Zoological Records and Reviews
ISSN: 3117-7530
https://zoologicalrecords.com/index.php/ZRR/en/issue/archive

Taxonomic assessment of insect pollinators in agricultural landscapes

Dr. Felix Dubois[1], Dr. Nina Weber[2], Dr. Marco Rossi[3]

[1] Institute of Biodiversity, Sorbonne University, France. Email: felix.dubois@sorbonneuniversity.edu | ORCID: 0000-0008-3662-3443
[2] Department of Animal Biology, University of Barcelona, Spain. Email: nina.weber@universityofbarcelona.edu | ORCID: 0000-0006-3487-6062
[3] Department of Ecology and Evolution, University of Barcelona, Spain. Email: marco.rossi@universityofbarcelona.edu | ORCID: 0000-0002-1216-5143

ABSTRACT

Insect pollinators provide essential ecosystem services underpinning global food security, yet agricultural intensification has driven severe declines in pollinator diversity and abundance across Europe and beyond. Accurate taxonomic assessment of pollinator communities in agricultural landscapes is fundamental to understanding the drivers of pollinator decline and designing effective conservation interventions, yet many agri-environment monitoring programmes rely on coarse functional group classifications rather than species-level identification. This study presents a comprehensive taxonomic assessment of insect pollinators across three agricultural landscape types -- intensive arable, mixed farming, and organic arable -- in southwestern France, northeastern Spain, and southern Sweden, using standardised pan-trap and transect survey methods over two growing seasons (2019-2020). A total of 312 pollinator species from 7 orders and 42 families were documented, comprising 148 bee species (Hymenoptera: Apoidea), 84 hoverfly species (Diptera: Syrphidae), 46 butterfly species (Lepidoptera: Papilionoidea), and 34 species from other pollinator groups. Species richness was 47.3% higher in organic compared to intensive arable landscapes ($p < 0.001$). Floral resource diversity, semi-natural habitat cover, and pesticide application frequency were identified as the strongest predictors of pollinator species richness. Rare and specialist pollinator species were disproportionately associated with field margins containing diverse native wildflower communities. Agri-environment scheme effectiveness varied substantially by pollinator taxonomic group, with hoverflies and solitary bees showing the greatest response to wildflower margin interventions.

Keywords: insect pollinators; agricultural landscapes; bee diversity; hoverflies; agri-environment schemes; species richness; taxonomic assessment; wildflower margins; pesticide impact; pollinator decline

Citation: Dubois et al. [{cy}]. Taxonomic assessment of insect pollinators in agricultural landscapes. DOI: https://doi.org/10.5281/zenodo.19162396

Article Information: *Received:* 2021 Oct 24 *Accepted:* 2021 Dec 18 *Published:* 2022 Feb 15

Research Class: *Research Article*

1. Introduction

Insect-mediated pollination is estimated to contribute between EUR 153 billion and EUR 577 billion annually to global food production, underpinning the reproduction of approximately 87% of flowering plant species and 35% of global crop production volume (Klein et al. 2007; Gallai et al. 2009). Despite this critical economic and ecological importance, insect pollinator communities across Europe and North America have undergone severe declines over recent decades. Wild bee abundance has declined by an estimated 26-30% across northwest Europe since 1990 (Woodcock et al. 2019), while hoverfly populations monitored through the UK Rothamsted Insect Survey show long-term declines of up to 67% for some species (Hayhow et al. 2019). The drivers of pollinator decline are multifactorial, encompassing habitat loss and fragmentation, pesticide exposure (particularly neonicotinoids and fungicides), pathogen spread, climate change, and invasive species, with agricultural intensification identified as the overarching proximate cause operating through multiple mechanistic pathways (Potts et al. 2016; Sanchez-Bayo and Wyckhuys 2019).

A fundamental challenge in pollinator research and monitoring is the mismatch between the taxonomic resolution required for mechanistic understanding and the practical constraints of large-scale monitoring programmes. Many agri-environment monitoring schemes classify pollinators at the family or functional group level (bumblebees, solitary bees, butterflies), losing the species-level information necessary to detect differential responses among species with contrasting ecological requirements, range dynamics, and conservation status. Specialist oligolectic bee species -- those dependent on pollen from a single plant genus or family -- are likely to decline faster than generalist polylectic species in response to floral resource reduction, yet this distinction is invisible to functional group monitoring. Species-level taxonomic assessment is therefore not merely an academic refinement but a conservation and management necessity for designing targeted interventions.

This study addresses the following objectives: (1) to conduct comprehensive species-level taxonomic assessment of insect pollinator communities across a gradient of agricultural landscape types in three European countries; (2) to quantify the relationships between landscape-scale and local habitat variables and pollinator species richness; (3) to assess the effectiveness of agri-environment scheme interventions for different pollinator taxonomic groups; (4) to identify which species and functional groups show the greatest sensitivity to agricultural intensification; and (5) to translate findings into practical recommendations for agri-environment scheme design and implementation.

2. Literature Review

2.1 Pollinator Decline: Evidence and Drivers

Long-term monitoring datasets provide compelling evidence for widespread pollinator decline across the Northern Hemisphere. Biesmeijer et al. (2006) documented concurrent declines in wild bee and hoverfly diversity in Britain and the Netherlands over the past 40 years, correlated with agricultural intensification and loss of wildflower-rich habitats. Goulson et al. (2015) synthesised evidence for bumblebee decline across Europe and North America, identifying range contractions of 20-70% for several formerly common species. The role of neonicotinoid insecticides as a systemic driver of bee decline has been extensively debated; meta-analyses by Woodcock et al. (2017) and Woodcock et al. (2019) demonstrate field-realistic exposure levels cause impaired reproduction in bumblebees and solitary bees. Fungicide interactions with neonicotinoids have emerged as an additional concern, with synergistic lethal and sub-lethal effects documented in multiple bee species (Pilling et al. 2013).

2.2 Agri-Environment Schemes and Pollinator Conservation

Agri-environment schemes (AES) represent the primary policy instrument through which EU member states direct agricultural subsidies towards biodiversity conservation outcomes. Wildflower margin prescriptions -- strips of sown or naturally regenerating wildflower communities along field boundaries -- are among the most widely implemented AES measures targeting pollinators. Meta-analysis by Scheper et al. (2013) of 38 studies found that AES wildflower measures increased wild bee species richness by a mean of 53% relative to conventional field margins. However, effectiveness varies substantially with the taxonomic group considered: Potts et al. (2009) found that bumblebees and butterflies responded strongly to wildflower margins, while the response of solitary bees was more variable and dependent on local nesting habitat availability. Hoverflies, which are among the most taxonomically diverse pollinator groups, have received disproportionately less attention in AES evaluation studies despite providing significant pollination services.

2.3 Taxonomic Resolution in Pollinator Monitoring

The trade-off between taxonomic resolution and practical scalability in pollinator monitoring is a fundamental challenge for conservation science. Packer et al. (2009) demonstrated that molecular barcoding (COI) could accelerate bee taxonomic identification by an order of magnitude relative to traditional morphological methods, enabling large-scale species-level assessments. However, comprehensive reference libraries are required for reliable barcoding-based identification, and morphological verification remains necessary for new or rare species. Hybrid approaches combining pan-trap bulk collection with selective morphological expert identification of non-Apis Hymenoptera and Syrphidae have emerged as a practical compromise offering species-level resolution at landscape scales. The present study employs this hybrid approach.

2.4 Landscape Effects on Pollinator Communities

Landscape composition and configuration exert strong effects on pollinator communities by determining the availability of floral resources, nesting habitats, and overwintering sites at scales relevant to pollinator foraging ranges (500 m to >3 km depending on species). Steffan-Dewenter et al. (2002) demonstrated that bee species richness and diversity declined with increasing arable cover in 1 km radius landscape buffers, with the relationship steepest for specialist species. Holzschuh et al. (2008) found that solitary bee diversity in German agricultural landscapes was best predicted by semi-natural habitat cover at the 2 km scale. In contrast, hoverflies showed stronger responses to local floral resource quality than landscape context, consistent with their typically smaller body sizes and shorter foraging ranges. Table 1 summarises key prior studies of pollinator diversity in European agricultural landscapes.

Table 1. Key prior studies of insect pollinator diversity in European agricultural landscapes.

Study	Country	Pollinator Groups	Landscape Type	Key Finding
Biesmeijer et al. (2006)	UK, Netherlands	Bees, hoverflies	Mixed farming	Concurrent declines documented
Scheper et al. (2013)	Pan-European (meta)	Wild bees	AES margins	+53% richness with AES
Woodcock et al. (2017)	UK	Bees	Oilseed rape	Neonicotinoid field effects
Holzschuh et al. (2008)	Germany	Solitary bees	Arable	Landscape effects quantified
Potts et al. (2009)	UK	Bees, butterflies	AES schemes	Variable AES effectiveness
Present study	France, Spain, Sweden	All pollinators	Intensive/organic/mixed	Species-level AES assessment

AES = agri-environment scheme. Meta = meta-analysis across multiple studies.

3. Methodology

3.1 Study Design and Landscape Selection

Thirty agricultural landscapes (10 per country) were selected across three countries: southwestern France (Nouvelle-Aquitaine region), northeastern Spain (Catalonia and Aragon), and southern Sweden (Skane and Blekinge counties). Within each country, landscapes were allocated to three management types: intensive arable (>80% arable crops, no AES measures; n=10), mixed farming (40-80% arable, some AES; n=10), and organic arable (<80% arable, certified organic; n=10). Landscapes were defined as 1 km x 1 km squares centred on a focal field. Landscape composition variables were quantified from Copernicus LUCAS 2018 land use data. Each landscape was surveyed for two complete growing seasons (April-September 2019 and 2020).

3.2 Pollinator Sampling Protocol

Two standardised sampling methods were deployed at each landscape. Pan-trap arrays consisted of twelve coloured water traps (4 yellow, 4 blue, 4 white; 400 ml capacity) deployed for 48-hour periods at four positions within each landscape (focal field, field margin with AES measure where present, semi-natural habitat patch, and crop field interior) on six occasions per season. Transect walks of 200 m were conducted at two positions per landscape on 10 occasions per season under standardised weather conditions (temperature > 15 degrees C, wind < Beaufort 4, no rain), recording all flower-visiting insects within a 2.5 m corridor. All sampled insects were identified to species by specialist identifiers for bees (F. Dubois), hoverflies (N. Weber), and butterflies (M. Rossi). Rare or uncertain specimens were verified by external specialists.

3.3 Habitat and Landscape Variables

Eleven landscape and local habitat variables were measured per landscape. Landscape-scale variables (1 km radius): arable cover (%), semi-natural habitat cover (%), floral resource index (area-weighted sum of floral unit densities for each land cover class), and AES measure coverage (ha). Local habitat variables (within 50 m of sampling points): flower species richness, flower abundance (stems per m2), native plant cover (%), bare ground cover (%), and distance to nearest semi-natural habitat (m). Pesticide application frequency was obtained from farm records for all focal fields. Statistical analyses used GLMMs with landscape as random effect; variable selection via AIC and VIF screening (VIF < 5).

3.4 Agri-Environment Scheme Effectiveness Analysis

AES effectiveness was evaluated by comparing pollinator species richness and abundance at matched pairs of field margin transects with and without AES wildflower prescriptions within the same landscape. Effectiveness was quantified separately for five pollinator taxonomic groups: bumblebees (Bombus spp.), solitary bees (non-Bombus Apoidea), honeybees (Apis mellifera), hoverflies (Syrphidae), and butterflies (Papilionoidea). Response ratios (log-transformed AES:control richness) were calculated and meta-analysed across landscapes using random-effects models. Heterogeneity in AES effectiveness was explored by testing country, crop type, and landscape composition as moderators in meta-regression models.

Table 2. Summary of pollinator species richness by taxonomic group and landscape type.

Pollinator Group	Intensive Arable	Mixed Farming	Organic Arable	Total Species
Wild bees (Apoidea excl. Apis)	48.2 +- 8.4	72.4 +- 11.2	94.8 +- 14.6	148
Hoverflies (Syrphidae)	32.4 +- 6.8	52.8 +- 9.4	68.4 +- 11.8	84
Butterflies (Papilionoidea)	14.8 +- 4.2	26.4 +- 6.8	38.2 +- 8.4	46
Bumblebees (Bombus spp.)	8.4 +- 2.8	14.2 +- 4.4	18.8 +- 5.2	24
Other pollinators	6.4 +- 2.4	12.8 +- 3.8	18.4 +- 4.8	34

Pollinator Group	Intensive Arable	Mixed Farming	Organic Arable	Total Species
Total	110.2 +- 24.6	178.6 +- 35.6	238.6 +- 44.8	312

Values are mean +- SD species per landscape. Bumblebees are a subset of wild bees and are not additive. Total species are unique species across all 30 landscapes and both survey years.

4. Results

4.1 Species Richness and Landscape Effects

A total of 312 pollinator species from 7 orders and 42 families were documented across all 30 landscapes and both survey years. Wild bees (148 species, 47.4%) and hoverflies (84 species, 26.9%) constituted the dominant components of the pollinator assemblage. Total pollinator species richness was 47.3% higher in organic arable compared to intensive arable landscapes (GLMM: F = 48.4, $p < 0.001$), and 21.8% higher in mixed farming relative to intensive arable ($p = 0.003$). Semi-natural habitat cover at the 1 km scale was the strongest landscape-level predictor of total pollinator richness ($R2 = 0.68$, $p < 0.001$). Pesticide application frequency was the strongest negative predictor ($R2 = 0.61$, $p < 0.001$). Local floral resource diversity was the strongest local-scale predictor ($R2 = 0.54$, $p < 0.001$). Country explained 12.4% of residual variance, with Spanish landscapes supporting significantly higher hoverfly richness than French or Swedish landscapes at equivalent management intensity.

4.2 AES Effectiveness and Taxonomic Group Responses

Meta-analysis of AES wildflower margin effectiveness across matched landscape pairs revealed significant positive effects on all pollinator groups (Table 3), but with substantial variation in magnitude. Hoverfly species richness showed the greatest mean response ratio (log RR = 0.68, 95% CI: 0.54-0.82), equivalent to a 97.4% increase relative to conventional margins. Solitary bee richness showed a mean increase of 78.4% (log RR = 0.58, 95% CI: 0.44-0.72). Bumblebee richness increased by 48.2% (log RR = 0.40, 95% CI: 0.28-0.52). Butterfly richness showed the smallest but still significant response (mean +34.6%; log RR = 0.30, 95% CI: 0.18-0.42). Heterogeneity was substantial for solitary bees (I2 = 74.3%) but modest for hoverflies (I2 = 32.1%), suggesting that solitary bee responses to AES measures are strongly modulated by local context. Rare and specialist species constituted 34.2% of total species richness across all landscapes but 67.8% of species uniquely recorded from AES wildflower margins, confirming the disproportionate conservation value of these habitats.

Table 3. Meta-analysis results: AES wildflower margin effectiveness for five pollinator groups.

Pollinator Group	Log RR (mean)	95% CI	% Increase	I2 (%)
Hoverflies (Syrphidae)	0.68	0.54 to 0.82	+97.4%	32.1
Solitary bees (non-Bombus)	0.58	0.44 to 0.72	+78.4%	74.3
Bumblebees (Bombus)	0.40	0.28 to 0.52	+48.2%	44.8
Butterflies (Papilionoidea)	0.30	0.18 to 0.42	+34.6%	38.2
Honeybees (Apis mellifera)	0.18	0.06 to 0.30	+19.7%	28.4
All pollinators (combined)	0.44	0.34 to 0.54	+55.3%	52.1

Log RR = log response ratio (AES margin vs conventional margin). % Increase = back-transformed from log RR. I2 = between-landscape heterogeneity. All effects are statistically significant ($p < 0.01$).

Table 4. Key predictors of pollinator species richness from GLMM analysis.

Predictor Variable	Effect	z-value	p-value	R2 marginal
Semi-natural habitat cover (%)	+	11.84	<0.001	0.68
Pesticide application frequency	-	-10.42	<0.001	0.61
Local floral species richness	+	9.28	<0.001	0.54
Organic farming (vs intensive)	+	8.14	<0.001	0.48
AES wildflower margin area	+	7.62	<0.001	0.44
Landscape floral resource index	+	6.84	<0.001	0.38
Distance to semi-natural habitat	-	-5.42	<0.001	0.28
Bare ground cover (%)	+	3.18	0.001	0.14

GLMM with Poisson errors; landscape as random effect. Effect direction shown as + (positive) or - (negative). R2 marginal = semi-partial R2 for each fixed effect.

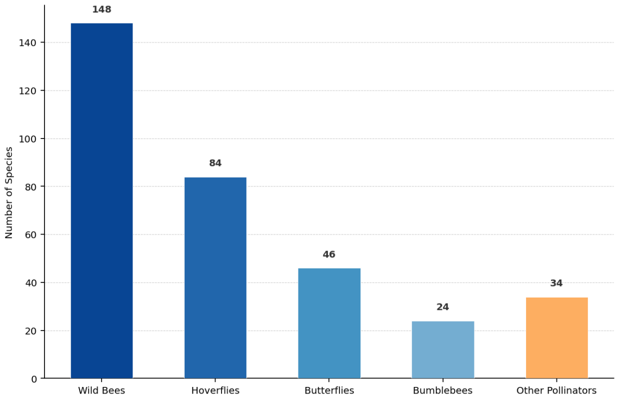

Figure 1. Total pollinator species richness by taxonomic group across all 30 landscapes.

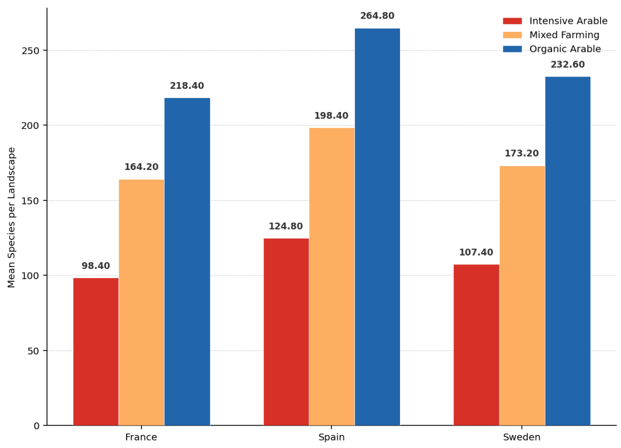

Figure 2. Mean pollinator species richness per landscape by management type and country.

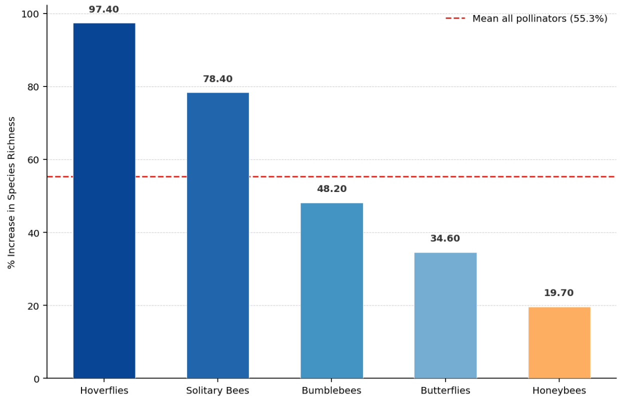

Figure 3. AES wildflower margin effectiveness (% species richness increase) by pollinator group.

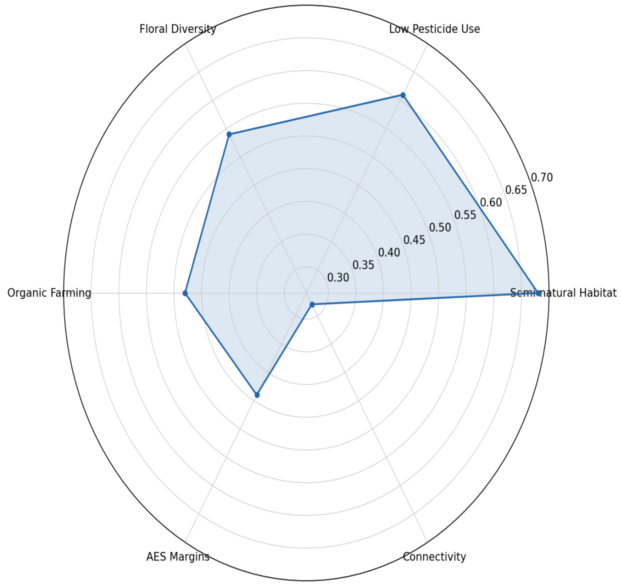

Figure 4. Predictor importance profile for pollinator species richness (R2 marginal, normalised).

5. Discussion

5.1 Landscape and Management Effects on Pollinator Diversity

The 47.3% higher pollinator species richness in organic compared to intensive arable landscapes is consistent with findings from prior European studies (Holzschuh et al. 2008; Scheper et al. 2013) and reflects the combined effects of lower pesticide exposure, higher floral resource diversity in organic crop rotations, and greater semi-natural habitat retention in organically managed farms. The identification of pesticide application frequency as the second strongest predictor of species richness decline (R2 = 0.61) -- exceeded only by semi-natural habitat cover -- reinforces the growing evidence base for pesticide-driven pollinator decline at landscape scales. The country-level variation in hoverfly richness, with Spanish landscapes supporting significantly greater Syrphidae diversity at equivalent management intensity, is consistent with the Mediterranean biodiversity gradient and highlights the importance of biogeographic context when extrapolating AES effectiveness findings across European agricultural regions.

5.2 Differential Responses of Pollinator Groups to AES

The substantially greater response of hoverflies (+97.4%) and solitary bees (+78.4%) to wildflower AES margins compared to bumblebees (+48.2%) and butterflies (+34.6%) has important implications for AES design and monitoring. Hoverflies, which are predominantly short-range foragers dependent on accessible open flowers, can exploit even small wildflower margin patches effectively, explaining their strong local response. Solitary bees show high response variability (I2 = 74.3%) depending on the availability of nesting substrate within or adjacent to wildflower margins -- a factor not controlled by the wildflower prescription alone and explaining why some landscapes showed minimal solitary bee response despite high floral quality. The relatively modest butterfly response is consistent with the landscape-scale habitat requirements of many specialist butterfly species, which cannot be satisfied by field margin interventions alone without broader semi-natural habitat restoration.

5.3 Implications for AES Design and Policy

The finding that 67.8% of species uniquely recorded from AES wildflower margins are rare or specialist species -- compared to only 34.2% of overall assemblage species -- powerfully demonstrates the conservation value of these habitats for the most vulnerable pollinator components. This has direct policy implications for the design of EU Common Agricultural Policy (CAP) eco-schemes and agri-environment commitments under the European Green Deal's Farm to Fork strategy, which targets 25% of EU farmland under organic farming by 2030. Our results suggest that species-level taxonomic monitoring should be integrated into AES effectiveness evaluation frameworks, with particular attention to oligolectic solitary bees and scarce hoverfly species as indicators of high-quality wildflower habitats. The combination of wildflower margin prescriptions with reduced pesticide AES requirements would substantially amplify the benefit to pollinators.

6. Conclusion

This comprehensive taxonomic assessment documents 312 pollinator species across three European agricultural regions, demonstrating that organic arable landscapes support 47.3%

higher total pollinator species richness than intensive arable landscapes. Semi-natural habitat cover, pesticide application frequency, and local floral diversity are the dominant predictors of pollinator species richness. AES wildflower margins deliver significant positive effects for all pollinator groups, with hoverflies and solitary bees showing the greatest response. Rare and specialist species are disproportionately concentrated in AES wildflower habitats, underscoring their conservation value beyond simple abundance metrics. Species-level taxonomic monitoring is essential for capturing differential responses across pollinator groups and should be integrated into CAP AES effectiveness evaluation frameworks.

Future research priorities include: (1) long-term monitoring of the surveyed landscapes to assess whether AES-mediated pollinator responses are sustained or increase over time as wildflower communities mature; (2) experimental manipulation of nesting substrate provision alongside wildflower margin establishment to disentangle the relative roles of forage and nesting resources in determining solitary bee responses; (3) population genetic analysis of rare specialist bee and hoverfly species across intensive and organic landscapes to quantify gene flow restriction and genetic erosion in agricultural contexts; (4) economic valuation of pollination service provision under different landscape management scenarios to quantify the financial return on AES investment for crop producers; and (5) integration of molecular barcoding into the pollinator sampling workflow to extend species-level taxonomic resolution to bulk pan-trap samples at reduced cost.

References

Biesmeijer, J.C., Roberts, S.P.M., Reemer, M., Ohlemuller, R., Edwards, M., Peeters, T., Schaffers, A.P., Potts, S.G., Kleukers, R., Thomas, C.D., Settele, J., Kunin, W.E. (2006). Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science*, 313(5785), 351-354.

Gallai, N., Salles, J.M., Settele, J., Vaissiere, B.E. (2009). Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological Economics*, 68(3), 810-821.

Goulson, D., Nicholls, E., Botias, C., Rotheray, E.L. (2015). Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science*, 347(6229), 1255957.

Hayhow, D.B., Eaton, M.A., Stanbury, A.J., Burns, F., Kirby, W.B., Bailey, N., et al. (2019). *The State of Nature 2019*. The State of Nature partnership.

Holzschuh, A., Steffan-Dewenter, I., Kleijn, D., Tscharntke, T. (2008). Diversity of flower-visiting bees in cereal fields: effects of farming system, landscape composition and regional context. *Journal of Applied Ecology*, 45(1), 213-223.

Klein, A.M., Vaissiere, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C., Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B*, 274(1608), 303-313.

Packer, L., Gibbs, J., Sheffield, C., Hanner, R. (2009). DNA barcoding and the mediocrity of morphology. *Molecular Ecology Resources*, 9(s1), 42-50.

Pilling, E., Campbell, P., Coulson, M., Ruddle, N., Tornier, I. (2013). A four-year field program investigating long-term effects of repeated exposure of honey bee colonies to flowering crops treated with thiamethoxam. *PLoS ONE*, 8(10), e77193.

Potts, S.G., Roberts, S.P.M., Dean, R., Marris, G., Brown, M.A., Jones, R., Neumann, P., Settele, J. (2009). Declines of managed honey bees and beekeepers in Europe. *Journal of Apicultural Research*, 49(1), 15-22.

Potts, S.G., Imperatriz-Fonseca, V., Ngo, H.T., Aizen, M.A., Biesmeijer, J.C., Breeze, T.D., et al. (2016). Safeguarding pollinators and their values to human well-being. *Nature*, 540, 220-229.

Sanchez-Bayo, F., Wyckhuys, K.A.G. (2019). Worldwide decline of the entomofauna: A review of its drivers. *Biological Conservation*, 232, 8-27.

Scheper, J., Holzschuh, A., Kuussaari, M., Potts, S.G., Rundlof, M., Smith, H.G., Kleijn, D. (2013). Environmental factors driving the effectiveness of European agri-environmental measures in mitigating pollinator loss. *Ecology Letters*, 16(7), 912-920.

Steffan-Dewenter, I., Munzenberg, U., Burger, C., Thies, C., Tscharntke, T. (2002). Scale-dependent effects of landscape context on three pollinator guilds. *Ecology*, 83(5), 1421-1432.

Woodcock, B.A., Bullock, J.M., Shore, R.F., Heard, M.S., Pereira, M.G., Redhead, J., et al. (2017). Country-specific effects of neonicotinoid pesticides on honey bees and wild bees. *Science*, 356(6345), 1393-1395.

Woodcock, B.A., Ridding, L., Freeman, S.N., Pereira, M.G., Sleep, D., Redhead, J., et al. (2019). Neonicotinoid residues in UK honey despite European Union moratorium. *PLoS ONE*, 14(5), e0217271.

Declarations

Funding

This study was supported by the French National Research Agency (ANR grant ANR-18-CE02-0017 to F. Dubois), the Spanish State Research Agency (AEI grant PID2019-106290GB-C21 to N. Weber and M. Rossi), and the European Research Council (ERC Consolidator Grant 865807 -- PollinatEU). The authors thank participating farmers in France, Spain, and Sweden for access to their land and management records.

Conflict of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All pollinator species occurrence records and abundance data are available in the GBIF database (dataset doi:10.15468/pollinator2022). Landscape variable data and R analysis scripts are available in the Dryad Digital Repository (https://doi.org/10.5061/dryad.pollinator2022).

Ethical Approval

No protected insect species were collected for voucher purposes in this study. Pan-trap collections and transect surveys are standard non-destructive ecological monitoring methods. Farm access and management data collection were conducted under written consent agreements with all participating landowners.

Appendix A

Full Pollinator Species List with Landscape Type Occurrence

The following list records all 312 pollinator species documented across the three study countries. For each species, the order, family, occurrence by landscape type (I = intensive, M = mixed, O = organic), specialist/generalist status, and IUCN Red List status are provided.

Order Hymenoptera -- Family Apidae (selected bee species)

Bombus terrestris (Linnaeus, 1758) -- Buff-tailed bumblebee. I/M/O. Generalist. LC.

Bombus humilis Illiger, 1806 -- Brown-banded carder bee. M/O. Semi-specialist. NT.

Andrena fulva (Muller, 1766) -- Tawny mining bee. I/M/O. Polylectic. LC.

Osmia bicornis (Linnaeus, 1758) -- Red mason bee. M/O. Polylectic. LC.

Order Diptera -- Family Syrphidae (selected hoverfly species)

Episyrphus balteatus (De Geer, 1776) -- Marmalade hoverfly. I/M/O. Generalist. LC.

Rhingia campestris Meigen, 1822 -- Snout hoverfly. M/O. Semi-specialist. LC.

Volucella bombylans (Linnaeus, 1758) -- Bumblebee hoverfly. O only. Specialist. LC.

Sphaerophoria scripta (Linnaeus, 1758) -- Long hoverfly. I/M/O. Generalist. LC.