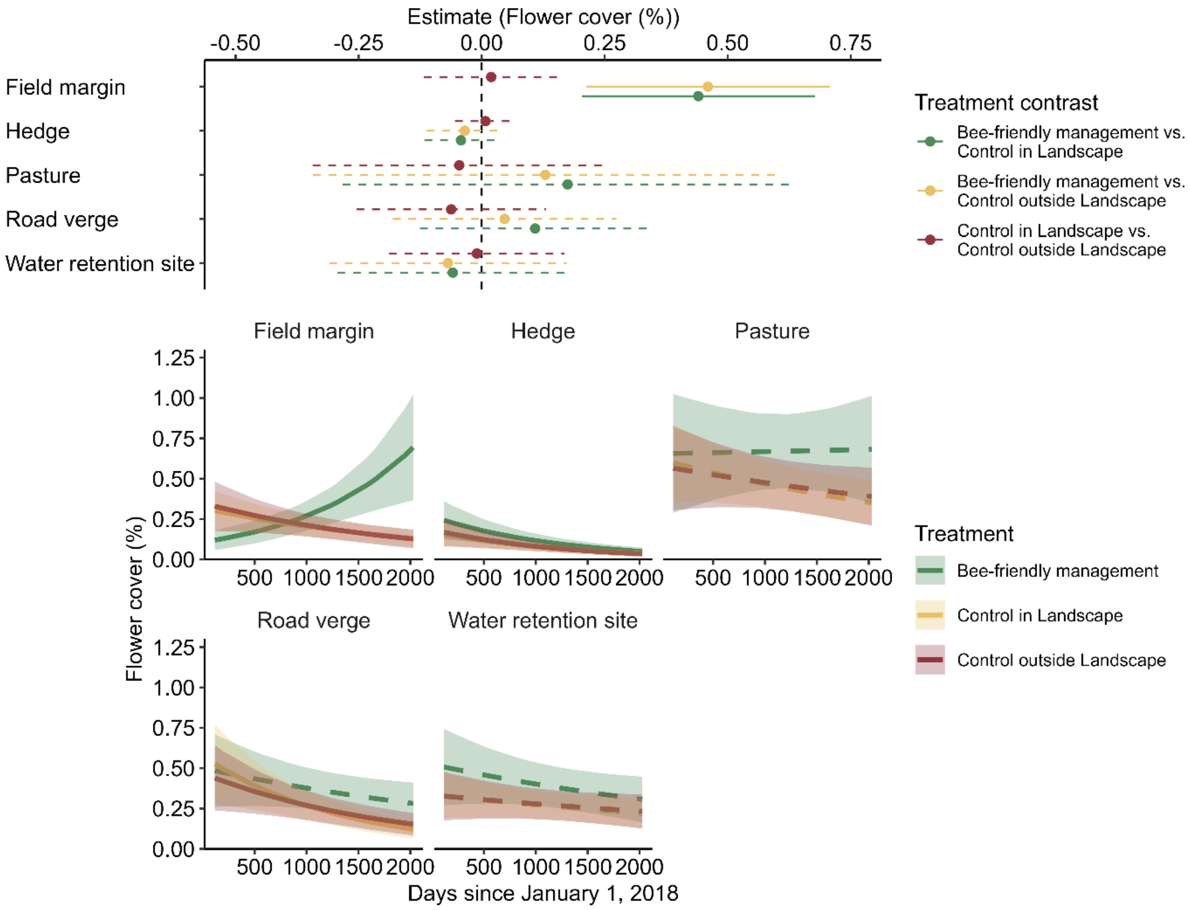


Figure 3. Upper panel: Pairwise comparisons of the rate of change in flower cover (%) by treatment type and habitat type. Points represent the difference in slope and lines are the 95% confidence interval. A solid line indicates a significant difference between treatment types (p < 0.05). Lower panel: Estimated marginal means of the linear trend in wild bee abundance, as a function of time (Days) and treatment type. Results are faceted by habitat type. A solid line indicates a significant trend (p < 0.05).

We found a significant positive trend over time in flower cover in field margins (slope = 0.003, SE = 0.0009, z(inf) = 3.84, *p* = 0.001) and hedgerows (slope = -0.001, SE = 0.0003, z(inf) = -3.63, *p* < 0.001) with bee-friendly management (Figure 3: lower panel). There were significant negative trends in field margins (slope = -0.001, SE = 0.0004, z(inf) = -2.85, *p* = 0.004), hedgerows (slope = -0.0007, SE = 0.0002, z(inf) = -3.41, *p* < 0.001) and road verges (slope = -0.002, SE = 0.0007, z(inf) = -3.53, *p* < 0.001) within the landscape. Field margins with bee-friendly management had significantly steeper slopes compared to both control sites within and outside the landscape (MA−CIL: β = 0.004, SE = 0.001, z(inf) = 4.36, p < 0.001; MA−COL:

β = 0.005, SE = 0.001, z(inf) = 4.35, p < 0.001) (Figure 3: upper panel). Full model results and all pairwise comparisons can be found in the supplement (Table S4–S5).

3.2. The effect multi-actor conservation at the landscape level on wild bees

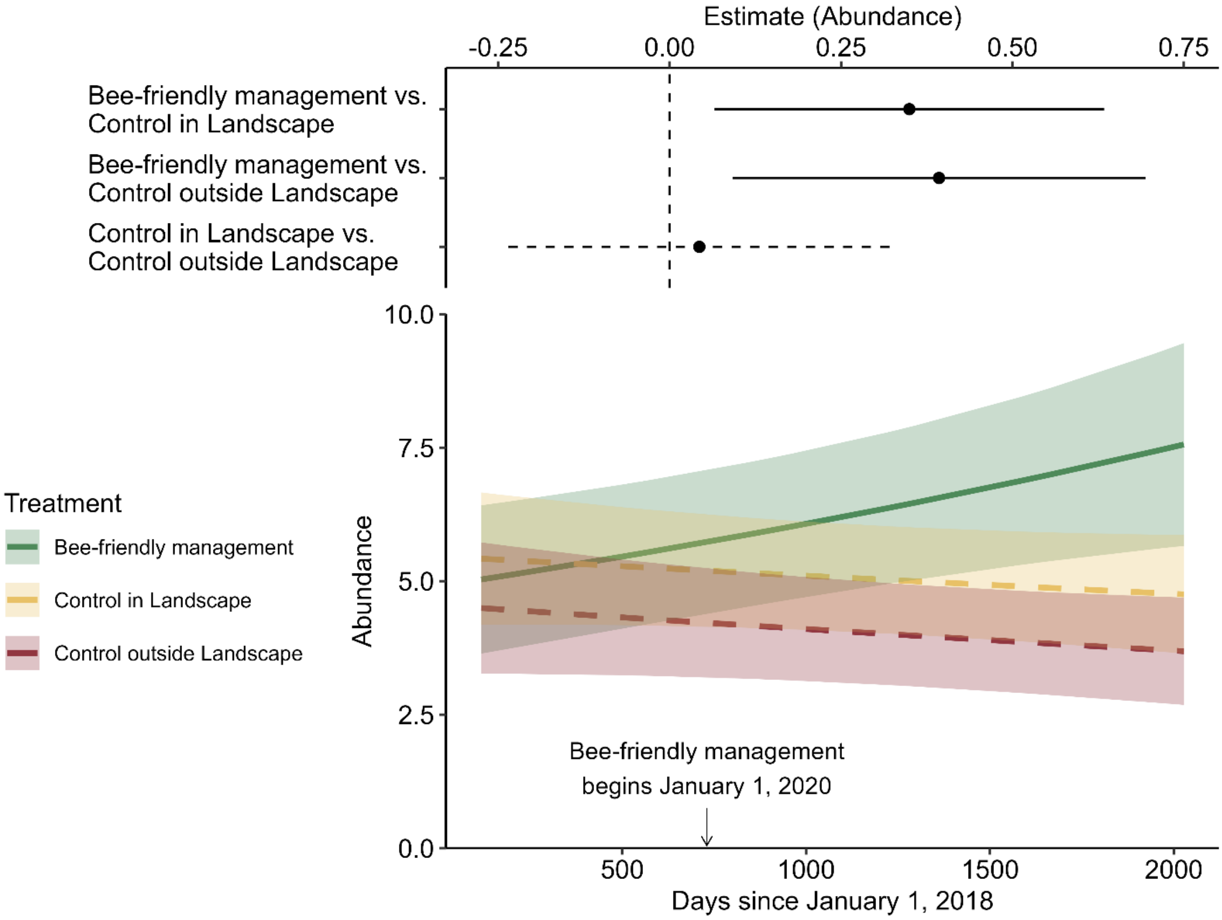


Figure 4. Upper panel: Pairwise comparisons of the rate of change in wild bee abundance by treatment type. Points represent the difference in slope and lines are the 95% confidence interval. A solid line indicates a significant difference between treatment types (p < 0.05). Lower panel: Estimated marginal means of the linear trend in wild bee abundance, as a function of time (DSS) and treatment type. A solid line indicates a significant trend (p < 0.05).

We found a significant positive trend over time in wild bee abundance in sites with bee-friendly management (slope = 0.26, SE = 0.09, z(inf) = 2.87, *p* = 0.004), and non-significant negative trends in control sites within the landscape (slope = -0.09, SE = 0.08, z(inf) = -1.09, *p* = 0.274) or outside the landscape (slope = -0.13, SE = 0.09, z(inf) = -1.43, *p* = 0.151) (Figure 4: lower panel). Sites with bee-friendly management had significantly steeper slopes compared to both control sites within and outside the landscape (MA−CIL: β = 0.35, SE = 0.12, z(inf) = 2.88, p = 0.011; MA−COL: β = 0.39, SE = 0.13, z(inf) = 3.06, p = 0.006) (Figure 4: upper panel). Full model results and all pairwise comparisons can be found in the supplement (Table S6–S7).

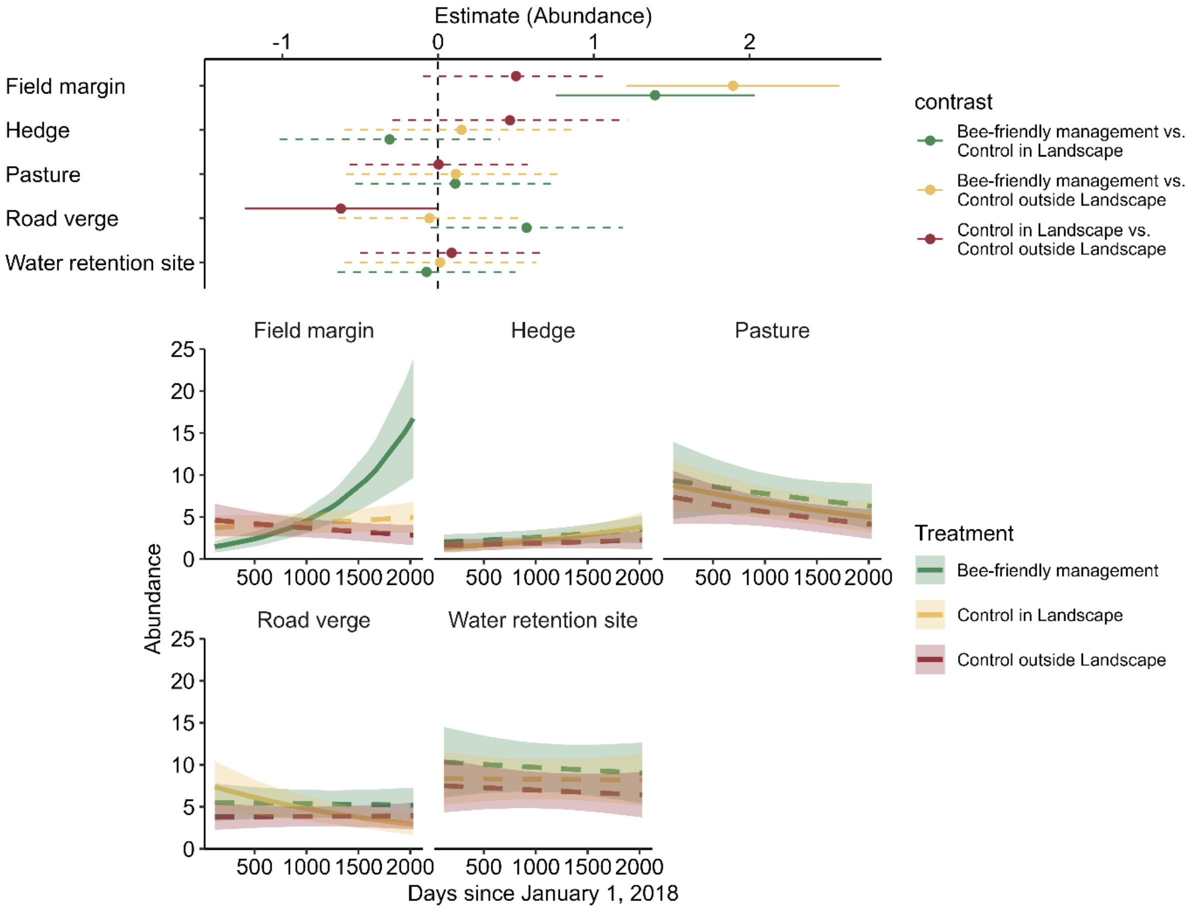


Figure 5. Upper panel: Pairwise comparisons of the rate of change in wild bee abundance by treatment type and habitat type. Points represent the difference in slope and lines are the 95% confidence interval. A solid line indicates a significant difference between treatment types (p < 0.05). Lower panel: Estimated marginal means of the linear trend in wild bee abundance, as a function of time (Days) and treatment type. Results are faceted by habitat type. A solid line indicates a significant trend (p < 0.05).

We found positive trends over time in wild bee abundance in field margins with bee-friendly management (slope = 1.57, SE = 0.22, z(inf) = 7.28, $p < 0.001$) and hedgerows in controls within the landscape (slope = 0.68, SE = 0.21, z(inf) = 3.17, $p = 0.002$) (Figure 5: lower panel). There were significant negative trends in pastures (slope = -0.38, SE = 0.14, z(inf) = -2.65, $p = 0.008$) and road verges (slope = -0.61, SE = 0.19, z(inf) = -3.13, $p = 0.002$) within the landscape. Field margins with bee-friendly management had more positive slopes compared to both control sites within and outside the landscape (MA−CIL: β = 1.39, SE = 0.27, z(inf) = 5.08, p < 0.001; MA−COL: β = 1.89, SE = 0.29, z(inf) = 6.47, p < 0.001) (Figure 5: upper panel). In road verges, controls within the landscape had a more negative slope compared to controls outside the landscape (MA−CIL: β = -0.62, SE = 0.26, z(inf) = -2.38, p = 0.046). Full model results and all pairwise comparisons can be found in the supplement (Table S8–S9).

3.3. Species richness by habitat in the Boshommellandschap

Wild bee species richness in hedgerows was significantly lower than road verges (ratio = 0.61, SE = 0.09, z(inf) = -3.34, p = 0.007), pastures (ratio = 0.48, SE = 0.07, z(inf) = -5.05, p <

0.0001), and water retention sites (ratio = 0.40, SE = 0.06, z(inf) = -6.43, $p < 0.0001$) (Figure 6). Field margins differed significantly from pastures (ratio = 0.68, SE = 0.09, z(inf) = -2.91, p = 0.030) and water retention sites (ratio = 0.56, SE = 0.073, z(inf) = -4.43, p = 0.0001). Road verges differed significantly from water retention sites (ratio = 0.65, SE = 0.09, z(inf) = -3.26, p = 0.010). 57 wild bee species were shared between all habitat types (Figure 7). Field margins had the lowest number of unique species (n = 4), while road verges had the highest number of unique species (n = 13). Hedges shared the fewest species with other habitat types (n = 92), and water retention sites shared the most (n = 133).

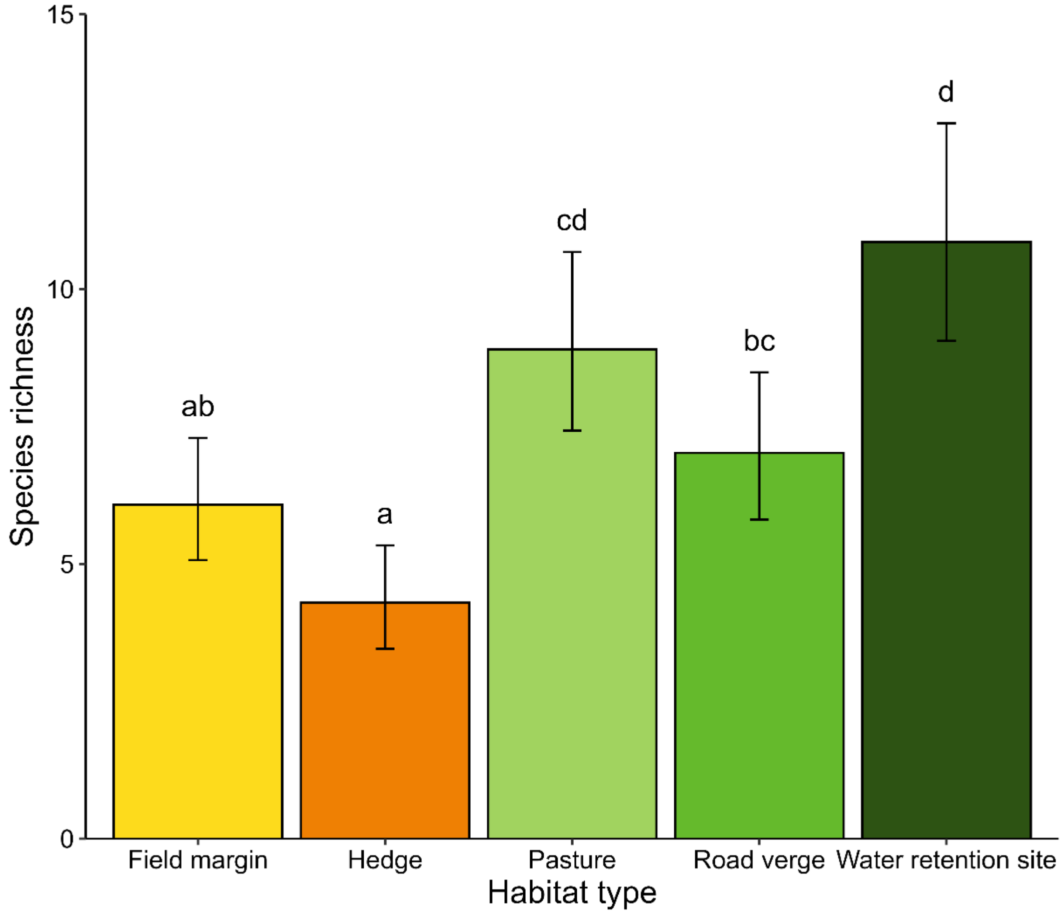


Figure 6. Pairwise comparisons of the estimated marginal means of wild bee species richness by habitat type. Values are on the response scale. Letters indicate significant differences between groups.

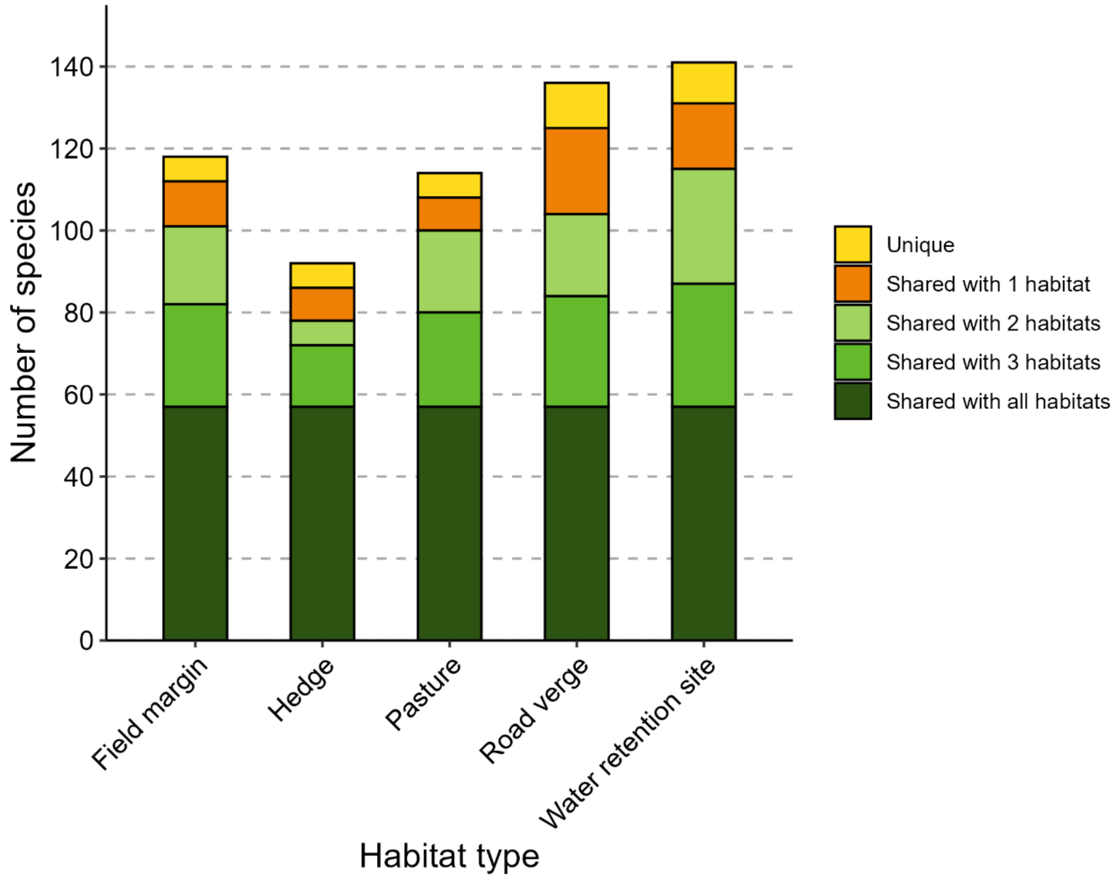


Figure 7. The number of wild bee species for each habitat that were unique to the habitat, shared with one other habitat, two other habitats, three other habitats, or were shared with all habitats.

4. Discussion

We found that collaborative, multi-actor conservation at the landscape scale overall had positive effects on wild bee population trends, both in terms of their abundance and species richness. Bee-friendly management resulted in wild pollinator abundances and species richness (Figures S3−S4) that significantly increased over time and furthermore, were significantly more positive than trends in sites that had been conventionally managed. However, the effectiveness of bee-friendly management varied considerably between the five habitat types that were targeted in this collaborative conservation initiative with field margins having the most pronounced effects and hedge management being least effective. This was partly driven by the extent to which bee-friendly management succeeded in enhancing flower cover and partly by implementation success of the planned management. In general, positive trends appeared to be related more to the proportion of sites with successful management (Table 3) than with anything else, which highlights a key weakness of multi-actor approaches.

The variable effectiveness of bee-friendly management in the five habitat types was partly linked to the initial ability of the different actors to modify management in their sites. In the Boshommellandschap, actors did not receive compensation for implementing interventions in pastures, hedges, road verges, or water retention sites. Consequently, measures such as staggered mowing or delayed grazing were chosen that were expected to have positive ecological effects but that were still acceptable to the actors that needed to implement them—potentially a common outcome of co-designed conservation actions. Field margins were the exception. Farmers received financial compensation through agri-environmental schemes for loss of income associated with establishing wildflower strips along field margins. Because conventional field margins were generally flower-poor (Figure 2) and, when implemented successfully, sowing wildflowers introduced a vast amount of additional floral resources, this type of bee-friendly management created a large ecological contrast which led to positive trends that differed significantly from the controls (Kleijn et al., 2011; Scheper et al., 2013). Flower availability in pastures, road verges, and water retention sites were initially higher, and measures did not introduce new floral resources but rather aimed to increase the continuity of the already available floral resources (staggered mowing/delayed grazing). This resulted in a much smaller ecological contrast for wild bees which probably explains why bee trends in sites with bee-friendly management in these individual habitat types were mostly not significantly different from trends in control sites.

Worryingly, while flower cover was stable over time in sites with bee-friendly management, flower cover declined significantly (by approximately 50%, Figure 4) in control sites. The decline in flower cover in conventionally managed sites is possibly due to warmer winters and the increasing number of extreme weather events. Warm winters, in combination with nitrogen deposition, create better conditions for grasses, which subsequently outcompete forbs (Bakker et al., 2024; Kreyling et al., 2019). Extremely dry summers result in fewer flowers, as desiccated plants do not flower (Phillips et al., 2018), and extremely wet summers can promote the dominance of grasses (Morecroft et al., 2004) which, similar to warm winters, result in forbs being outcompeted. All three processes seem to constrain the persistence of forbs and keep them from producing the flowers that wild bees rely on (Phillips et al., 2018). That we see stronger effects for wild bees, with a clear positive trend across all habitats in sites with bee-friendly management, may have to do with the fact that if flowers become more limiting to bees, the relationship between the two becomes more pronounced (Bishop et al., 2024).

Significant increases in floral resources relative to controls were only found in field margins (flower cover; Figure 3) and pastures (flower species richness; Figure S2). Nevertheless, we do not think that this precludes bee-friendly management in water retention sites and road verges. Although differences were small and non-significant, trends in bees were generally more positive in road verges and water retention sites with bee-friendly management than in conventionally managed sites. Many insignificant but consistent effects in subsets of sites can add up to a significant effect across all subsets. Furthermore, our study analyses effects on bee densities and does not consider the area in which bee-friendly management has been implemented. Small but consistent differences in bee densities can add up to considerable increases in the total number of bees when scaled up to the landscape level (Fijen et al., 2025; Kleijn et al., 2018). Bee-friendly management was particularly effective in field margins, however the inherent quality of pastures and water retention sites was higher, as indicated by the significantly higher average bee species richness (Figure 6). Water retention sites in particular were important as a nesting habitat as the slopes of these artificially created depressions in the landscape offered ideal nesting conditions for a wide range of species, as well as large aggregations of *Halictus scabiosae*, *H. quadricinctus*, *Lasioglossum malachurum* and *Andrena flavipes,* which could be found in water retention sites along with their kleptoparasites. Such aggregations were seldom encountered in any of the other habitat types. Finally, many species were observed in the other habitats that were not observed in the field margins (Figure 7). These were mostly singletons and doubletons which makes it difficult to say with confidence that they are bound to a specific habitat type, but it does suggest that focusing on a single habitat type runs the risk to miss out on the requirements of a subset of species. Altogether, this suggests that implementing bee-friendly management in different habitat types does produce some level of synergy.

A key factor driving the more positive trends in bees and flowers in sites with bee-friendly management was implementation success (Table 3). In the first year of implementation, bee-friendly management was implemented successfully in only one-third of the sites, which improved gradually to 79% in the fourth year. In one habitat type, the hedges, bee-friendly management failed completely as ultimately farmers did not allow their hedges to grow out following the verbal agreement with Natuurrijk Limburg, the cooperative responsible for agri-environment scheme implementation, and an actor in the Boshommellandschap initiative. The most common reasons for unsuccessful implementation of bee-friendly management were miscommunication between the actors and the tenant or contractor implementing the management, unwillingness of the contractor to modify conventional road management, and inclement weather (prolonged periods of rain; flooding) forcing land managers to modify their mowing schemes. Ecological monitoring has proven to be pivotal to identify instances with failed management and, by providing feedback to the actors responsible for it, has helped in improving the success rate of implementation. At the same time, monitoring has helped identify types of bee-friendly management that failed altogether and should be discontinued. Starting in 2024, bee-friendly management in hedges has been discontinued. Further, monitoring the ecological outcome of the multi-actor initiative has inspired the Waterboard to implement additional measures to promote bees in water retention sites starting in 2024. Seeing that delayed grazing did little to enhance wild bees, but that the sloped, sparsely-vegetated sides of water retention sites were key nesting habitats for bees, the Waterboard created earth banks to increase the value of this habitat as nesting sites (Tsiolis et al., 2022). This is a good example of the “learning by doing” approach that the Boshommellandschap initiative set out to do. Generally, actors may be more willing to implement costlier measures when there is evidence that the management they implement in the habitats they are responsible for is (not yet) effective in enhancing the target species.

Collaborative, landscape-scale conservation has enabled the implementation of conservation management on 47 sites, covering an area of 56.96 ha—something that would not have been possible using traditional conservation approaches. The combined effects of bee-friendly management in all 47 sites add up to significant affect the trends in bee abundance and species richness, even though effects in individual habitat types are often small. By addressing a variety of habitat types, managed by different actors, it is more likely that bee-friendly management includes sites that are important for different parts of the life cycle of wild bees, such as the water retention sites for nesting. This approach also allows for connecting the key habitats of target species (here, pastures and water retention sites) through improving the quality of linear landscape elements (road verges, field margins, hedges) in between them, which have been shown to facilitate pollinator movement through a landscape (Jauker et al., 2009). By improving the quality of both seminatural habitat and linear landscape elements, wild bee movement through the landscape may be enhanced, and with it, pollination (le Clech et al., 2024). However, our study also highlights a key weakness of multi-actor approaches. For individual actors, a multi-actor conservation initiative generally represents a small proportion of their daily activities. One cannot simply assume that conservation management will be implemented in the agreed way from the start of the initiative. With increasing number of stakeholders involved in the implementation, the proportion of conservation management that fails to be implemented in the correct way will likely increase. This stresses the importance of empirically monitoring the ecological outcome of multi-actor conservation approaches as this is often the only way to check if management is being correctly implemented. A second important benefit of ecological monitoring is that it makes it possible to adapt future management to the results of past management and improve outcomes for "failed" management types. Money, time, and effort can be saved by dropping interventions that have been repeatedly shown to fail (either in terms of implementation or expected outcomes). Additionally, management can be adapted to respond to changing environmental conditions. In this study, monitoring suggested that bee-friendly management targeting flower cover at best maintained flower cover, while flower cover in unmanaged sites declined drastically—most likely because of the negative effects of warm winters, wet summers, and summer drought. These insights can be used to improve the effectiveness of bee-friendly management, for example by introducing practices that target grass suppression, or increasing grazing pressure or mowing frequency after a warm winter or conversely reducing grazing pressure and mowing frequency during droughts (Piseddu et al., 2021). This study shows that without ecological monitoring it is impossible to make claims about the effectiveness or the success of collaborative multi-actor approaches. It is therefore worrying that the current study is, to the best of our knowledge, the first one to evaluate the ecological effects of the collaborative multi-actor approach. Based on this, the following concrete recommendations on optimal implementation of collaborative approaches can be made:

- Collaborative approaches can best be implemented using actors managing different parts of the landscape (agricultural land, public space, protected areas) as this offers the highest chance for ecological synergies.
- Whether agreed wildlife-friendly management has actually been implemented should be monitored to make sure the planned efforts of actors does not get lost in business as usual.
- Monitoring the ecological outcomes of collaborative approaches is motivating for actors and can inspire them to implement additional wildlife-friendly measures.
- Monitoring the ecological outcomes of collaborative approaches is essential to make sure that efforts made by actors actually result in biodiversity benefits (as this cannot be taken for granted).

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7. Supplementary Information

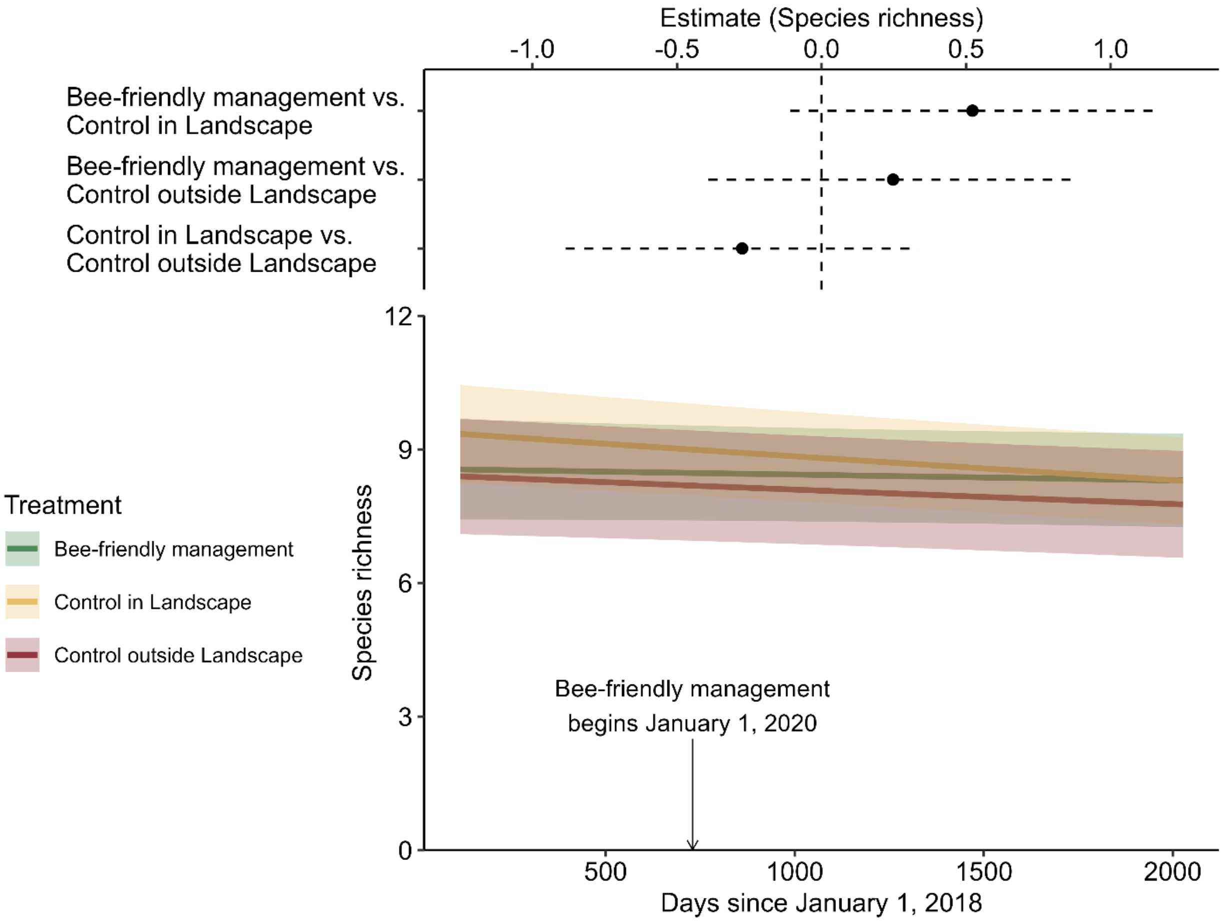

Figure S1. Upper panel: Pairwise comparisons of the rate of change in flower species richness. Points represent the difference in mean response and lines are the 95% confidence interval. A solid line indicates a significant difference between management types ($p < 0.05$). Lower panel: Linear trend in flower species richness, as a function of time (DSS) and management type. A solid line indicates a significant trend ($p < 0.05$).

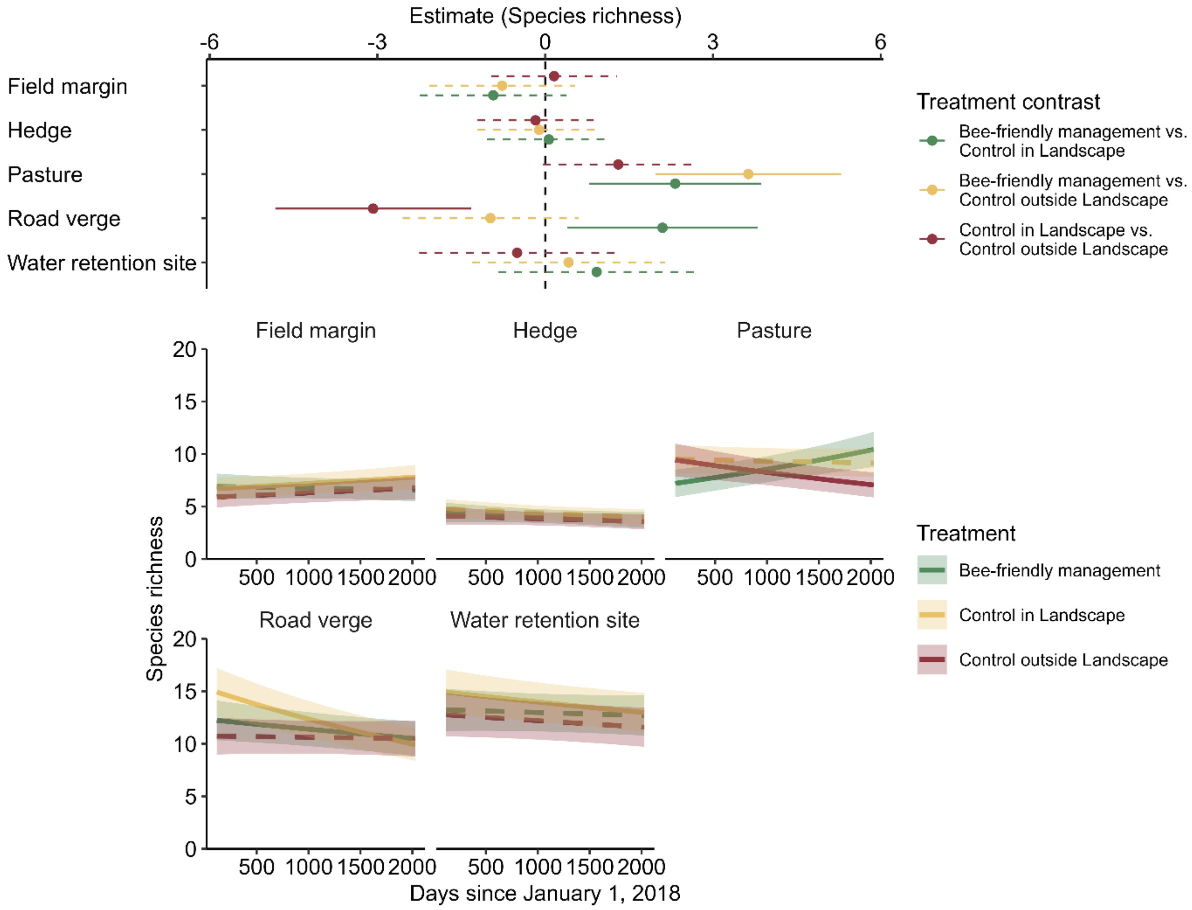

Figure S2. Upper panel: Pairwise comparisons of the rate of change in flower species richness by management type and habitat type. Points represent the difference in slope and lines are the 95% confidence interval. A solid line indicates a significant difference between management types ($p < 0.05$). Lower panel: Linear trend in flower species richness, as a function of time (DSS) and management type. Results are faceted by habitat type. A solid line indicates a significant trend ($p < 0.05$).

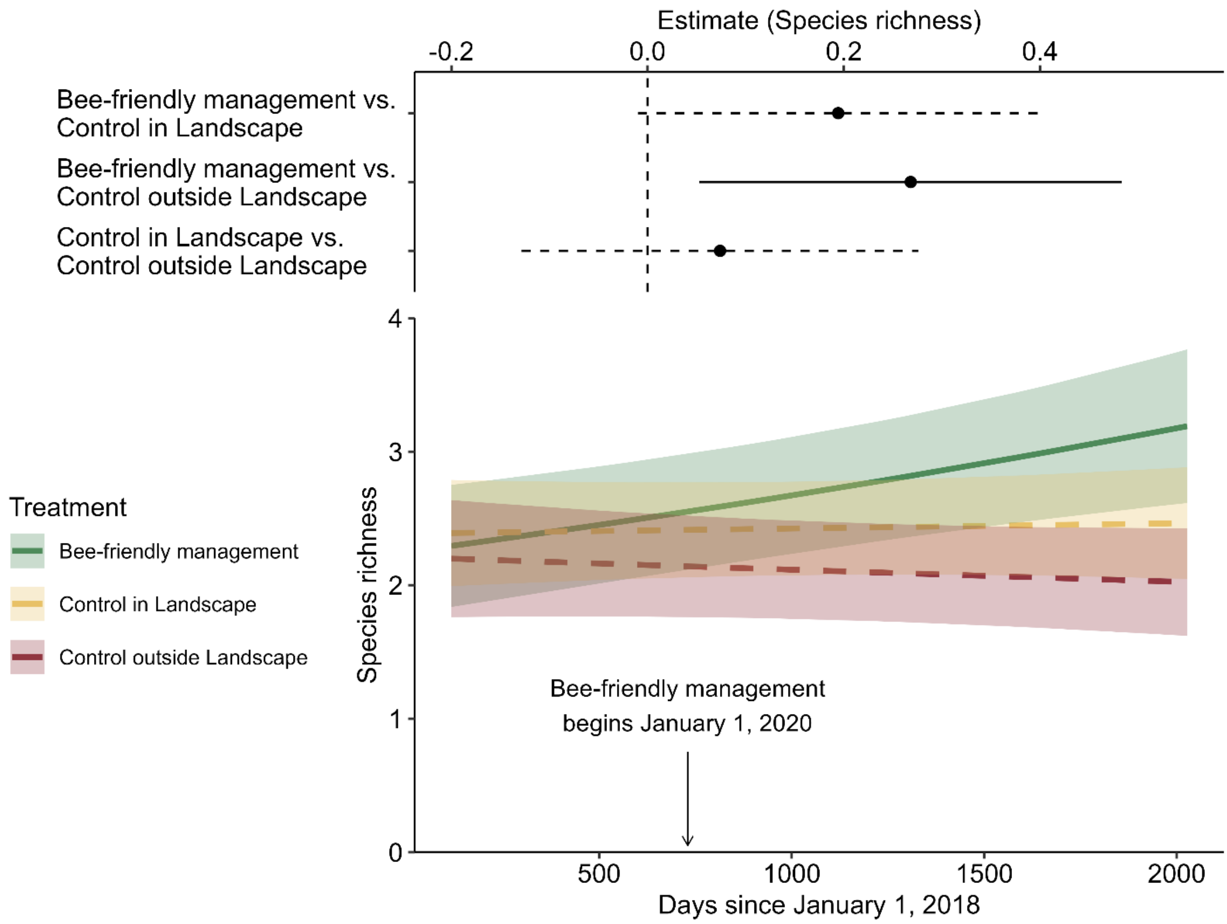

Figure S3. Upper panel: Pairwise comparisons of the rate of change in wild bee species richness. Points represent the difference in slope and lines are the 95% confidence interval. A solid line indicates a significant difference between management types ($p < 0.05$). Lower panel: Linear trend in wild bee species richness as a function of time (DSS) and management type. A solid line indicates a significant trend ($p < 0.05$).

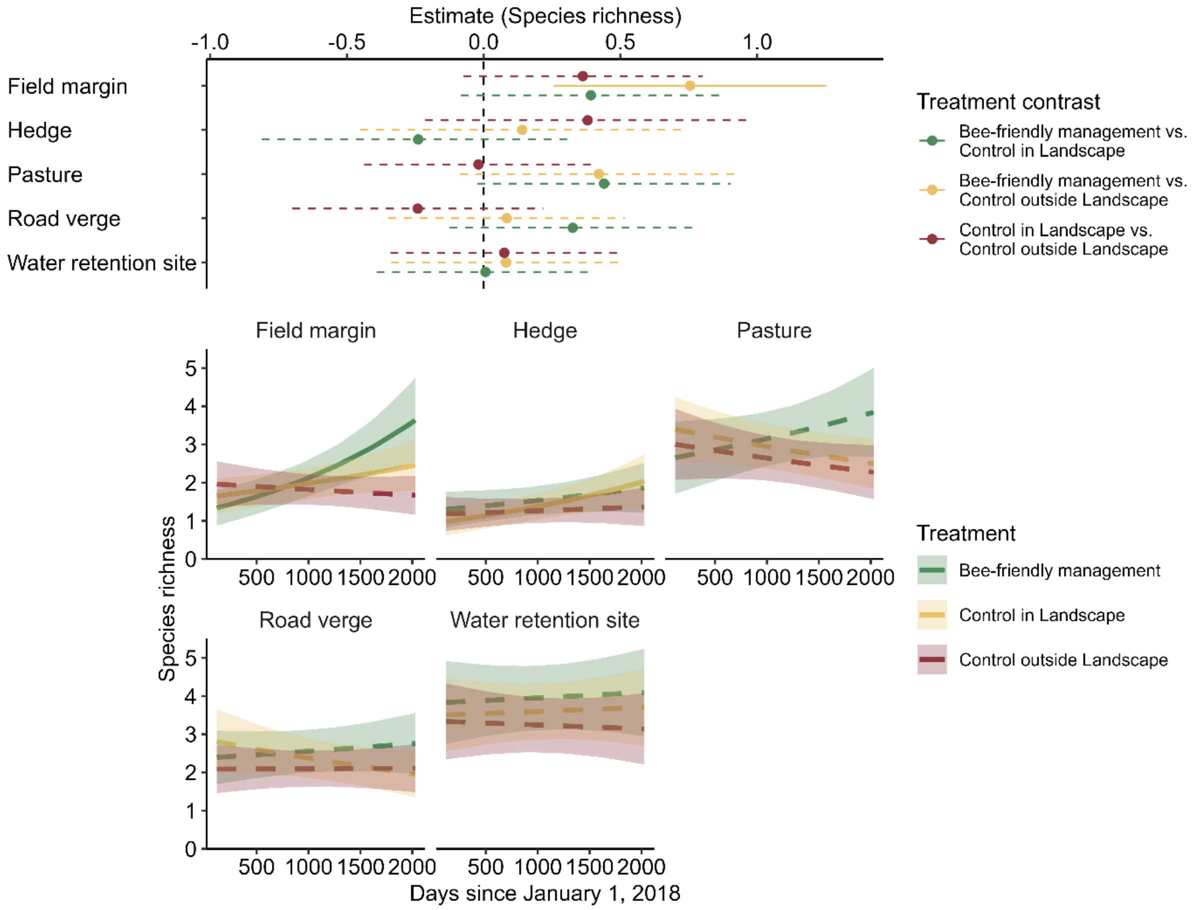

Figure S4. Upper panel: Pairwise comparisons of the rate of change in wild bee species richness by management type and habitat type. Points represent the difference in slope and lines are the 95% confidence interval. A solid line indicates a significant difference between management types ($p < 0.05$). Lower panel: Linear trend in wild bee species richness as a function of time (DSS) and management type. Results are faceted by habitat type. A solid line indicates a significant trend ($p < 0.05$).

Table S1. List of seed mixes used for sowing wildflower strips in field margins. When known, the percentage of each species is included.

Name	Species included
Shrill carder bee mix	*Trifolium pratense, Cichorium intybus, Centaurea jacea*
Flora and fauna mix	49.5% *Triticum aestivum*, 10% *Avena sativa*, 1.5% *Festuca rubra*, 1% *Lolium pratense*, 1% *Agrostis stolonifera*, 1% *Phleum pratense*, 1% *Lolium multiflorum*, 0.5% *Helianthus annuus*, 3% *Trifolium pratense*, 3% *Trifolium repens*, 2.5% *Fagopyrum esculentum*, 2.5% *Pisum sativum*, 2.5% *Onobrychis viciifolia*, 2.5% *Linum usitatissimum*, 2% *Carum carvi*, 2% *Medicago sativa*, 2% Vicia faba, 2% *Vicia villosa*, 0.5% *Leucanthemum vulgare*, 1.5% *Vicia sativa*, 1% *Tanacetum vulgare*, 1% *Glebionis segetum*, 1% *Camelina sativa*, 1% *Papaver rhoeas*, 1% *Centaurea jacea*, 1% *Daucus carota*, 0.5% *Viola arvensis*, 0.5% *Achillea millefolium*, 0.5% *Centaurea cyanus*
Pasture mix	8% *Phleum pratense*, 6% *Schedonorus arundinacea*, 5% *Lolium pratense*, 5% *Dactylis glomerata*, 5% *Festuca rubra*, 3% *Cynosurus cristatus*, 3% *Agrostis capillaris*, 10% *Lotus corniculatus*, 6% *Pastinaca sativa*, 5% *Cichorium intybus*, 5% *Centaurea jacea*, 5% *Medicago sativa*, 5% *Leucanthemum vulgare*, 5% *Trifolium pratense*, 5% *Plantago lanceolata*, 5% *Trifolium repens*, 4% *Achillea millefolium*, 4% *Melilotus albus*, 3% *Tanacetum vulgare*, 3% *Daucus carota*

Basic mix	*Papaver rhoeas, Centaurea cyanus, Glebionis segetum, Matricaria chamomilla*. This mix also contained exotic flower species.

Table S2. Pairwise comparisons of the rate of change in flower cover (%). Trends with a p-value < 0.05 were considered significant. β = the difference in the rate of change (trend) between management types.

Contrast	β	SE	df	z	p
Bee-friendly management - Control in Landscape	0.00056	0.00048	Inf	1.15234	0.482
Bee-friendly management - Control outside Landscape	0.00057	0.00050	Inf	1.14926	0.484
Control in Landscape - Control outside Landscape	0.00002	0.00037	Inf	0.04932	0.999

Table S3. Estimated linear trend in flower cover (%) as a function of time and management type. Trends with a p-value < 0.05 were considered significant.

Management Type	Trend (DSS)	SE	df	z	p
Bee-friendly management	-0.0007	0.0004	Inf	-1.59	0.112
Control in Landscape	-0.001	0.0002	Inf	-5.12	**<0.001**
Control outside Landscape	-0.001	0.0003	Inf	-4.37	**<0.001**

Table S4. Pairwise comparisons of the rate of change in flower cover (%). Trends with a p-value < 0.05 were considered significant. β = the difference in the rate of change (trend) between management types.

Habitat type	Contrast	β	SE	df	z	p
Field margin	Bee-friendly management - Control in Landscape	0.004	0.001	Inf	4.36	**<0.001**
	Bee-friendly management - Control outside Landscape	0.005	0.001	Inf	4.35	**<0.001**
	Control in Landscape - Control outside Landscape	0.0002	0.0006	Inf	0.33	0.941
Hedgerow	Bee-friendly management - Control in Landscape	-0.0004	0.0003	Inf	-1.33	0.381
	Bee-friendly management - Control outside Landscape	-0.0003	0.0003	Inf	-1.04	0.554
	Control in Landscape - Control outside Landscape	0.0001	0.0003	Inf	0.29	0.954
Pasture	Bee-friendly management - Control in Landscape	0.002	0.002	Inf	0.90	0.642
	Bee-friendly management - Control outside Landscape	0.001	0.002	Inf	0.64	0.797
	Control in Landscape - Control outside Landscape	-0.0005	0.001	Inf	-0.36	0.932
Road verge	Bee-friendly management - Control in Landscape	0.001	0.001	Inf	1.09	0.522
	Bee-friendly management - Control outside Landscape	0.0005	0.001	Inf	0.48	0.880
	Control in Landscape - Control outside Landscape	-0.0006	0.0008	Inf	-0.75	0.731

Habitat type	Contrast	β	SE	df	z	p
Water retention site	Bee-friendly management - Control in Landscape	-0.0006	0.001	Inf	-0.59	0.827
	Bee-friendly management - Control outside Landscape	-0.0007	0.001	Inf	-0.67	0.784
	Control in Landscape - Control outside Landscape	-0.0001	0.0008	Inf	-0.13	0.991

Table S5. Estimated linear trend in flower cover (%) as a function of time, management type, and habitat type. Trends with a p-value < 0.05 were considered significant.

Habitat type	Management Type	Trend (DSS)	SE	df	z	p
Field margin	Bee-friendly management	0.003	0.0009	Inf	3.84	**<0.001**
	Control in Landscape	-0.001	0.0004	Inf	-2.85	**0.004**
	Control outside Landscape	-0.001	0.0005	Inf	-2.60	**0.009**
Hedgerow	Bee-friendly management	-0.001	0.0003	Inf	-3.63	**<0.001**
	Control in Landscape	-0.0007	0.0002	Inf	-3.41	**<0.001**
	Control outside Landscape	-0.0008	0.0002	Inf	-3.40	**<0.001**
Pasture	Bee-friendly management	0.0002	0.002	Inf	0.09	0.926
	Control in Landscape	-0.002	0.0008	Inf	-1.94	0.053
	Control outside Landscape	-0.001	0.001	Inf	-1.13	0.257
Road verge	Bee-friendly management	-0.003	0.0008	Inf	-1.62	0.106
	Control in Landscape	-0.002	0.0007	Inf	-3.53	**<0.001**
	Control outside Landscape	-0.002	0.0006	Inf	-2.93	**0.003**
Water retention site	Bee-friendly management	-0.001	0.0009	Inf	-1.48	0.139
	Control in Landscape	-0.0007	0.0005	Inf	-1.36	0.173
	Control outside Landscape	-0.0006	0.0006	Inf	-1.06	0.288

Table S6. Pairwise comparisons of the rate of change in wild bee abundance. Trends with a p-value < 0.05 were considered significant. β = the difference in the rate of change (trend) between management types.

Contrast	β	SE	df	z	p
Bee-friendly management - Control in Landscape	0.35	0.12	Inf	2.88	**0.011**
Bee-friendly management - Control outside Landscape	0.39	0.13	Inf	3.06	**0.006**
Control in Landscape - Control outside Landscape	0.04	0.12	Inf	0.36	0.929

Table S7. Estimated linear trend in wild bee abundance as a function of time and management type. Trends with a p-value < 0.05 were considered significant.

Management Type	Trend (DSS)	SE	df	z	p
Bee-friendly management	0.26	0.09	Inf	2.87	**0.004**
Control in Landscape	-0.09	0.08	Inf	-1.09	0.274
Control outside Landscape	-0.13	0.09	Inf	-1.43	0.151

Table S8. Pairwise comparisons of the rate of change in wild bee abundance. Trends with a p-value < 0.05 were considered significant. β = the difference in the rate of change (trend) between management types.

Habitat type	Contrast	β	SE	df	z	p
Field margin	Bee-friendly management - Control in Landscape	1.39	0.27	Inf	5.10	**<0.001**
	Bee-friendly management - Control outside Landscape	1.89	0.29	Inf	6.50	**<0.001**
	Control in Landscape - Control outside Landscape	0.50	0.26	Inf	1.96	0.123
Hedgerow	Bee-friendly management - Control in Landscape	-0.31	0.30	Inf	-1.03	0.557
	Bee-friendly management - Control outside Landscape	0.15	0.32	Inf	0.47	0.886
	Control in Landscape - Control outside Landscape	0.46	0.32	Inf	1.43	0.324
Pasture	Bee-friendly management - Control in Landscape	0.11	0.27	Inf	0.40	0.914
	Bee-friendly management - Control outside Landscape	0.11	0.30	Inf	0.38	0.924
	Control in Landscape - Control outside Landscape	0.00	0.24	Inf	0.01	>0.999
Road verge	Bee-friendly management - Control in Landscape	0.57	0.26	Inf	2.16	0.078
	Bee-friendly management - Control outside Landscape	-0.06	0.25	Inf	-0.22	0.973
	Control in Landscape - Control outside Landscape	-0.62	0.26	Inf	-2.37	**0.046**
Water retention site	Bee-friendly management - Control in Landscape	-0.07	0.24	Inf	-0.30	0.951
	Bee-friendly management - Control outside Landscape	0.01	0.26	Inf	0.05	0.999
	Control in Landscape - Control outside Landscape	0.09	0.25	Inf	0.35	0.936

Table S9. Estimated linear trend in wild bee abundance as a function of time, management type, and habitat type. Trends with a p-value < 0.05 were considered significant.

Habitat type	Management Type	Trend (DSS)	SE	df	z	p
Field margin	Bee-friendly management	1.58	0.22	Inf	7.32	**<0.001**
	Control in Landscape	0.18	0.16	Inf	1.12	0.263
	Control outside Landscape	-0.32	0.20	Inf	-1.62	0.106
Hedgerow	Bee-friendly management	0.37	0.21	Inf	1.74	0.083
	Control in Landscape	0.68	0.21	Inf	3.16	**0.002**
	Control outside Landscape	0.22	0.24	Inf	0.90	0.366
Pasture	Bee-friendly management	-0.26	0.23	Inf	-1.14	0.254
	Control in Landscape	-0.37	0.15	Inf	-2.53	**0.011**
	Control outside Landscape	-0.37	0.20	Inf	-1.91	0.057
Road verge	Bee-friendly management	-0.04	0.18	Inf	-0.23	0.821
	Control in Landscape	-0.61	0.19	Inf	-3.13	**0.002**
	Control outside Landscape	0.02	0.18	Inf	0.09	0.931
Water retention site	Bee-friendly management	-0.09	0.18	Inf	-0.48	0.629
	Control in Landscape	-0.01	0.16	Inf	-0.08	0.933
	Control outside Landscape	-0.10	0.19	Inf	-0.53	0.596

Table S10. Pairwise comparisons of the rate of change in flower species richness. Trends with a p-value < 0.05 were considered significant. β = the difference in the rate of change (trend) between management types.

Contrast	β	SE	df	z	p
Bee-friendly management - Control in Landscape	0.04	0.03	Inf	1.12	0.50
Bee-friendly management - Control outside Landscape	-0.001	0.05	Inf	-0.03	1.00
Control in Landscape - Control outside Landscape	-0.04	0.05	Inf	-0.78	0.72

Table S11. Estimated linear trend in flower species richness as a function of time and management type. Trends with a p-value < 0.05 were considered significant.

Management Type	Trend (DSS)	SE	df	z	p
Bee-friendly management	-0.46	0.12	Inf	-3.78	**0.0002**
Control in Landscape	-0.49	0.13	Inf	-3.89	**0.0001**
Control outside Landscape	-0.46	0.12	Inf	-3.77	**0.0002**

Table S12. Pairwise comparisons of the rate of change in flower species richness. Trends with a p-value < 0.05 were considered significant. β = the difference in the rate of change (trend) between management types.

Habitat type	Contrast	β	SE	df	z	p
Field margin	Bee-friendly management - Control in Landscape	-0.93	0.56	Inf	-1.66	0.222
	Bee-friendly management - Control outside Landscape	-0.77	0.56	Inf	-1.39	0.348
	Control in Landscape - Control outside Landscape	0.16	0.48	Inf	0.33	0.942
Hedgerow	Bee-friendly management - Control in Landscape	0.07	0.47	Inf	0.14	0.990
	Bee-friendly management - Control outside Landscape	-0.11	0.47	Inf	-0.23	0.972
	Control in Landscape - Control outside Landscape	-0.17	0.44	Inf	-0.39	0.920
Pasture	Bee-friendly management - Control in Landscape	2.32	0.66	Inf	3.55	**0.001**
	Bee-friendly management - Control outside Landscape	3.63	0.71	Inf	5.13	**<0.001**
	Control in Landscape - Control outside Landscape	1.31	0.58	Inf	2.27	0.060
Road verge	Bee-friendly management - Control in Landscape	2.10	0.72	Inf	2.89	**0.011**
	Bee-friendly management - Control outside Landscape	-0.98	0.67	Inf	-1.46	0.311
	Control in Landscape - Control outside Landscape	-3.08	0.75	Inf	-4.12	**<0.001**
Water retention site	Bee-friendly management - Control in Landscape	0.92	0.75	Inf	1.23	0.437

Habitat type	Contrast	β	SE	df	z	p
	Bee-friendly management - Control outside Landscape	0.42	0.74	Inf	0.57	0.838
	Control in Landscape - Control outside Landscape	-0.50	0.75	Inf	-0.67	0.780

Table S13. Estimated linear trend in flower species richness as a function of time, management type, and habitat type. Trends with a p-value < 0.05 were considered significant.

Habitat type	Management Type	Trend (DSS)	SE	df	z	p
Field margin	Bee-friendly management	-0.21	0.44	Inf	-0.48	0.628
	Control in Landscape	0.72	0.34	Inf	2.11	**0.035**
	Control outside Landscape	0.56	0.34	Inf	1.63	0.104
Hedgerow	Bee-friendly management	-0.47	0.35	Inf	-1.33	0.183
	Control in Landscape	-0.53	0.32	Inf	-1.69	0.092
	Control outside Landscape	-0.36	0.31	Inf	-1.15	0.252
Pasture	Bee-friendly management	2.09	0.54	Inf	3.91	**<0.001**
	Control in Landscape	-0.23	0.37	Inf	-0.63	0.526
	Control outside Landscape	-1.54	0.45	Inf	-3.44	**<0.001**
Road verge	Bee-friendly management	-1.13	0.47	Inf	-2.40	**0.016**
	Control in Landscape	-3.22	0.57	Inf	-5.61	**<0.001**
	Control outside Landscape	-0.15	0.48	Inf	-0.31	0.757
Water retention site	Bee-friendly management	-0.35	0.52	Inf	-0.67	0.503
	Control in Landscape	-1.27	0.54	Inf	-2.35	**0.019**
	Control outside Landscape	-0.77	0.52	Inf	-1.47	0.142

Table S14. Pairwise comparisons of the rate of change in wild bee species richness. Trends with a p-value < 0.05 were considered significant. β = the difference in the rate of change (trend) between management types.

Contrast	β	SE	df	z	p
Bee-friendly management - Control outside Landscape	0.27	0.09	Inf	2.92	**0.010**
Bee-friendly management - Control in Landscape	0.19	0.09	Inf	2.23	0.066
Control in Landscape - Control outside Landscape	0.07	0.09	Inf	0.86	0.669

Table S15. Estimated linear trend in wild bee species richness as a function of time and management type. Trends with a p-value < 0.05 were considered significant.

Management Type	Trend (DSS)	SE	df	z	p
Bee-friendly management	0.21	0.07	Inf	3.29	**0.001**
Control outside Landscape	-0.05	0.06	Inf	-0.83	0.405
Control in Landscape	0.02	0.06	Inf	0.35	0.727

Table S16. Pairwise comparisons of the rate of change in wild bee species richness. Trends with a p-value < 0.05 were considered significant. β = the difference in the rate of change (trend) between management types.

Habitat type	Contrast	β	SE	df	z	p
Field margin	Bee-friendly management - Control in Landscape	0.39	0.20	Inf	1.93	0.130
	Bee-friendly management - Control outside Landscape	0.75	0.21	Inf	3.55	**0.001**
	Control in Landscape - Control outside Landscape	0.36	0.19	Inf	1.94	0.127
Hedgerow	Bee-friendly management - Control in Landscape	-0.24	0.24	Inf	-0.98	0.589
	Bee-friendly management - Control outside Landscape	0.14	0.25	Inf	0.56	0.843
	Control in Landscape - Control outside Landscape	0.38	0.25	Inf	1.50	0.291
Pasture	Bee-friendly management - Control in Landscape	0.44	0.20	Inf	2.23	0.067
	Bee-friendly management - Control outside Landscape	0.42	0.22	Inf	1.94	0.127
	Control in Landscape - Control outside Landscape	-0.02	0.18	Inf	-0.11	0.994
Road verge	Bee-friendly management - Control in Landscape	0.33	0.19	Inf	1.70	0.207
	Bee-friendly management - Control outside Landscape	0.08	0.18	Inf	0.46	0.891
	Control in Landscape - Control outside Landscape	-0.24	0.20	Inf	-1.23	0.435
Water retention site	Bee-friendly management - Control in Landscape	0.01	0.17	Inf	0.04	>0.999
	Bee-friendly management - Control outside Landscape	0.08	0.18	Inf	0.46	0.892
	Control in Landscape - Control outside Landscape	0.08	0.18	Inf	0.42	0.905

Table S17. Estimated linear trend in wild bee richness as a function of time, management type, and habitat type. Trends with a p-value < 0.05 were considered significant.

Habitat type	Management Type	Trend (DSS)	SE	df	z	p
Field margin	Bee-friendly management	0.65	0.16	Inf	4.08	**<0.001**
	Control in Landscape	0.26	0.12	Inf	2.11	**0.035**
	Control outside Landscape	-0.11	0.14	Inf	-0.75	0.456
Hedgerow	Bee-friendly management	0.24	0.17	Inf	1.37	0.169
	Control in Landscape	0.48	0.17	Inf	2.75	**0.006**
	Control outside Landscape	0.10	0.19	Inf	0.51	0.607
Pasture	Bee-friendly management	0.24	0.16	Inf	1.48	0.139
	Control in Landscape	-0.20	0.11	Inf	-1.88	0.060
	Control outside Landscape	-0.18	0.14	Inf	-1.26	0.206
Road verge	Bee-friendly management	0.09	0.13	Inf	0.72	0.471
	Control in Landscape	-0.23	0.14	Inf	-1.63	0.104
	Control outside Landscape	0.01	0.13	Inf	0.06	0.955
Water retention site	Bee-friendly management	0.04	0.12	Inf	0.35	0.725
	Control in Landscape	0.04	0.12	Inf	0.31	0.759
	Control outside Landscape	-0.04	0.13	Inf	-0.30	0.767