Supplementary Information for

Complex agricultural landscapes host more biodiversity: a global meta-analysis

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This PDF file includes:

- Supplementary text
- Figures S1 to S9 (not allowed for Brief Reports)
- Tables S1 to S6

Supplementary Information Text
Previous meta-analysis assessing landscape complexity effect on biodiversity

Table S1. Summary of other meta-analyses or syntheses explicitly assessing the response of biodiversity to landscape complexity. The articles included in each of the listed meta-analyses were also included and screened in our analysis except those articles that calculated landscape complexity a posteriori. Previous meta-analyses and synthesis used on average evidence from 50 articles (standard error = 9) and 157 effect sizes (standard error = 26). Our study, condensing 157 articles and over 1000 effect sizes, is therefore, the most comprehensive and systemic assessment designed to understand landscape complexity and how it affects biodiversity in agricultural landscapes.

| Descriptor | Bianchi et al., 2006 (1) | Batáry et al., 2011 (2) | Chaplin-Kramer et al. 2011 (3) | Shackelford et al. 2014 (4) | Gonthier et al. 2014 (5) | Tuck et al. 2014 (6) | Lichtenberg et al. 2017 (7) | Coutinho et al., 2018 (8) | Marja et al., 2022 (9) | This research |
|------------|-------------------------|------------------------|-------------------------------|--------------------------|------------------------|------------------------|--------------------------|------------------------|------------------------|---------------|
| Studies No. | 28                      | 93                     | 46                            | 46                       | 31                     | 94                     | 60                       | 23                     | 29                     | 157           |
| Effect sizes | na                      | 223                    | 159                           | 88                      | 266                    | 184                    | 110                     | 45                     | 184                    | abundance, richness, richness, evenness, richness, richness & abundance, richness & abundance |
| Biodiversity metric | no data                | richness & abundance | richness, Shannon, richness and abundance & richness & abundance | richness & abundance | richness & abundance | richness & abundance | richness & abundance | richness & abundance | richness & abundance |
| Biodiversity group (class or order) | aphids, thrips, weevils, lepidoptera, beetle (pest species) and parasitoids, spiders, carabid beetles, syrphids, coccinellids (natural enemy species) | plants, invertebrates and vertebrates | bees, predatory beetles, parasitid wasps, and spiders (pollinators and natural enemies) | plants, invertebrates and vertebrates | arthropods, birds, microbes and plants | plants, invertebrates and vertebrates | arthropods, birds, microbes and plants | bees | arthropods | abundance, richness, diversity, anura araneae birds chiroptera coleoptera dermaptera diptera gastropoda hémiptera hymenoptera insect lepidoptera mammals microorganism s multitaxa neuroptera opiliones opisthopora orthoptera passeriformes plants rodentia thysanoptera |
| Descriptor | Bianchi et al., 2006 (1) | Batáry et al., 2011 (2) | Chaplin-Kramer et al. 2011 (3) | Shackelford et al. 2014 (4) | Gonthier et al. 2014 (5) | Tuck et al. 2014 (6) | Lichtenberg et al. 2017 (7) | Coutinho et al., 2018 (8) | Marja et al., 2022 (9) | This research |
|------------|-------------------------|-------------------------|-----------------------------|-----------------------------|-------------------------|-------------------------|------------------------|------------------------|------------------------|-------------------------|
| Maincrop / mgmt. | cereals, vegetables, oil crops, sugar crops, roots and tubers, fiber crops, grassland, cropland under agri-environmental management vs. conventional | no data | no data | no data | no data | no data | no data | no data | no data | cereals under agri-environment schemes vs conventional |
| Landscape measures inverted? | no data | the measures for % non-crop and % crop (inverted) were kept separate because of different assumptions regarding the composition of non-crop habitats | no data | no data | no data | no data | no data | % of arable land |
| Landscape complexity metrics | % non-crop habitats | % natural habitat, % non-crop habitat, % crop (inverted), habitat diversity and another category (comprised of one study measuring) | % of non-crop or natural habitats | % of non-crop areas, number diff habitat types (shannon) | (i) % arable fields – the % of the landscape covered by arable fields; (ii) number of habitats – the number of distinguishable habitats found | the % of natural and seminatural habitat surrounding the farm classified as simple<20% and complex >20% natural habitat. | % non-crop area, % crop-area | % seminatural habitats or non-crop area, shannon diversity indices of crop or habitat diversity, land-use diversity, the inverted percentage of aggregation (conf.) comp & conf & hete connectivity (conf.) lu diversity (hete.) lu eveness (hete.) non-crop area |
| Descriptor                                                                 | Bianchi et al., 2006 (1) | Batáry et al., 2011 (2) | Chaplin-Kramer et al. 2011 (3) | Shackelford et al. 2013 (4) | Gonthier et al. 2014 (5) | Tuck et al. 2014 (6) | Lichtenberg et al. 2017 (7) | Coutinho et al., 2018 (8) | Marja et al., 2022 (9) | This research |
|---------------------------------------------------------------------------|--------------------------|-------------------------|-------------------------------|---------------------------|------------------------|------------------------|---------------------------|-------------------------|----------------------|------------------|
| distance to natural habitat and three studies measuring linear features such as length of woody edges at the landscape scale. |                          |                          |                               |                           |                        |                        |                           |                         |                      |                  |
| in the landscape; and (iii) average field size – the average size of arable fields in the landscape. the percentage of arable fields is a measure of land-use intensity, while the number of habitats represents landscape complexity. |                          |                          |                               |                           |                        |                        |                           |                         |                      |                  |
| arable land, and the inverted landscape homogeneity (comp.)               |                          |                          |                               |                           |                        |                        |                           |                         |                      |                  |
| Landscape complexity metrics post classified by authors?                 | yes                      | yes                     |                               |                           |                        |                        |                           |                         |                      |                  |
| Effect sizes reported as                                                  | na (review)              | hedges's d              | z                             | z                         | z                      | log response ratio     | log-response ratio      | z or pearson's correlation coefficient (r) | hedges' g and pearson's correlation coefficient (r) depending on the data type | z or pearson's correlation coefficient (r) and hedges' g (after converted to r) depending on the data type |
| Publication bias                                                         | na                       | rosenthal's technique (>5n+10) | (1) funnel plots, (2) a spearman-rank correlation test achieves, (3) we also calculated rosenthal's fail-safe number | funnel plots, correlation tests for funnel-plot asymmetry and chi-squared tests to compare the number of studies in different | no data | funnel plot and estimated the slope of the association between sampling variance and effect size | funnel plot, asymetry to funnel plot, regression test for funnel plot and fail-safe numbers | funnel plot, regression test for funnel plot and fail-safe numbers | funnel plot, regression test, inverse of sample size as predictor |

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|------------|--------------------------|-------------------------|-----------------------------|-----------------------------|--------------------------|-------------------------|---------------------------|--------------------------|-------------------------|---------------|
| Minimum radius | no data | 1000m | 500m | 10m | 250m | 500m | 1000m | no data | no data | 100m |
| Minimum sample size (landscape) | no data | 2 | 5 | no data | no data | 5 | 4 | no data | 3 | 5 |
Meta-analysis workflow and details
Our search string, tailored to capture research specifically referring to landscape complexity in Web of Science, Scopus, and Google Scholar, resulted in 614 articles (unique DOI's). All articles were fully screened by at least two authors and classified as include or exclude before data extraction. A third person checked and verified the few instances where article inclusion/exclusion discrepancies existed among the two authors. The 614 articles were screened following the PICOC components (10) and against the following criteria:

**Eligible population:** any non-domesticated species in terrestrial ecosystems surveyed at any life stage and located above or below ground.

**Eligible interventions (also referred to as the treatment):** Here, a landscape covers an area with a radius above 100m and has more complex landscape patterns either because is more heterogeneous (e.g., crop richness) or have more complex configurations (e.g., edge density) or compositions (e.g., seminatural habitat).

**Eligible comparators (also referred to as the control):** cleared, simple, homogeneous, isolated agricultural landscapes at a radius above 100m.

**Eligible outcomes:** quantified impact of interventions and comparators on the eligible population measured as species richness, species abundance, or evenness indices (e.g., Shannon's diversity index). Articles can report outcomes from the comparator and intervention either by providing means, variation, and sample size or by providing the strength of the relationship (correlation coefficient and slope) based on at least five data points (i.e., landscapes). We further excluded studies where: a) information on the correlation between the interventions and comparators' outcomes for linear associations is missing or impossible to estimate with the provided information (e.g., linear regression without the data points), b) variation information (e.g., standard deviation, standard error) for pre-classified landscapes is missing, c) data transformation is poorly described limiting back transforming the data to linear relationships for linear associations, d) landscape metric directionality is unclear (e.g., % semi-open area or habitat slope (angle)), or e) outcomes from eligible interventions and comparators in the same study with different or not comparable sampling methods.

**Context:** We further excluded non-primary articles (e.g., meta-analysis), articles conducted under controlled conditions (e.g., greenhouses, cages, rings), theoretical articles (e.g., simulations, modeling), articles with non-experimental/observational experimental designs or articles in landscapes which are strictly urban, marine or natural were excluded. We only include articles with full text in English taking place in agricultural landscapes (e.g., mixed natural and cultivated land uses).
We identified 157 articles that fully satisfied our inclusion criteria and extracted data in a standardized template (Fig. S1, Table S2). We extracted biodiversity and landscape complexity data from articles' text, tables, or digitized figures included in the main document, supplementary material, or associated datasets. We used WebPlotDigitizer v 4.2 (12) to digitize values and visually inspected all data to identify and correct errors (e.g., erroneous extreme values or duplicate entries). We back-transformed associations given as logarithmic or polynomial equations into linear relations. Sample sizes correspond to the digitized or entered values rather than original ones since points overlap in some cases resulting in smaller sample sizes. We recorded all extents analyzed and shared in each study even if they were not statistically significant (e.g., 500 m, 1000 m). We entered only the values of the latest year when values were reported for multiple years, and if all years have the same sample size, otherwise we entered the values from the year with the largest sample size. When values were given across crop stages, we entered the most mature stage (e.g., ripening over flowering). All entered observations were verified by one of the co-authors.
**Table S2. Information extracted from the peer-reviewed articles measuring landscape complexity and biodiversity outcomes and additional fields created after reclassifying or converting collected information**

| Categories                              | Extracted information                                                                 | Additional fields from reclassifying/converting collected information                                                                 | Additional data sources - notes                                                                 |
|-----------------------------------------|---------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Article                                 | Authors, affiliations, title, year, journal, and DOI.                                  | • StudyID  
• EffectsizeID                                                                                                                       |                                                                                               |
| Crops                                   | Monitored crop(s) common name                                                          | • FAO commodity group  
• Life cycle  
• Growth form  
https://www.fao.org/in-action/mafap/common-elements/commodity-group/en/, https://eol.org, https://www.prota4u.org |                                                                                               |
| Production system and management        | Dominating management system (e.g. organic vs conventional)                           | • Management system (high, low, mixed intensity)                                                                                           | Mcgarigal 2015; Teixeira-Duarte et al. 2018                                                   |
| Landscape variables                     | Landscape complexity metrics as used in the original study (e.g. percentage of non-crop habitat, edge density) | • Dimension (composition, configuration, heterogeneity)  
• Landscape indicator  
• Metric directionality (e.g. if larger landscape complexity values benefit biodiversity)  
• Measured element type (areal (e.g. patches) and lineal (e.g. riparian or lineal) elements)  
https://www.fao.org/in-action/mafap/common-elements/commodity-group/en/, https://eol.org, https://www.prota4u.org |                                                                                               |
| Landscape radius or extent evaluated    | Radius, or area, in original units                                                    | • Radius in meters                                                                                                                          |                                                                                               |
| Minimum distance between landscapes     | Distance, in original units from the text or maps and statement by authors if landscapes overlap or not. | • Distance in meters from the centroid  
• Overlap (yes, no, nd)  
https://www.fao.org/in-action/mafap/common-elements/commodity-group/en/, https://eol.org, https://www.prota4u.org | Radius$^2$<Minimum distance                                                                  |
| Biodiversity details                    | Species common and scientific name, taxa details (e.g. migratory birds) and function when given (e.g. pollinator, natural enemy of crop pests, crop pathogens, or biodiversity conservation) | • Taxonomic order and class  
• Arthropod (yes, no)  
• Vertebrates (yes, no)  
• Common name (standardized)  
• Functional group  
https://www.fao.org/in-action/mafap/common-elements/commodity-group/en/, https://eol.org, https://www.prota4u.org | GBIF                                                                                         |
| Biodiversity indicators                 | Measures of biodiversity as used in the original study (e.g. species richness, Shannon's diversity, activity density) | • Biodiversity indicators (richness, abundance and evenness)  
https://www.fao.org/in-action/mafap/common-elements/commodity-group/en/, https://eol.org, https://www.prota4u.org |                                                                                               |
| Comparators and Interventions from linear | Equation intercept, slope, R², min and max X value.                                 | • Pearson product-moment correlation coefficients r  
https://www.fao.org/in-action/mafap/common-elements/commodity-group/en/, https://eol.org, https://www.prota4u.org |                                                                                               |
### Landscape complexity, crop and biodiversity species reclassifications

#### Landscape complexity dimensions, indicators, and metrics

In landscape ecology literature, landscape patterns (more complex patterns mean more complexity) are characterized by the composition of habitat types and the spatial arrangement of those habitats (also called configuration) (14, 15). Those patterns affect four distinct landscape-level ecological processes: landscape complementation and supplementation, source-sink dynamics, and neighborhood effect (14). Landscape composition is measured through indicators and metrics that capture habitat types’ abundance, richness, and evenness. In contrast, landscape configuration is measured through indicators and metrics capturing patch area and

#### Table S3. Equations used for transforming correlation (r) values to Fisher’s z scale (z) (i-iv). Equations used for transforming standardized mean difference (d) to correlation values (r) (v-vii). Equations obtained from Borenstein and colleagues(13)

| Equation | Description |
|----------|-------------|
| **Equation i** – Fisher’s z values | $z = 0.5 \times \ln\left(\frac{1 + r}{1 - r}\right)$ |
| **Equation ii** – variance (V) of z, $n$=sample size | $V_z = \frac{1}{n - 3}$ |
| **Equation iii** – standard error (SE) of z | $SE_z = \sqrt{V_z}$ |
| **Equation iv** – transform from z back to r | $r = \frac{e^{2z} - 1}{e^{2z} + 1}$ |
| **Equation v – correlation (r)** | $r = \frac{d}{\sqrt{d^2 + a}}$ |
| **Equation vi – correction factor (a)** | $a = \frac{(n_1 + n_2)^2}{n_1 n_2}$ |
| **Equation vii – variance of r** | $V_r = \frac{a^2 V_d}{(d^2 + a)^3}$ |

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### Landscape complexity, crop and biodiversity species reclassifications

#### Comparative and Interventions from pre-classified landscapes (e.g. simple vs complex)

For both Comparator -> less complex landscapes and Intervention -> more complex landscapes:
- biodiversity central tendency (average, median), and variation (standard deviation, error, interquartile, confidence intervals) data
- Standard mean difference (i.e. Intervention minus Comparator)

#### Number of years monitored

- <1 year
- 1-2 years,
- ≥3 years

#### Sample size

Sample size (e.g. number of replicates) associated with biodiversity indicators
- n (values were adjusted when estimated from digitized figures to avoid bias)

#### Location

Country, state/region
edge, patch shape complexity, core area, contrast, aggregation, subdivision, or isolation/proximity (15). Recent research indicates the need for better capturing and differentiating the compositional heterogeneity, namely the number and proportions of different habitats or cover types since species perceive landscapes (particularly agricultural ones) in complex forms (16). For this reason, we separated landscape composition into two dimensions: compositional heterogeneity (hereafter heterogeneity for short), which measure habitat richness, and evenness. Composition, on the other hand, measures the dominance of habitats (i.e. the percentage of one or each habitat type). We kept configuration as a dimension that measures the spatial arrangement of landscape elements.

We noticed that landscape heterogeneity is conceptualized in different forms in the scientific literature, such as the combination of landscape configuration and composition (e.g. (17, 18)) or even seen as a separate aspect of landscape complexity (19). However, our results mark landscape compositional heterogeneity as a stand-alone dimension of landscape complexity that is severely understudied.
Fig. S2. Landscape metrics classification into indicators and three landscape complexity dimensions. The numbers represent the total number of simple or composed (indicated with +) metrics found in the meta-analysis. Metrics in italics were inversed (*-1) for comparability across metrics, where larger values indicate greater contributions to biodiversity. Two metrics: % semi-open vegetation and habitat slope, were excluded since the directionality is unclear. LU: land use.
We found that landscape complexity research articles used 75 simple and 11 composed landscape metrics (Fig. S2). We assigned each metric to the respective indicator and landscape complexity dimension following Fragstats and Teixeira Duarte and colleagues (15, 20). Among the metrics used in landscape complexity research, the percentage of seminatural, arable, and agriculture dominates, representing 38% of the effect sizes (Fig. S3). On the contrary, 91 out of 1134 effect sizes used 44 metrics rarely used (≤5 effect sizes; <1% effect sizes). Some rarely used metrics are percentage riparian, small grain crops, deciduous forest, and flowering crops. See the complete list of metrics and their classification across levels (indicator and dimension) in Fig. S2 and S3.

![Cascade diagram showing frequency of effect sizes for landscape metrics](image)

Fig. S3. Frequency of the original (as mentioned in the source article) landscape metrics used by at least ≥1% of the effect sizes across studies.
Fig. S4. Landscape complexity dimensions' effect (estimated mean and 95% confidence intervals) on biodiversity functional group, indicator, vertebrates, and overall effect. Mixed level in vertebrates refers to multi-taxa assessments. Effects sizes are calculated as Pearson correlations. Hence, values >0 indicate larger biodiversity outcomes in complex landscapes than in simple landscapes, and confidence interval values overlapping zero indicate no significant difference between complex and simple landscapes. Numbers in parenthesis indicates number of effect sizes / number of studies with a significance level of p-value<0.001***, p-value<0.01**, p-value<0.05. The size of the circles corresponds to the number of effect sizes.
Original crop classification into commodity crops and crop growth form and life cycle

We reclassified crops as listed in the source article into the FAO commodity groups including: 1 - cereals; 2 - roots and tubers, 4 - pulses, 5 – nuts, 6 - oil-bearing crops, 7 – vegetables, 8 – fruits, 10 – spices, 11 - fodder crops and, 12 - stimulant crops. We added four extra categories including 15- biomass (e.g. cup plant or pine), 16- seminatural margin, 17 - mixed commodities and 18 -no data. Some commodities are underrepresented; hence, we grouped 2 and 4 (roots and tubers – pulses), 6 and 15 (oil-bearing crops and biomass), and 5 and 12 (stimulant crops – nuts). Additionally, we used the Encyclopedia of Life and Prota4u to identify each crop growth form and life cycle (Table S2).

Overall, crop classification was straightforward except for those cases when authors provide very limited or null information about the studied cropping system. For example, some articles called or described the crops in the assessed landscapes as annual, horticulture, mix of cereals, mixed dicots, orchard, or agroforestry system without further details on the crop name or crop information constraining our classification. In some cases, despite the vague and unclear description, it was possible to deduct the growth form and life cycle, like in the case of crops described as "annuals or mix of cereals". However, in the cases where crops are described only as "mixed crops" with no extra information, further classification is pointless. In some cases, authors describe their cropping as "mixed crops" system and clearly indicate the purpose of these crops "fodder" and even list their names (i.e., wheat, pea, maize, soybean), allowing a proper classification. Finally, in three articles and 22 effect sizes, the authors did not provide any information related to the crop being studied (Fig. S5).
Fig. S5. Commodity crop groups, crop growth form, life cycle, and crop name found across articles. Crop names are displayed as shared in articles; hence, there are both reported broad categories such as cereals and specific crops (i.e., wheat or maize). The horizontal position and the size of the circle indicate the proportion of effect sizes, whereas values on the circle show the number of articles. Colors indicate and differentiate the growth form and life cycle. Nd refers to effect sizes and articles with poor or no description of the crop and cropping systems.

**Biodiversity classification into taxonomic and functional groups**

Species functional group was directly obtained from the source article indicated as pollinators, natural enemies of pests, weeds, pests or pathogens, or species of conservation concern. Species without a clear function assigned by authors in the methods or other sections (e.g., introduction or discussion) of the source document were defined as species of conservation concern. We retrieved all information available in the original source regarding the species’ scientific name, common name, and taxonomic classification. When missing taxonomic information, we used GBIF (https://www.gbif.org) to identify species order and, if not possible,
species class (Table S2). For example, in some assessed articles, species are only described as "arthropods," hence, class insect. Finally, we also classified species as arthropods or vertebrate species (Table S4).

Table S4. Terrestrial biodiversity assessed across studies grouped by arthropods (Yes, No, and Mixed or multi-taxon studies) and invertebrates, plants, unicellular, vertebrates, or multi-taxon. Only one study analyzed multiple taxa (birds, ants, and herbs), hence the mixed category. Total article count is 203 since one article can assess multiple functional groups such as natural enemies of pests, pests or pathogens, conservation, pollinators, or weeds.

| Arthropod | Vertebrate | Functional group | Effect sizes (n) | Effect sizes (%) | Studies (n) | Studies (%) |
|-----------|------------|------------------|------------------|------------------|-------------|-------------|
| arthropods| invertebrates| natural enemies | 333              | 29               | 63          | 40          |
| arthropods| invertebrates| pest/pathogens  | 256              | 23               | 29          | 18          |
| arthropods| invertebrates| pollinators      | 221              | 19               | 36          | 23          |
| arthropods| invertebrates| conservation    | 91               | 8                | 21          | 13          |
| no arthropods| vertebrate| conservation  | 104              | 9                | 22          | 14          |
| no arthropods| vertebrate| natural enemies | 4                | 0                | 3           | 2           |
| no arthropods| vertebrate| pest/pathogens | 2                | 0                | 1           | 1           |
| no arthropods| plants    | conservation    | 36               | 3                | 14          | 9           |
| no arthropods| plants    | weeds           | 64               | 6                | 10          | 6           |
| no arthropods| invertebrates| conservation | 2                | 0                | 1           | 1           |
| no arthropods| invertebrates| pest/pathogens | 9                | 1                | 1           | 1           |
| no arthropods| unicellular| conservation   | 2                | 0                | 1           | 1           |
| no arthropods| unicellular| pest/pathogens | 2                | 0                | 1           | 1           |
| multi-taxa| multi-taxa | conservation   | 8                | 1                | 1           | 1           |
| **Total** |            |                 | **1134**         | **100**          | **204**     | **130**     |

**Biodiversity indicators classification**

Multiple biodiversity metrics are also used to quantify biodiversity. Here, we grouped metrics into three categories: richness to capture species or taxa counts, abundance to capture the dominance at the species or community level either as in activity, cover, visitation, or abundance, and evenness to capture species distribution (Fig. S6). Biodiversity indicators are used differently to capture different functional groups (Fig. S6).
Fig. S6. Biodiversity indicators used to assess the different functional groups. **Abundance** includes metrics such as abundance weighted mean cwm, density, activity density, cover (%), visitation frequency, and abundance. **Richness** includes metrics such as family richness, species number, rarefied species richness, richness, species richness, specific richness, and standardized species richness. **Evenness** includes metrics such as evenness (calculation method undefined), exponential shannon index - hill numbers, pielou index, shannon-wiener index, shannon index, simpson index, and species evenness.
Moderator analyses –
Moderator analyses are promising for hypothesis testing and better understanding what variables can affect the relationship between landscape complexity and biodiversity (21). However, methods for estimating moderators’ importance are not straightforward (22). To overcome this limitation, we tested linear and non-linear relationships through two complementary assessments: meta-analytical methods and global sensitivity analysis. We focus on all significant variables with a likely moderating effect in the main text, given the uncertainty about what assessment provides more accurate moderator’s importance. However, we also recognize other variables with no moderating effect due to statistical artifacts (e.g., overlapping confidence intervals at all levels) but with key results. For example, moderators with all levels (e.g., landscape extent assessed has two levels: ≤1km and >1km) having positive and significant average effect sizes and confidence intervals. These moderators, in particular, suggest no differences in the biodiversity assessed (population) and hence a consistent and significant response to landscape complexity regardless of the levels assessed (21).

Univariate and extended meta-analytic models to test moderating effects
We tested the effect of each one of the moderators individually, and then we included all significant moderators simultaneously in an extended meta-analytical model (22). We used the omnibus test using the F-distribution to assess if estimates (i.e. regression coefficients) are equal to zero (Table S5). Across tested meta-analytical models, we found significant unexplained variance remained after moderators were added (Table S5). Through this method, we found biodiversity indicator, biodiversity functional group, biodiversity taxonomic class, and monitoring length have all a significant moderating effect since estimators significantly deviate from zero (p-value≥0.05) (Table S5). However, biodiversity taxonomic class seems to have cofounding effects since the omnibus test was statistically insignificant in the extended model.
Table S5. Overall tested categorical moderators (variables) and levels. The levels of each moderator are separated if the mean estimated value is positive (i.e., increase biodiversity) or negative (i.e., reduce biodiversity), and the significance of each level is given at p-value<0.05*, <0.01**, and 0.001***. The test for residual heterogeneity reveals significant variation, regardless of the tested moderators. Significant moderators identified through the omnibus test are highlighted in gray. The extended meta-analytical model including all significant moderators simultaneously indicate that at least one of the regression coefficients $F(df1 = 18, df2 = 1115) = 3.0281, p$-value < 0.0001 deviates from zero. Biodiversity indicators ($t(1115) = 3.5608, p$-value = 0.0004); functional groups ($t(1115) = 2.7347, p$-value = 0.0063); and monitoring length ($t(1115) = 2.8374, p$-value = 0.0046) have an unique, robust with not confounded moderating effect on the landscape complexity — biodiversity association (highlighted in bold). The moderator significance column indicates the method selecting the moderators with strong effects on landscape complexity-biodiversity association. Single- individual meta-analytical model, extended – meta-analytical model with all significant moderators, and the also called global sensitivity analysis combining randomForest and Classification and regression trees-CART.

| Theme         | moderators                          | reason for inclusion                                                                 | levels – significance level indicated by *<0.05, **<0.01, ***<0.001 estimated without the intercept positive mean effects | Q$_\alpha$-test for residual heterogeneity | moderator omnibus test estimated with the intercept f-distribution | p-value | Moderator significance |
|---------------|-------------------------------------|---------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------|-----------------------------------------------------------|--------|------------------------|
| biodiversity  | landscape complexity may have different, even contradictory effects on each indicator with different consequences for ecosystem functioning | abundance**, richness***, evenness*                                               | (df = 1129) = 5929.6430                                                                      | f(df1 = 4, df2 = 1129) = 2.9431                                    | f(df1 = 9, df2 = 1124) = 1.9357                                  | 0.002  | Single, extended      |
| level         | biodiversity functional group       | pollinators***, natural enemies***, biodiversity conservation***, pest & pathogens***, weeds***, gastropoda***, insects***, arachnida***, birds***, multitaxa***, plants***, amphibia***, citellata***, mammals*** | (df = 1129) = 5929.6430                                                                      | f(df1 = 4, df2 = 1129) = 2.9431                                    | f(df1 = 9, df2 = 1124) = 1.9357                                  | 0.020  | Single, extended, randomForest |
|               | taxonomic class                     | microorganisms n.s                                                                   |                                                                                                 |                                                                                                         |                                                                                                         | 0.044  | Single, CART          |
|               | arthropods                          | previous meta-analysis exploring landscape complexity-biodiversity association use this categorization (e.g. (3, 7)) | yes***, no***, mixed**                                                                          | f(df1 = 1131) = 5945.2581                                   | f(df1 = 2, df2 = 1131) = 2.9517                                  | 0.053  |                      |
|               | vertebrates                         | previous meta-analysis exploring landscape complexity-biodiversity association use this categorization (e.g. (23)) | invertebrates***, vertebrates***, plants***, mixed**                                           | f(df1 = 1129) = 5930.1278                                    | f(df1 = 4, df2 = 1129) = 1.8880                                  | 0.110  |                      |
|               | biodiversity location               | species located above or below ground have different mobility capacities, hence their response to landscape complexity may be different | above***, below*                                                                               | f(df1 = 1, df2 = 1132) = 0.2238                                |                                                                                                         | 0.636  |                      |
| landscape    | landscape dimension                 | each dimension contributes to complementary ecological processes that affect differently biodiversity with different consequences for ecosystem functioning. | composition***, configuration***, heterogeneity*, mixedd a                                          | f(df1 = 1130) = 6045.2206                                     | f(df1 = 3, df2 = 1130) = 0.0423                                  | 0.988  |                      |
| level         |                                     |                                                                                       |                                                                                                 |                                                                                                         |                                                                                                         |        |                      |
| Theme                  | moderators                                    | reason for inclusion                                                                                           | levels – significance level indicated by *<0.05, **<0.01, ***<0.001 estimated without the intercept | $Q_t$-test for residual heterogeneity | moderator omnibus test estimated with the intercept | $f(df1 = 8, df2 = 1125)$ | $f(df1 = 2, df2 = 1131)$ | $Q_t$-test for residual heterogeneity | $f(df1 = 9, df2 = 1124)$ | $f(df1 = 3, df2 = 1130)$ | $Q_t$-test for residual heterogeneity | $f(df1 = 6, df2 = 1127)$ | $f(df1 = 3, df2 = 1130)$ | Moderator significance |
|-----------------------|-----------------------------------------------|---------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-----------------------------------|--------------------------------------------------|-------------------------|-------------------------|-----------------------------------|---------------------------------|-------------------------|-----------------------------------|---------------------------------|-------------------------|--------------------------------|
| landscape indicator   | similarly, each dimension is measured         | through different indicators and metrics capturing different ecological patterns or process with a different effect on biodiversity | non-crop area***, proximity, conf&hete\textsuperscript{n,s} seminatural area***, connectivity***, comp&conf***, aggregation\textsuperscript{n,s}, lu diversity\textsuperscript{n,s}, lu evenness\textsuperscript{n,s} | (df = 1125) = 5893.4282                      | f(df1 = 2, df2 = 1125) = 1.4887                          | 0.157                                               | randomForest            |
| landscape element     | the measured element contributes differently to biodiversity; hence each may have a different effect on biodiversity | area***, linear**,mixed**                                                                                   | (df = 1131) = 6049.3353 = f(df1 = 2, df2 = 1131) = 1.5408                          | 0.215                                           |
| measured extent       | landscape complexity at different extents may have a different effect for species with contrasting mobility ranges. | <=1km***, >1km***                                                                                        | (df = 1113) = 5904.1253 = f(df1 = 1, df2 = 1113) = 2.0669                          | 0.151                                           |
| production-level      | crop growth form and life cycle signals the potential level of disturbances and the complexity of the managed habitat with different effects on biodiversity | herb\_annual***, woody\_perennial**, herb\_perennial\textsuperscript{n,s},nd\_annual\textsuperscript{n,s} , nd\_nd\textsuperscript{n,s} cereals**, mixed**, oilcrops&biomass*, forage\textsuperscript{n,s} fruits\textsuperscript{n,s}, nd\textsuperscript{n,s}, nuts&stimulant\textsuperscript{n,s}, seminatural\textsuperscript{p,s}, vegetables\textsuperscript{n,s} high***, low***, nd**, mixed\textsuperscript{n,s} | (df = 1129) = 6045.5192 = f(df1 = 4, df2 = 1129) = 0.0845                          | 0.987 C\textsuperscript{ART}                                      |
| management system     | Crops tend to be cropped in different landscape complexity types and trop type may offer different resources to biodiversity hence response may vary per group. | pulses\&tubers\textsuperscript{n,s}                                                                 | (df = 1124) = 6025.6062 = f(df1 = 9, df2 = 1124) = 0.2894                          | 0.978 randomForest, C\textsuperscript{ART}                                      |
| study-level           | agricultural landscapes are dynamic, hence evidence with different monitoring lengths may capture differently the effects of landscape complexity on biodiversity | <1yr***, 1-2yr***, >=3yr** nd\textsuperscript{n,s}                                                      | (df = 1130) = 5915.6307 = f(df1 = 3, df2 = 1130) = 2.9144                          | 0.033 Single, extended                           |
| biodiversity monitor  | data collected in different regions may follow different standards, procedures and ecological histories affecting differently biodiversity's response to landscape complexity | high***, medium**, low\textsuperscript{n,s} extremely low\textsuperscript{n,s} european**, north america**, africa, asia\textsuperscript{n,s}, latin america\textsuperscript{n,s}, oceania\textsuperscript{n,s} multi-continents\textsuperscript{p,s} | (df = 1130) = 5997.2322 = f(df1 = 3, df2 = 1130) = 1.2441                          | 0.292 randomForest                                      |
| quality               | study-level                                   | study-level monitor                                           |                                                                                             |                                                                                                      |                                                                                                      |                                                                                                      |                                                                                                      |                                                                                                      |                                                                                                      |                                                                                                      |
**GSA - Global sensitivity analysis for testing moderating effects**

A global sensitivity analysis is very useful in this context with multiple variables not following the parametric assumptions and with complex interactions. Hence, it permits testing the combined rather than the individual effect of variables (24). RandomForest is a tree-based bootstrapping algorithm that splits the data into training, and test data (70% and 30%, respectively) and randomly tests each moderator at the multiple nodes or levels when growing the tree. This iterative process creates a forest of classification trees (i.e., 10,000) to estimate moderator importance in explaining response variability (25). We complement RandomForest with CART (26) to create a pruned tree and visualize higher level interactions (i.e., moderators across levels) since RandomForest lack a forest averaging function (24).

The RandomForest classification (categorical data) model created with all tested moderators explained 26% of the effect size variability (mean squared residuals = 0.12). RandomForest results agreed with the meta-analytical model in the sense that despite the tested wide range of potential moderators, much of the variability remains unexplained. The five most important moderators identified with RandomForest account for 43% of the relative importance, including landscape indicator, data quality, crop group, and functional group (Fig. S7 - Left). However, combinations among taxonomic group, crop group, and crop growth form and life cycle seem to drive the higher or lower effect sizes (Fig. S7 - Right)

| 1st level | 2nd level | 3rd level | EffectProp. Avg. sizes (%) effect no. |
|-----------|-----------|-----------|---------------------------------------|
| Taxonomic group | Crop group | Growth form and life cycle | arabignida, birds, clitellata, gastropoda, insects, mammals, plants | forage, fruits, nd, seminatural margin, vegetables | 431 | 38 | 0.01 |
| | | | cereals, mixed, nuts & stimulant, oilcrops & biomass, pulses & tubers | herb / annual, nd / annual, nd / nd | 634 | 56 | 0.10 |
| | | | woody / perennial | | 48 | 4 | 0.42 |
| Amphibia, microorganism, multitaxon | | | | | 21 | 2 | 0.55 |
| Total | | | | | 1134 | 100 |

Fig. S7. Global sensitivity analysis results. Left: moderator relative importance measured as the contribution to the reduction in node impurity from the RandomForest analysis, vertical line indicates the five most important moderators contributing to >40% of the relative importance. Right: horizontal classification and regression tree, indicating taxonomic group, crop commodity group, and crop growth form and life cycle interactions drive larger or smaller effect sizes. For example, biodiversity (i.e., Arachnida, birds, insects, and plants) collected in woody and perennial crops (i.e., nuts & stimulants, oil crops & biomass) comes from 48 effect sizes with an average effect size of 0.42. Similarly, evidence for Amphibia, microorganisms and studies analyzing multiple taxa recorded the largest effect sizes regardless of the crop group (0.55). Effects sizes are calculated as Pearson correlations; hence, values >0 indicate larger biodiversity outcomes in complex than in simple landscapes. Nd: no data.
| Category                | Value (N) | Pearson's Correlation |
|-------------------------|-----------|-----------------------|
| **Anthropods**          |           |                       |
| no anthropods           | 194/443   |                       |
| anthropods (032/128)    |           |                       |
| **Taxonomic Class**     |           |                       |
| multiforma (62/15)     |           |                       |
| gastropoda (91/1)       |           |                       |
| ciliatea (2/1)          |           |                       |
| amphibia (91/1)         |           |                       |
| birds (75/17)           |           |                       |
| arachnida (75/19)       |           |                       |
| plants (100/23)         |           |                       |
| insect (829/114)        |           |                       |
| mammals (26/9)          |           |                       |
| microorganisms (4/2)    |           |                       |
| richness (349/94)       |           |                       |
| evenness (83/11)        |           |                       |
| abundance (702/110)     |           |                       |
| plants (100/23)         |           |                       |
| mixed (398)             |           |                       |
| vertebrate (79/22)      |           |                       |
| invertebrate (912/125)  |           |                       |
| soil fauna (18/2)       |           |                       |
| **Biodiversity Location**|          |                       |
| above (192/119)         |           |                       |
| below (113/22)          |           |                       |
| **Functional Group**    |           |                       |
| pollinators (223/36)    |           |                       |
| nat enemies (357/65)    |           |                       |
| conservation (243/49)   |           |                       |
| weeds (64/10)           |           |                       |
| pests/pathogens (269/30)|           |                       |
| mixed intensity (441/3) |           |                       |
| low intensity (507/66)  |           |                       |
| **Management System**   |           |                       |
| mixed commodities (168/26)|      |                       |
| nuts & stimulant (23/5) |           |                       |
| oil crops & biomass (81/17) |      |                       |
| **Crop Commodity Group**|          |                       |
| cereals (416/64)        |           |                       |
| fodder (102/13)         |           |                       |
| seminatural margin (13/4)|         |                       |
| vegetables (224/14)     |           |                       |
| nd (22/3)               |           |                       |
| **Crop Growth & Cycle** |           |                       |
| woody/ perennial (114/19)|        |                       |
| herb/ annual (810/107)  |           |                       |
| **Landscape Element**   |           |                       |
| aerial & meal (748)     |           |                       |
| lineal (97/19)          |           |                       |
| area (23/1)             |           |                       |
| configuration (173/2)   |           |                       |
| composition (794/133)   |           |                       |
| **Landscape Dimension** |           |                       |
| heterogeneity (79/17)   |           |                       |
| comp & conf (57/7)      |           |                       |
| **Landscape Indicator** |           |                       |
| non-crop area (456/68)  |           |                       |
| lu evenness (hete) (35/3)|          |                       |
| aggregation (conf.) (18/3)|      |                       |
| lu richness (hete) (45/4)|          |                       |
| proximity (conf.) (54/20)|         |                       |
| conf & hete (28/3)      |           |                       |
| measured extent          |           |                       |
| >1km (211/39)           |           |                       |
| <=1km (904/121)         |           |                       |
| monitoring length        |           |                       |
| 3 years (30/10)         |           |                       |
| 2 years (350/40)        |           |                       |
| 1 year (744/108)        |           |                       |
| nd (102)                |           |                       |
| continent               |           |                       |
| central & south america (123/13)|      |                       |
| europe (604/94)         |           |                       |
| north america (363/95)  |           |                       |
| africa (19/3)           |           |                       |
| multi-continental (1/1) |           |                       |
| data quality            |           |                       |
| high (392/81)           |           |                       |
| medium (520/42)         |           |                       |
| low (186/33)            |           |                       |
| e low (32/5)            |           |                       |
| overall                 |           |                       |
| estimate (1134/157)     |           |                       |
Fig. S8. Landscape complexity effect (estimated mean and 95% confidence intervals) on biodiversity across all tested moderators. Moderators are grouped by theme, green-biodiversity, orange-cropping system, blue-landscape, gray-study design. Effects sizes are calculated as Pearson correlations; hence, values >0 indicate larger biodiversity outcomes in complex than in simple landscapes, and confidence interval values overlapping zero indicates no significant difference between complex and simple landscapes. Numbers in parenthesis indicates number of effect sizes / number of studies with a significance level of p-value<0.001***, p-value<0.01**, p-value<0.05*. The black vertical solid line shows zero, whereas the dotted line shows the mean overall estimate. The size of the circles corresponds to the number of effect sizes.

Outliers and data quality

Table S6. Tests assessing the impact of removing outliers or data with lower quality. The results suggest a reduction in the heterogeneity (QE); however, model results remain significant, and estimates remain similar across comparisons (See, for example, model results estimate and p-value). Hence, we pursued the analysis with the whole dataset (1134 effect sizes, 157 studies).

| Restricted maximum-likelihood ("REML") estimation parameters meta-analytic model | a) Overall model – all data | b) Overall model without outliers | c) Overall model without extremely low-quality effect sizes | d) Overall model without extremely low- and low-quality effect sizes |
|---|---|---|---|---|
| k | 1134 | 1121 | 1102 | 912 |
| logLik | -811.221 | -811.201 | -674.335 |
| Deviance | 1622.441 | 1622.402 | 1348.670 |
| AIC | 1628.441 | 1628.402 | 1354.670 |
| BIC | 1643.504 | 1643.414 | 1369.114 |
| AICc | 1628.463 | 1628.424 | 1354.696 |
| sigma^2.1 estim | 0.150 | 0.141 | 0.148 | 0.155 |
| sqrt | 0.387 | 0.376 | 0.384 | 0.393 |
| nivls | 1134 | 1121 | 1102 | 912 |
| fixed factor | ES_ID | ES_ID | ES_ID | ES_ID |
| sigma^2.1 estim | 0.104 | 0.099 | 0.107 | 0.091 |
| sqrt | 0.323 | 0.314 | 0.328 | 0.302 |
| nivls | 157 | 149 | 152 | 119 |
| fixed factor | studyID | studyID | studyID | studyID |
| Test for Heterogeneity | | | | |
| QE | 6076.775 | 5674.169 | 5993.827 | 5012.593 |
| df | 1133 | 1120 | 1101 | 911 |
| p-val | <.0001 | <.001 | <.001 | <.001 |
| Model results | | | | |
| Estimate | 0.182 | 0.168 | 0.189 | 0.202 |
| Se | 0.033 | 0.033 | 0.034 | 0.037 |
| Tval | 5.520 | 5.144 | 5.598 | 5.518 |
| Pval | <.0001 | <.001 | <.001 | <.001 |
| ci.lb | 0.118 | 0.104 | 0.123 | 0.130 |
| ci.ub | 0.247 | 0.232 | 0.255 | 0.273 |

Publication bias

Our data is unbiased according to the funnel plot test (Fig. S9), adapted Egger’s (27) and Doleman’s (28) methods. Adapted Egger’s method (27) uses the mixed-effects meta-regression model and the square root of effect sizes’ standard error as moderator. The omnibus test suggest the intercept do not deviate from zero statistically (QM(df = 1) = 0.0631, p-val = 0.8016). Similarly, Doleman’s method (28) using 1/n as the predictor in the mixed-effects meta-regression model also indicates unbiased data (Test for Funnel Plot Asymmetry: z = 0.4656, p = 0.6415).
Fig. S9. Egger’s methods using model=lm and predictor=sei in regtest(29). The funnel test suggest data is unbiased (Test for Funnel Plot Asymmetry: t = 0.4713, df = 1132, p = 0.6375).

References
1. F. J. J. a Bianchi, C. J. H. Booij, T. Tscharntke, Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. Proc. Biol. Sci. 273, 1715–1727 (2006).
2. P. Batáry, A. Báldi, D. Kleijn, T. Tscharntke, Landscape-moderated biodiversity effects of agri-environmental management: A meta-analysis. Proc. R. Soc. B Biol. Sci. 278, 1894–1902 (2011).
3. R. Chaplin-Kramer, M. E. O’Rourke, E. J. Blitzer, C. Kremen, A meta-analysis of crop pest and natural enemy response to landscape complexity. Ecol. Lett. 14, 922–932 (2011).
4. G. Shackelford, et al., Comparison of pollinators and natural enemies: A meta-analysis of landscape and local effects on abundance and richness in crops. Biol. Rev. 88 (2013).
5. D. J. D. J. Gonthier, et al., Biodiversity conservation in agriculture requires a multi-scale approach. Proc. R. Soc. B Biol. Sci. 281, 20141358–20141358 (2014).
6. S. L. Tuck, et al., Land-use intensity and the effects of organic farming on biodiversity: A hierarchical meta-analysis. J. Appl. Ecol. 51, 746–755 (2014).
7. E. M. Lichtenberg, et al., A global synthesis of the effects of diversified farming systems on arthropod diversity within fields and across agricultural landscapes. Glob. Chang. Biol. 23, 4946–4957 (2017).
8. J. G. da E. Coutinho, L. A. Garibaldi, B. F. Viana, The influence of local and landscape scale on single response traits in bees: A meta-analysis. Agric. Ecosyst. Environ. 256, 61–73 (2018).
9. R. Marja, T. Tscharntke, P. Batáry, Increasing landscape complexity enhances species richness of farmland arthropods, agri-environment schemes also abundance – A meta-analysis. Agric. Ecosyst. Environ. 326, 107822 (2022).
10. W. Mengist, T. Soromessa, G. Legese, Method for conducting systematic literature review and meta-analysis for environmental science research. MethodsX 7, 100777 (2020).
11. N. Estrada-Carmona, A. C. Sánchez, R. Roseline, S. K. Jones, Complex agricultural landscapes host more biodiversity than simple ones: a global meta-analysis - dataset (2022) https://doi.org/https://doi.org/10.7910/DVN/GZJCP0.
12. A. Rohatgi, WebPlotDigitizer (2020).
13. M. Borenstein, L. V. Hedges, J. P. . Higgins, H. R. Rothstein, Introduction to meta-analysis (John Wiley & Sons Ltd, 2009).
14. J. B. Dunning, B. J. Danielson, H. R. Pulliam, I. Ecology, Ecological Processes That Affect Populations in Complex Landscapes. Oikos 65, 169–175 (1992).
15. K. Mcgarigal, Fragstats: spatial pattern analysis program for quantifying landscape structure - help. Fragstats v.4, 1–182 (2015).
16. L. Fahrig, et al., Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. *Ecol. Lett.* **14**, 101–112 (2011).
17. A. M. Jönssson, et al., Sown flower strips in southern Sweden increase abundances of wild bees and hoverflies in the wider landscape. *Biol. Conserv.* **184**, 51–58 (2015).
18. Y. Zhang, N. L. Haan, D. A. Landis, Landscape composition and configuration have scale-dependent effects on agricultural pest suppression. *Agric. Ecosyst. Environ.* **302** (2020).
19. T. Tscharntke, I. Grass, T. C. Wanger, C. Westphal, P. Batáry, Beyond organic farming – harnessing biodiversity-friendly landscapes. *Trends Ecol. Evol.* **36**, 919–930 (2021).
20. G. Teixeira-Duarte, P. M. Santos, T. G. Cornelissen, M. C. Ribeiro, A. P. Paglia, The effects of landscape patterns on ecosystem services: meta-analyses of landscape services. *Landsc. Ecol.* **33**, 1247–1257 (2018).
21. M. I. Hwang, F. L. Schmidt, Assessing moderating effect in meta-analysis: A re-analysis of top management support studies and suggestions for researchers. *Eur. J. Inf. Syst.* **20**, 693–702 (2011).
22. M. Assink, C. J. M. Wibbelink, Fitting three-level meta-analytic models in R: A step-by-step tutorial. *Quant. Methods Psychol.* **12**, 154–174 (2016).
23. E. M. Olimpi, et al., Shifts in species interactions and farming contexts mediate net effects of birds in agroecosystems. *Ecol. Appl.* **30**, 1–14 (2020).
24. E. B. Harper, J. C. Stella, A. K. Fremier, Global sensitivity analysis for complex ecological models: a case study of riparian cottonwood population dynamics. *Ecol. Appl.* **21**, 1225–1240 (2011).
25. T. Breiman, A. Cutler, Package ‘randomForest.’ 15 (2012).
26. T. M. Therneau, B. Atkinson, rpart: Recursive Partitioning and Regression Trees. 30 (2022).
27. C. W. Habeck, A. K. Schultz, Community-level impacts of white-tailed deer on understorey plants in North American forests: a meta-analysis. *AoB Plants* **7**, plv119 (2015).
28. B. Doleman, S. C. Freeman, J. N. Lund, J. P. Williams, A. J. Sutton, Funnel plots may show asymmetry in the absence of publication bias with continuous outcomes dependent on baseline risk: presentation of a new publication bias test. *Res. Synth. Methods* **11**, 522–534 (2020).
29. W. Viechtbauer, metafor: Meta-analysis package for R. *R Packag. version 2.4-0*. *R Packag. version 2.4-0*, 1–275 (2020).