Medför en ökad gröddiversitet i tid och rum en förbättrad biologisk mångfald i jordbrukslandskapet?

Genomförandeplan för en systematisk översikt

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Innehållsförteckning

1 Summary

1.1 Background

Systematic compilation of scientific evidence to inform decision-making is a way to improve both effectiveness and efficiency of decision support. Systematic reviews have come to be considered the gold standard for such evidence compilations (Pullin and Stewart 2006). However, a less appreciated issue is how the fragmented character of evidence in the environmental area affects the accessibility of systematic review methods (e.g., using the Cochran approach template) as a way to synthesize evidence for decision support (Ekroos et al. 2017, Sutherland and Wordley 2018).

In environmental research there may be a multitude of outcomes, environmental contexts, scale of effects and more, making it difficult to summarize evidence into simple effect size measures (Sutherland and Wordley 2018). To overcome this, one way is to generalize outcomes or interventions under common groupings to compartmentalize heterogeneity, potentially identifying modifiers if data allows (Gurevitch et al. 2018). Another way is to use expert knowledge to interpolate between heterogeneous evidence (Dicks et al. 2014). These approaches come with their own difficulties, including lack of relevance to decision makers and risk of bias when using expert judgement.

Here we focus on the consequences of agricultural management on biodiversity. The number of meta-analysis/systematic reviews focussing on these issues have increased considerably in recent years. However, we contend that the breadth of scope when it comes to outcomes, interventions and environmental context often limits the usability of these evidence compilations. Additionally, previous efforts have aggregated results across disparate management interventions creating synthetic evidence, yet for non-actionable approaches from stakeholders' point of view. If these differences are not addressed and stakeholder needs not accounted for, the compiled evidence risks misinforming management and policy. However, fully accounting for the differences may instead result in evidence being too sparse to be useable in a specific decision context. A key aim in this project is if and how evidence synthesis can be performed to compile existing evidence in a quantitative way, yet usable to real world decision-making.

Our concrete example will be the effect of crop diversity in space and time on biodiversity. We base our selection of a concrete example on the recent interest of the Swedish Board of Agriculture on small-scale interventions to benefit biodiversity and by broader EU interest in crop diversity, which was targeted by the "Greening of the CAP" (Hauck et al. 2014).

1.2 Purpose

Loss of ecological heterogeneity at multiple spatial scales have been argued to be the most important driver of biodiversity loss in farmland (Benton et al. 2003, Tscharntke et al. 2005). Ecological heterogeneity may benefit biodiversity e.g. by moderating habitat filtering, promoting cross-habitat spillover, create resource complementarity, generate resource continuity and make disturbances asynchronous (Dunning et al. 1992, Tscharntke et al. 2012, Chase et al. 2020, Nicholson et al. 2020). While much attention has been given heterogeneity generated by non-productive elements in the landscape (Marja et al. 2022), increasing attention has been devoted to various form of productive in-field heterogeneity (Beillouin et al. 2021). Increasing this crop heterogeneity may be a way to restore historically lost ecological variation in farmland (Sirami et al. 2019).

1.3 Method

Our approach will be to a) provide a conceptual framework on the links between crop diversification and biodiversity as a basis for collecting evidence, b) investigate the option space by exploring existing variation in crop diversity across scales on Swedish farmland, c) divide the literature with a particular consideration of the complexity regarding objectives, drivers and modifiers and d) use suitable means such as quantitative synthesis or soliciting expert knowledge informed by evidence (Dicks et al. 2017) to synthesize existing evidence. Given the sparse evidence, our approach will initially be global. We will approach this using a mixed method approach, by creating a conceptual framework based on theory, evaluating the option space from GIS data, synthesizing evidence using systematic review methodology, and evaluate these approaches jointly to create a practical evidence base for stakeholders.

2 Background

To date, there are a number of syntheses on the effect of crop diversity on biodiversity, including reviews of reviews (Beillouin et al. 2019, Tamburini et al. 2020, Beillouin et al. 2021, Sánchez et al. 2021, Estrada-Carmona et al. 2022, Sánchez et al. 2022), one ongoing systematic review (Moss et al. 2020) and one meta-analysis (Priyadarshana et al. 2024). However, with the *possible* exception of the ongoing review, these have either not considered farm-landscape scale crop diversity in space, or subsumed it in composite drivers (Table 1). In contrast, there are more studies on crop rotation, but few of those have aboveground biodiversity as outcome (Table 1).

Table 1. Recent systematic reviews or meta-reviews on crop diversification effects on biodiversity

Study	**Type**	**Crop Diversity specifically**
Tamburini et al. (2020) Agricultural diversification promotes multiple ecosystem services without compromising yield. Sci Adv, 6, eaba1715.	Second order meta-analysis	Farm/landscape scale crop diversity not covered. Includes crop rotation studies, but only with microbial biodiversity as response variable.
Estrada-Carmona et al. (2022) Complex agricultural landscapes host more biodiversity than simple ones: A global meta-analysis. Proc Natl Acad Sci U S A, 119, e2203385119.	Systematic review	Farm/landscape scale crop diversity included in landscape heterogeneity; 79 effect sizes, 17 studies; only 2 specific studies with evenness as outcome. Crop rotation includes 45 effect sizes in 4 studies.
Beillouin et al. (2021) Positive but variable effects of crop diversification on biodiversity and ecosystem services. Glob Change Biol, 27, 4697-4710.	Second order meta-analysis	No between field category.

Moss et al. (2020) The effects of crop diversity and crop type on biological diversity in agricultural landscapes: a systematic review protocol. Welcome Open Res, 4.	Systematic review protocol	No between field category in search, but landscape-scale crop diversity acknowledged in protocol. Search produced 15000 hits with 2% crop diversity between fields -> 300 studies
Priyadarshana et al. (2024) Crop and landscape heterogeneity increase biodiversity in agricultural landscapes: A global review and meta-analysis. Ecol Lett, 27, e14412.	Meta-analysis	Meta-analysis of 122 datasets. Problematic definitions of crop heterogeneity. Globally aggregated.

3 Purpose/issues

There are several difficulties of using existing evidence on the effects of crop diversity on biodiversity to inform management decisions in agriculture:

1. The **Outcome** (i.e., to conserve/enhance biodiversity) is difficult to define, because biodiversity is inherently multi-dimensional (Naeem et al. 2016, Pascual et al. 2021) and can thus be captured by a plethora of indices (Magurran 2021). Any indicator of biodiversity will depend on how variation in e.g. taxonomy, phylogeny, or function is considered across space and time (González-Megías et al. 2011, Socolar et al. 2016). Still most studies use only species richness and evenness or their combination in a diversity index without considering how they vary across scales (e.g. Estrada-Carmona et al. 2022). Since different ways of capturing biodiversity may show moderate to low correlations (Wolters et al. 2006, Flynn et al. 2011, Sahlin et al. 2021), it matters how the objective is formulated. First, different aspects of biodiversity can be assumed to be affected by field-based heterogeneity in different ways, depending on what ecological process is involved (Smith et al. 2014), such as crop heterogeneity effects on local resource availability or landscape-scale resource continuity. Second, stakeholders may value different aspects of biodiversity; putting an emphasis on conservation of species per se or on their functional value (Mace et al. 2012, Senapathi et al. 2015). The choice of indicator may in turn have profound consequences for the recommendations that are extracted from a synthesis; it has for example been argued that local biodiversity effects of agro-environmental measures may not scale up to farm or regional scales (Schneider et al. 2014). Hence, if the measured effects of crop diversity on biodiversity vary depending on how the objective “to conserve biodiversity” is defined, syntheses that do not consider this may be difficult to use in real-world decision making and may even lead to sub-optimal recommendations.

2. Crop diversity as an **Intervention** is often not strictly defined. Crop diversity in space (field-farm-landscape crop diversity) is an emergent property of crop diversity in time (crop rotation), which may be efficiently disentangled in experimental but not in space-for-time substitution studies (Aramburu Merlos and Hijmans 2020). The spatio-temporal character of crop diversity generates several complexities. First, whether or not diversity is considered over time may have distinct effects on biodiversity outcomes; some organisms may be able to track shifting time-space dynamics and others not. Second, crop diversity may relate to both compositional and configurational complexity (cf. Martin et al. 2019), which in turn

results in measures of crop diversity being scale dependent. Third, crop diversity estimates may depend on what is considered to be different crops, e.g. if functional or taxonomic distinctions are made (cf Stjernman et al. 2019). Fourth, as crop diversity depends on decisions about crop selection, an apparent effect of crop diversity may instead be an effect of crop identity (e.g. if inclusion of ley is the measure to increase crop diversity) (cf. Martin et al. 2020). Thus, although the specific decisions that farmers make result in emergent spatial or temporal patterns of crop diversity, these aspects are largely absent from syntheses of crop diversity effects, and there is a need to disaggregate the evidence along these axes of space and time. It is seldom considered what choices are actually available for farmers in different situations, because a mapping of the practices available to farmers ("**option space**") has not been done.

3. The effects of many agri-environmental measures on biodiversity are ***context dependent*** (i.e. depend on **modifiers**) (Tscharntke et al. 2005), such that evidence is not readily transferable from one context to another. This may be true also for variation in crop diversity on biodiversity, such that it differs depending on local conditions (Palmu et al. 2014), farming system (e.g. plant crop production vs. mixed farming), landscape context (cf Sánchez et al. 2022) and pedo-climatic regions (e.g. forested landscapes vs. plains). Modifiers should be considered based on an ecological understanding of mechanisms that potentially shape crop diversity – biodiversity relationships, yet many studies simply lack the descriptors allowing this (Estrada-Carmona et al. 2022). Broad syntheses may therefore fail to account for the specific decision-making situations facing managers and policy makers, either because evidence is too sparse, too heterogeneous, or because it is simply non-existent for a specific situation.

Hence, although the amount of evidence is sufficient for a proper systematic compilation of evidence, the evidence may still be too contextualized and fragmented to guide decisions in a specific situation because of heterogeneity in objectives, drivers and contexts that have not or cannot be accounted for. It is presently *unclear how such gaps in the fragmented crop diversity – biodiversity literature are to be filled.*

We aim to review and structure this fragmented research according to the spatio-temporal scale at which crop diversity varies, in order to reveal where the weight of evidence is most and least strong. We intend to identify methods for gap filling, e.g. based on letting evidence inform ecological theory and expert elicitation (Dicks et al. 2014, Ekroos et al. 2017).

3.1 Study questions

What are the effects of spatial and temporal crop diversity on the biological diversity of fauna and flora in agricultural landscapes?

What are the effects of spatial and temporal crop diversity on specific taxonomic groups?

Which crop diversification practices have the strongest impacts on biodiversity?

Do results depend on how and at what scale biodiversity is defined?

What is the most influential spatial and temporal scale of crop diversity?

4 Stakeholder involvement

The project has been initiated internally by Formas after a workshop on biodiversity with researchers and government representatives on February 10, 2020.

Representatives of central authorities and organizations will be involved during the project, such as the Swedish Board of Agriculture, LRF, and the Swedish Environmental Protection Agency, with, for example, communicating what type of data is important to include in the Excel database and providing input to the systematic review.

5 Method

We will use a mixed methods approach that will (1) develop a conceptual framework grounded in ecological theory on biodiversity across scales of space and time; (2) use spatially explicit analyses to explore existing patterns of crop diversity in the Swedish context to identify and map the management option space; (3) perform a systematic review and if possible a meta-analysis of the evidence of crop diversity's effect on biodiversity. We combine these methods to create evidence that is explicit with regards to ecological scale and current Swedish agricultural practice, thus potentially improving both effectiveness and efficiency of decision support.

5.1 Conceptual framework

We will develop a conceptual framework regarding how crop diversity drives biodiversity in farmland based on ecological theory. This will include mapping how existing empirical studies have accounted for the multiple dimensions of objectives (biodiversity) and drivers (crop diversity) in relation to ecological theory.

5.2 Option space

To guide our evidence synthesis, we will investigate the options that farmers have regarding crop rotations and diversity related to context such as geographic region and farm type. We will also investigate how farmer decisions translate into consequences across time and space, such as the relationship between crop rotation and crop diversity and between farm- and landscape scale crop diversity. We will investigate how different definitions of crop diversity, more or less reflecting the ecological processes assumed to be targeted when using crop rotation/diversity as biodiversity driver, affect indices of diversity. To this end, we will perform a spatial analysis of current variation in crop diversity in Sweden. Analyses will be spatially explicit and on both a farm and landscape level. The analysis will be based on GIS analysis of the LPIS (block) database. Based on the results, we will suggest what the important aspects of variation in a decision context are. Our analyses will extend recent analyses in Sweden, which were not spatially explicit and thus could not account for time-scale relationships (Sjulgård et al. 2022), and another analysis that was done at a low spatial resolution not including crop sequences, and which did not analyse scale-related relationships (Schaak et al. 2023).

We will analyse institutional fit sensu, by comparing the results of our conceptual mapping and the description of the option/practice space, to determine to what extent existing evidence and synthesis can be used to inform management by Swedish farmers and by implication policies.

5.3 Systematic review

To answer the questions about the effects of crop diversity on biodiversity a systematic search for relevant studies is carried out. Literature searches are made in bibliographic databases (Scopus, Web of Science Core Collection, Academic Search Premier, CAB Abstracts, and ProQuest Natural Science Collection).

Inclusion of studies will be based on selection criteria, see below. From the included studies, bibliographic data, where and when the study was conducted, study design, study population, exposure, comparison options and outcomes are extracted and compiled in Excel databases. The reliability, the risk of distorted results, in the studies will be assessed according to a revised CEECAT checklist. Meta-analyses will be performed on data from studies performed in an equivalent way, narrative syntheses will be used in cases where analyses cannot be carried out, e.g. where the outcome variable differs between the studies. Knowledge gaps will be identified using expert elicitation (see e.g. Dicks et al. 2014).

5.4 Literature search

5.4.1 Search in bibliographic databases

Searches will be conducted in the five bibliographic databases listed in Table 1. The search strings are adapted to the specific syntax of each database. Searches are not limited on publication date but we intend to only include peer-reviewed studies that are written in English or Swedish. Before completion of the systematic review, a renewed literature search will be carried out to ensure that newly published research is included.

Table 1. Bibliographic databases

Database	Search bar	Subscription and access
Scopus	Title, Abstract, Keywords	Access via Formas subscription
Web of Science Core Collection	Topic	Formas' subscription includes: Science Citation Index Expanded; Social Sciences Citation Index; Arts & Humanities Citation Index; Conference Proceedings Citation Index- Science; Conference Proceedings

		Citation Index- Social Science & Humanities; Emerging Sources Citation Index
Academic Search Premier	Title, Abstract, Subject Terms, Author-Supplied Keywords	Access via Formas' subscription to EBSCO's platform
CAB Abstracts	Title, Abstract, Heading Words	Access via Formas' subscription to Ovid's platform
ProQuest Natural Science Collection	Title, Abstract, All subjects & indexing	Formas subscription includes: AGRICOLA; Agricultural Science database; Aquatic Sciences and Fisheries Abstracts; Biological Science database; Biological Science index; Earth, atmosphere & Aquatic Science database; Environmental Science database; Environmental Science index; Meteorological & Geoastrophysical Abstracts

5.4.2 Search string

(agricultur* OR agro$ecosystem* OR crop* OR cultivat* OR farm*) AND ("alley crop" OR "alley crops" OR "barrier crop" OR "barrier crops" OR bicultur* OR "catch crop" OR "catch crops " OR "companion crop" OR "companion crops" OR "cover crop" OR "cover crops" OR "crop diversification" OR "crop diversity" OR "crop mixture" OR "crop mixtures" OR "crop sequence" OR "crop sequences" OR "crop sequencing" OR "cropping diversity" OR "cultivar mixture" OR "cultivar mixtures" OR "diverse crop" OR "diverse crops" OR "diversifying crop" OR "diversifying crops" OR "double crop" OR "double cropping" OR "double crops" OR "genetic mixture" OR "genetic mixtures" OR "heterogeneous landscape" OR "inter cropping" OR intercropping OR inter-cropping OR "landscape complexity" OR "landscape diversification" OR "landscape diversity" OR "landscape heterogeneity" OR "landscape richness" OR "mixed crop" OR "mixed cropping" OR "mixed crops" OR "mixed cultivar" OR "mixed farming" OR "mixing crop" OR "mixing crops" OR "multiple crop" OR "multiple cropping" OR "nurse crop" OR "nurse crops" OR "phased planting" OR polyculture OR "production diversity" OR "relay crop" OR "relay crops" OR rotating OR rotation* OR "sequence of crop" OR "sequence of crops" OR "sequential crop" OR "sequential cropping" OR "species mixture" OR "species mixtures" OR "strip crop" OR "strip crops" OR "successive crop" OR "successive crops" OR "trap crop" OR "trap crops" OR tricultur* OR underplant* OR undersow* OR "varietal diversity" OR "varietal mixture" OR "varietal mixtures" OR "variety diversity" OR "variety mixture" OR "variety mixtures") AND (abundance* OR assemblage* OR biodiversity OR "biological diversity" OR "biological variability" OR "community composition" OR "community compositions" OR "community structure" OR "community structures" OR "diversity index" OR "endangered species" OR evenness OR extinct* OR "functional diversity" OR "rare species" OR rarity OR richness OR "Shannon index" OR "Simpson index" OR "species diversity" OR threatened)

”cropping system” was added in Web of Science after external critical appraisal.

5.5 Selection of studies

The documentation of the selection process is in accordance with international conventions such as the PRISMA statement. The abstracts of the articles are assessed according to selection criteria by Formas. Included studies are ordered in full text and reviewed by experts according to the selection criteria. To ensure uniform decisions among the experts, 5 % of the papers will be reviewed by more than one expert independently of each other. An agreement rate > 80 % will be accepted, in case it is lower the disagreements will be discussed among the experts and another 5 % of the papers will be reviewed by more than one expert, until the acceptable agreement rate is reached. The final lists of included and excluded studies reviewed in full text, including reasons for exclusion of studies, are included as annexes in the systematic review. If the expert is the author or co-author of a given article, he or she is not included in the assessment of the article.

5.6 Selection criteria

For a study to be eligible and included, all the selection criteria must be met.

<u>Inclusion criteria</u>

- Controlled experiments or observational studies
- Quantitative studies on the impacts of crop diversity on one of the following biodiversity metrics: richness, diversity, abundance, evenness.
- Drivers measure crops grown or cultivated for immediate human or livestock use or consumption including food, feed, fibres, fuels as well as soil improvements and fallow.
- Studies with biodiversity response variables measuring:
  - seeds or seed banks;
  - larvae or eggs;
  - genetic, phylogenetic, or functional biodiversity
- The following controls/reference habitats will be included:
  - Spatial crop diversity (mixed, pattern or inter-cropping) compared to monoculture
  - Higher spatial crop diversity compared to lower spatial crop diversity at plot, field and landscape level
  - Temporal crop diversity (crop rotation) compared to lack of rotation (i.e. single crop continuously cultivated)
  - Higher temporal crop diversity compared to lower temporal crop diversity.

<u>Exclusion criteria</u>

- Simulation or scenario-based modelling studies
- Qualitative studies
- Studies on damaged, contaminated, or disturbed land or on land restored or reclaimed from damage caused by natural or anthropogenic disturbances e.g. fire, soil salinity, heavy metals, previous high-intensity agriculture
- Mixed crop-livestock primarily represented permanent pasture- or grassland-dominated systems and when crop diversity cannot be separated from grazing management effects.

- Crop-aquaculture systems
- Studies within ponds, streams or river habitats
- Before-after studies or time trend studies without proper controls/reference habitats
- If crop diversity is totally confounded by agricultural management practices it is excluded unless the management difference is an integral part of the crop diversity intervention.
- Diversity measures include genetic modification, varieties, or cultivars.
- The following controls/reference habitats will be excluded:
    - Monoculture or continuous cultivation of a crop which is not included within the crop diversity study group.
    - Natural grazing lands e.g. meadow, rangeland

5.7 Categorization of metadata

From the included studies, the contents of a data matrix are compiled in Excel. Relevant bibliographic data such as title of article, author, publication year will be included in the matrix. Furthermore, information about where and when the study was conducted, study design, study population, exposure, comparison options and outcomes will be reported in the matrix.

In cases where data are not reported appropriately in the study, we will estimate effect size from (1) optical approximation from figures, (2) estimation from F-values. If the necessary data exists or is missing and in what way the data has been produced will be reported in the matrix.

5.8 Critical appraisal of included studies

Critical appraisal, to identify potential sources of distorted outcomes, will be conducted. A revised CEE Critical Appraisal Tool (CEECAT) from Collaboration for Environmental Evidence (https://environmentalevidence.org/cee-critical-appraisal-tool/) will be used. The critical appraisal tool includes the assessment of internal and external validity. The appraisal is carried out by two experts independently of each other. If the expert is the author or co-author of a given article, he or she is not part of the appraisal. In the event experts are uncertain about judgment, this will be discussed among themselves. If there is disagreement, additional experts will be included. The results of the critical appraisal are included as a figure or table in the systematic review.

5.9 Compilation of results

Relevant results for answering the above questions based on the data matrix are compiled in tables, and where appropriate, data are compiled in quantitative meta-analyses and in narrative syntheses in consultation with experts and stakeholders.

Quantitative meta-analyses (including weightings where possible) will be carried out on data from studies performed in an equivalent way, narrative syntheses will be used in cases where mergers cannot be carried out, for example where the outcome variable differs significantly between the studies. Expert elicitation may be used if needed.

Sensitivity analyses will be carried out in cases where experts deem this necessary and may be, for example, that meta-analyses are performed with and without results from studies with a high risk of distorted results to see if the overall result is affected.

Knowledge gaps are defined based on the specific information needs of Swedish stakeholders, which will be discussed with relevant stakeholders. A knowledge gap may be due to a lack of results of relevance to stakeholders or that existing results are methodologically too substandard to be of value to stakeholders. The knowledge gaps are made concrete by the project's experts in consultation with a selection of key stakeholders.

5.10 Conclusions and evidence grading

Conclusions will be formulated based on results from meta-analyses, narrative syntheses and gap filling. These conclusions will be evidence-graded, i.e. we will describe how much confidence we have in the conclusions based on shortcomings from the critical appraisal of the studies, transferability to the Swedish context and consistency between studies. The evidence grading is carried out together by the entire project team. The stronger the evidence, the less likely it is that reported results will be affected by new research findings in the foreseeable future.

The evidence grading of the conclusions will have the following levels:

We are very confident

When we are *very confident* in a conclusion, we believe that the result is robust and is unlikely to be significantly affected by future research results. To be *very confident*, this means, for example:

- The conclusion is based on several studies conducted by different research groups in different locations.
- No methodological shortcomings in the studies that form the basis for the conclusion have been identified, or the identified shortcomings are not considered to affect the conclusion.
- The studies included are relevant to the context examined in the review.
- The overall results remain even when individual studies are excluded.

We are confident

When we say that we are *confident* in a conclusion, it means that some problems have been identified, but that they are not judged to undermine the conclusion in a decisive way. To be *confident*, this means, for example:

- The conclusion is based on several studies conducted by different research groups in different locations.
- Some methodological shortcomings in the studies that form the basis for the conclusion have been identified but are not considered to have a significant impact on the conclusion.
- The studies included may differ slightly from the context examined in the review.
- The overall results remain even when individual studies are excluded, but the results in the weighting may be less robust than in the higher grading.

We are less confident

If we say that we are *less confident*, it may be because problems have been identified that could significantly undermine the conclusion, and the weighted results may therefore be misleading. To be *less confident*, this means, for example:

- The conclusion is based on fewer studies with a small geographical spread.
- Methodological shortcomings in the studies that form the basis for the conclusion have been identified.
- The studies included may differ from the context examined in the review. The overall results in the weighting are less robust when individual studies are excluded.

We are uncertain

At the lowest grading, where we say that we are *uncertain*, serious methodological problems have been identified and the overall result is not considered robust. To be able to be *uncertain*, this means, for example, that:

- The conclusion is based on single or few studies with a small geographical spread.
- There are significant methodological shortcomings in the studies that form the basis for the conclusion.
- The studies included are conducted in a different context than the one examined in the review.
- The overall results of the weighting are not robust.

When studies are lacking, available studies have low reliability or where studies of similar reliability show contradictory results the scientific evidence is insufficient to form any conclusions.

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