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Author(s):
Elmiger, Noëmi; Finger, Robert; Ghazoul, Jaboury; Schaub, Sergei

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Review

Biodiversity indicators for result-based agri-environmental schemes – Current state and future prospects

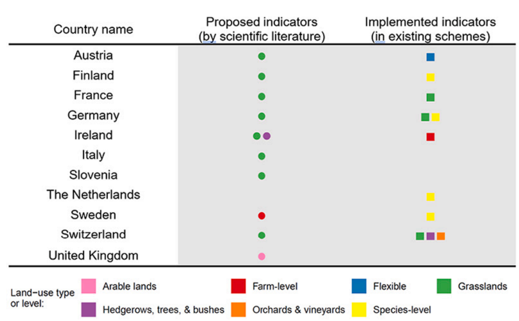
By Noëmi Elmiger [a,1], Robert Finger [a], Jaboury Ghazoul [b], Sergei Schaub [a,b,c,1,*]

[a] Agricultural Economics and Policy Group, ETH Zürich, Zürich, Switzerland
[b] Ecosystem Management, ETH Zürich, Zürich, Switzerland
[c] Business Management and Value Creation, Agroscope, Ettenhausen, Switzerland

HIGHLIGHTS

- We systematically review proposed biodiversity indicators for result-based agri-environmental schemes.
- Additionally, we synthesize indicators currently used in result-based schemes.
- Most studies and schemes focus on grasslands and plant species diversity using vascular plants as indicators.
- Policymakers can draw upon various options to design their biodiversity indicators.
- Technological advances could improve the design and monitoring of biodiversity indicators.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Many agricultural policies target the conservation of biodiversity worldwide. Result-based agri-environmental schemes can be more effective and efficient than the more commonly used action-based schemes. The efficiency of result-based schemes, and thus their likely inclusion in agricultural policy frameworks, depends critically on the indicators used to measure biodiversity.

OBJECTIVE: We investigate how biodiversity indicators for result-based schemes might be designed and implemented.

METHODS: To this end, we first conduct a systematic review of the scientific literature to identify the range of proposed biodiversity indicators. Second, we synthesize the currently used biodiversity indicators in existing result-based agri-environmental schemes. Third, we compare the proposed and implemented indicators. Fourth, we provide an overview of planned result-based schemes under the 2023–27 reform of the EU Common Agricultural policy. Fifth, we propose how the schemes and indicators might be improved by drawing from technological advances.

RESULTS AND CONCLUSIONS: Our analysis of proposed schemes shows that most schemes use vascular plants as indicators, representing plant species diversity in grassland. These indicators are designed and applied uniformly for large regions such as states or countries. Recently published papers propose more often indicators that consider more biodiversity aspects and are adapted to conditions at smaller scales. We observe similar patterns

* Corresponding author at: Agricultural Economics and Policy Group, ETH Zürich, Zürich, Switzerland.
E-mail address: seschaub@ethz.ch (S. Schaub).
[1] These authors equally contributed to the paper.

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for currently implemented as for proposed schemes: They are using mostly vascular plants to represent grassland plant species diversity. Moreover, implemented schemes and their indicators are also rather simple in their design and not adapted to smaller regional conditions. More recently implemented schemes are taking both dimensions increasingly into account.
Policymakers need to consider their objectives when choosing and designing biodiversity indicators and result-based schemes. They often face trade-offs between improving biodiversity and costs. Therefore, they need to decide which aspects of biodiversity should be considered and how many thresholds that trigger payments should be established. However, studies showed that some indicator designs allow policymakers to cost-effectively consider different aspects of biodiversity. Furthermore, policymakers need to select the indicators based on whether they want to conserve existing or restore lost biodiversity. Finally, new technologies can help improve the design and monitoring of biodiversity in the future.
SIGNIFICANCE: Our insights into proposed and implemented biodiversity indicators for result-based schemes provide guidelines for future policy design. Moreover, we show how technological advances can potentially improve biodiversity-oriented result-based agri-environmental schemes.

1. Introduction

Many countries have developed and implemented agri-environmental policies to reduce ongoing biodiversity loss with increasing efforts since the 1990s (e.g., Baylis et al., 2008, 2022, Simoncini et al., 2019, European Court of Auditors, 2020). Voluntary result-based schemes[2] that incentivize farmers to implement biodiversity-friendly practices embedded in agri-environmental policies have often been suggested as contributing solutions to reduce biodiversity loss (e.g., Burton and Schwarz, 2013; Herzon et al., 2018). Under such schemes, farmers receive payment for delivering predefined environmental outcomes. Indeed, with the 2023–27 reform of the EU Common Agricultural Policy (CAP), the interest of member states in introducing result-based schemes increased (European Commission, 2022a).[3] One key challenge in designing biodiversity-oriented result-based schemes is finding the appropriate biodiversity indicators that approximate biodiversity and upon which outcome evaluation, and hence farmer payment, is determined (Burton and Schwarz, 2013).

This study aims to provide an overview from a policy perspective of biodiversity indicators for result-based schemes in Europe and future prospects by answering the following two questions. First, what are the proposed and implemented biodiversity indicators for result-based schemes (i.e., current state)? Second, how can we improve the design and implementation of biodiversity indicators in result-based schemes? To this end, we synthesize biodiversity indicators proposed by the scientific community through a systematic review, evaluate those indicators already implemented in existing policies, and discuss future pathways for measuring biodiversity for result-based schemes.

Most implemented agri-environmental schemes are action-based, i.e., farmers are compensated for implementing certain actions (Simoncini et al., 2019). However, in many cases, implemented action-based schemes targeting biodiversity have failed to deliver desired results (European Court of Auditors, 2020). This might be due to a lack of evidence underlying the design of action-based schemes, and that they do not sufficiently consider local environmental conditions and targets (e.g., common vs. endangered species) (e.g., Sutherland et al., 2004; Kleijn et al., 2006; Finn et al., 2009; Kleijn et al., 2011; Pe'er et al., 2021). Furthermore, many implemented schemes that include result-based payments, such as those for species-rich grasslands in Switzerland or the German state of Baden-Württemberg, are hybrid schemes that combine action- with result-based payments.

Result-based compared to action-based schemes are thought to have several advantages. Farmers are likely to be more motivated as they can choose the means by which to deliver the results, and thus adapt (cost-effective) methods fitting the local requirements (Matzdorf et al., 2008; Bertke et al., 2008; Matzdorf and Lorenz, 2010; Wuepper and Huber, 2021). Farmers might also select land best suited for environmental protection, whereas this might not be the case in action-based schemes (Matzdorf et al., 2008). There is also likely to be higher acceptance by farmers due to fewer restrictions and regulations (Bertke et al., 2008; Klimek et al., 2008).

While result-based schemes might be more efficient in achieving the desired results, they also imply more risk for farmers than action-based schemes due to the uncertainty of biodiversity outcomes (Matzdorf and Lorenz, 2010; Burton and Schwarz, 2013).[4] Those risks might increase as weather extremes and variability, predicted to increase under climate change, influence biodiversity (e.g., Gruner et al., 2017; Zhang et al., 2018). Moreover, the monitoring costs for result-based schemes and their indicators are higher for both farmers and policymakers (Simoncini et al., 2019). Finally, designing appropriate biodiversity indicators for result-based schemes that effectively measure biodiversity to reach policy objectives is a major challenge. Allen et al. (2014) proposed that designs need to take account of, and resolve, the complexity of biodiversity. They also need to be broadly accepted and legitimized by farmers, biodiversity experts, officials, and the public. Moreover, predefined biodiversity targets of result-based schemes must be feasible for farmers to reach, and indicators need to be transparent and assessable at reasonable costs (Allen et al., 2014).

Herzon et al. (2018) recently summarized the opportunities and challenges of result-based schemes and the elements for ensuring their effective design. They highlighted the importance of biodiversity indicators in the design of such schemes but gave little further detail. Other policy-oriented handbooks and reports provide an overview of the design of implemented schemes, including biodiversity indicators (Underwood, 2014; Allen et al., 2014), or propose how to develop new schemes without presenting the current state of research (Stolze et al., 2015). However, a detailed overview of the biodiversity indicators and their integration in result-based schemes is lacking, despite being important for policymakers and farmers.

We address these gaps in five ways. First, we systematically synthesize the proposed biodiversity indicators of result-based schemes in the scientific literature (Section 4). Second, we present an extensive overview of indicators implemented in existing schemes (Section 5).

[2] We use here the term result-based payment, synonyms for it are result-orientated (Wittig et al., 2006; Bertke et al., 2008), results-based (Magda et al., 2015), result-oriented (Kaiser et al., 2010), outcome-oriented (Höft et al., 2007), indicator-based payment (Hasund, 2013), performance-based (Derissen and Quaas, 2013), and payment-by-results (Birge et al., 2017; Chaplin et al., 2021).

[3] Note that information about the final national strategies and the designs of result-based schemes are often not yet available.

[4] Farmers' decisions to adjust their management to achieve predefined outcomes, such as by reducing management intensity or buying expensive species-rich seed mixtures (e.g., Smith et al., 2003; Schaub et al., 2021), are done before obtaining the outcomes, which are uncertain, and payments are received. Thus, those management changes represent an uncertain investment.

Third, we compare the proposed and implemented indicators, and consider how they have developed over time (Section 6). Fourth, we provide a brief overview of the planned result-based scheme under the CAP reform 2023–27 (Section 8.1). Fifth, we discuss technological advances that might help to design and monitor biodiversity indicators (Section 8.2).

2. Background on biodiversity indicators for result-based payments

Indicators in biodiversity-oriented result-based schemes are i) proxies[5] for biodiversity more generally, and ii) measures against which payments to farmers are determined. Earlier definitions and assessments of biodiversity by ecologists and/or economists often focused on three components: the number of species, relative abundance of species, and dissimilarities in their features (e.g., Büchs, 2003; Baumgärtner, 2007; Yang et al., 2021a). These approaches ignore important components of biodiversity including, for example, the value of rare and endemic species, or undesirable species that negatively affect ecosystem health. Biodiversity indicators have thus been adapted to consider regional characteristics, habitats, rare species, and different scales (e.g., Matzdorf et al., 2008, Klimek et al., 2008, Underwood, 2014, Liu et al., 2018, Marshall et al., 2020, Yang et al., 2021a). Further, these indicators are defined based on context and (policy) objectives (Baumgärtner, 2007; Hasund, 2011).

Biodiversity indicators can be classified into biotic and non-biotic indicators. Biotic indicators include all living things, such as plants, insects, or mammals,[6] whereas non-biotic indicators include environmental and management conditions (e.g., Kleinebecker et al., 2018). Non-biotic indicators, therefore, also comprise structural elements. These include, for example, hedgerows, ditches, and dry-stone walls at the plot or farm level, or the composition and configuration of landscapes. In the following, we refer to a list of biodiversity indicators that focus on one dimension (such as specific taxa or structural elements) as unidimensional indicator lists. Different unidimensional indicator lists can be combined into a composite index for measuring different biodiversity dimensions.

The predictive power of using a biotic indicator to proxy biodiversity can depend on the environmental and management conditions (e.g., Manning et al., 2015; Brunbjerg et al., 2018). For example, in agricultural grasslands, the number of plant species could indicate the number of species of other taxa and multi-diversity in grasslands with lower land-use intensity while not in those with higher land-use intensity (Manning et al., 2015). In contrast, the number of insects of some taxa was, in grasslands with higher land-use intensity, able to indicate multi-diversity (Manning et al., 2015). For policy purposes, it can also be interesting to use indicators linked to the biodiversity of a habitat with a certain land-use (henceforth referred to as "target habitat"), such as species-rich grasslands with low land-use intensity (e.g., Carignan and Villard, 2002; Matzdorf et al., 2008; Kaiser et al., 2010). This can be especially relevant, as grasslands with low land-use intensity and their biodiversity are increasingly threatened due to land-use intensification (e.g., Mountford et al., 1993; Gough et al., 2000; Hünig and Benzler, 2017; Auffret et al., 2018; Bardgett et al., 2021).

In addition to biotic indicators, the presence and quality of structural elements, such as hedgerows and their quality, have been positively linked to biodiversity (e.g., Van Dijk et al., 2014; Graham et al., 2018; Montgomery et al., 2020). Moreover, other non-biotic indicators at the landscape scale can predict biodiversity, such as the composition and configuration of the landscape (e.g., Tscharntke et al., 2005; Martin et al., 2019). Assuming that those different unidimensional indicator lists measure different aspects of biodiversity, combining different lists into a composite index can provide a more comprehensive overview of the biodiversity state than a single unidimensional indicator list (see, e.g., Carignan and Villard, 2002, Tasser et al., 2019).

It is also necessary to determine how remuneration should be related to the quantity of biodiversity as indicated by selected indicators, and whether payment schemes should include one or multiple thresholds at which payment is triggered or, alternatively, be quantitatively linked to a continuous measure of biodiversity. The answers to these questions depend on several factors, including policy objectives (e.g., if the goal is to represent a certain target habitat (e.g., Matzdorf et al., 2008, Kaiser et al., 2010, Ruff et al., 2013)) and financial resources.

Furthermore, the question of how the biodiversity indicators were selected and if their predictive power of biodiversity was validated also arises. These processes might differ as indicators could, for example, be based on ad hoc choices, literature, experts, or data.

Summarizing, biodiversity indicator lists and indices can differ in i) their complexity (design of indicator lists/indices and the number of thresholds), ii) whether they are adapted to smaller regional conditions and the target habitat (e.g., species-rich grasslands with low land-use intensity), and iii) system focus (referring to focus on smaller (smallest = species level) or larger systems (largest = farm-level across land-uses)). Lower degrees of those dimensions can align with policy objectives, but increasing the complexity, adapting to smaller regional and target habitat conditions, and having a larger system focus might benefit biodiversity overall – as discussed above. Moreover, biodiversity indicators might also differ according to which and how many taxa they consider, and how they were chosen and validated. We consider these different dimensions when reviewing the proposed and implemented biodiversity indicators.

3. Methods

Our methodological approach follows two steps. First, we systematically review proposed biodiversity indicators in the existing scientific literature. Second, we gather information about biodiversity indicators in implemented result-based schemes. We uploaded a pre-registration plan of our research design to the 'Open Science Framework' on November 1, 2021 (Elmiger et al., 2021),[7] and before systematically retrieving information about proposed and implemented schemes.

3.1. Proposed biodiversity indicators – a systematic review

Systematic reviews synthesize the knowledge state concerning a formulated research question (Page et al., 2021). The four steps of our systematic review, following the PRISMA guidelines (Page et al., 2021) and defined in our pre-registration plan, are 1) identification of our research question ("Which biodiversity indicators or modification of indicators for result-based agri-environmental schemes are newly proposed in scientific literature, how do they measure biodiversity and how can they be used to improve agricultural policies?"), 2) identification of the relevant studies, 3) a critical appraisal, and 4) a synthesis of the studies.

3.1.1. Search strategy and eligibility criteria

For identifying the studies in our literature search, we grouped the keywords into five categories: "indicator", "biodiversity", "agriculture", "scheme", and "result-based". We identified a set of keywords for each keyword group based on our knowledge (Table S2). Based on these keywords, we retrieved records from three databases, Scopus, Web of

[5] Indicators for measuring the entire biodiversity (i.e., diversity of life) is often not feasible.

[6] Biotic indicators also include "indicator values" when derived from living things, such as plants. Such biotic indicator values are Ellenberg indicator values as they are derived from plants (e.g., Diekmann, 2003).

[7] The few cases and their explanations when we deviated from the pre-registration plan are recorded in Table S1.

Science Core Collection, and Web of Science CABI (see Table S3 for search strings). Additionally, we extended our set of keywords to avoid bias in the keyword selection and included omitted keywords using a text mining and keyword co-occurrence networks approach, which is based on records identified with our initial keywords (Grames et al., 2019) (Table S2). For this additional set, we extracted records again from the same databases. The records were retrieved between November 2 and November 5, 2021.

Records were included in our review if 1) they proposed new biodiversity indicators or newly modified existing indicators for result-based policy schemes, 2) the indicators were either based on wild biota or structures (e.g., diversity of landscape), 3) the selected literature was set in European and North American countries because, in these areas, agri-environmental schemes are an important element of agricultural policies (e.g., Baylis et al., 2008, 2022), 4) they were peer-reviewed articles containing primary research, 5) they were published in English, and 6) published between 2000 and 2021.[8]

All titles and abstracts of the retrieved records were then screened by N. Elmiger. The full texts of the remaining records were independently screened and discussed by N. Elmiger and S. Schaub. To find further articles covering the topic, N. Elmiger screened the reference list of the shortlisted articles and the articles which cited the shortlisted articles. The results were again discussed and selected by two reviewers (N. Elmiger, S. Schaub). Finally, the data were extracted by N. Elmiger.

3.1.2. Critical appraisal

We followed the CASP (Critical Appraisal Skills Programme) Checklists for qualitative research and randomized controlled trials for the critical appraisal of the selected articles (CASP, 2018, CASP, 2018, Bird et al., 2019). The selected articles were critically appraised for their quality based on four criteria: 1) clear description of study and methods, 2) appropriate study design, 3) clear description of results, and 4) bias-free execution (Table S4 and S5). Each of these criteria were checked to rate the articles. Per criteria met, a point was given. Thus, a maximum of 4 points could be scored.

3.1.3. Overview of selected studies

The systematic literature search identified 2005 unique records (Fig. S1). Of those, 39 records remained after the title and abstract screening and 13 articles after the full-text screening. Three additional articles were identified by screening the citations in the selected studies and those that cited the shortlisted studies. Based on critical appraisal, none of the 14 selected articles were excluded (Table S5). Those 14 articles comprise 16 individual studies.

3.2. Selection of implemented result-based schemes

In addition to the review of the scientific literature, a search was conducted to find European[9] result-based schemes which are implemented and ongoing and use indicators for the conservation and promotion of biodiversity. In contrast to the schemes described in scientific literature, these schemes are implemented as part of the existing agri-environmental policy mix. This search aimed not to compile an exhaustive list but a general overview.

3.2.1. Search strategy and eligibility criteria

The search for implemented schemes is based on three sources. First, we used the website Result Based Payments Network, 2022), which is the most comprehensive online source of result-based schemes we could find. Second, based on a recent review that conducted an in-depth search of implemented result-based schemes (Herzon et al., 2018). Third, based on two policy-oriented handbooks and reports summarizing information about implemented schemes (i.e., Underwood (2014) and Stolze et al. (2015)). Implemented schemes were deemed eligible if they 1) define the conservation and promotion of biodiversity as the main goal, 2) are either designed as purely result-based schemes or hybrids of result-based and action-based schemes, and 3) are implemented and ongoing.[10] We consulted the projects' websites, official websites (e.g., federal states), leaflets, and the scientific literature to find additional information about the eligible schemes.[11]

4. Results: biodiversity indicators proposed in the scientific literature

Out of the 16 studies included in the systematic review of the proposed biodiversity indicators, twelve focused on the conservation of biodiversity on grassland (Wittig et al., 2006, Höft et al., 2007, Matzdorf et al., 2008, Bertke et al., 2008,[12] Kaiser et al., 2010, Magda et al., 2015, Birge et al., 2017, Kaiser et al., 2019, Tasser et al., 2019, Ruas et al., 2021, Šumrada et al., 2021); one examined the case of hedgerows (Ruas et al., 2021). In two studies, biodiversity conservation was proposed to be integrated into a scheme for whole farms or farm systems (Hasund, 2011; Hasund, 2013). One study focused on biodiversity indicators on arable land (Chaplin et al., 2021). In the results section, we focus on grasslands due to the high representation of this land-use type.

All studies were situated in one or several countries in Western, Central, and Northern Europe, namely in Austria (Tasser et al., 2019), France (Magda et al., 2015; Tasser et al., 2019), Germany (Wittig et al., 2006; Höft et al., 2007; Matzdorf et al., 2008; Bertke et al., 2008; Kaiser et al., 2010; Kaiser et al., 2019; Tasser et al., 2019), Italy (Tasser et al., 2019), Switzerland (Tasser et al., 2019), Slovenia (Šumrada et al., 2021), UK (Chaplin et al., 2021), Ireland (Ruas et al., 2021), Sweden (Hasund, 2011, Hasund, 2013), and Finland (Birge et al., 2017) (Fig. 1). Studies situated in North America could not be found.

Studies that focused on different land-use types defined several criteria that biodiversity indicator lists or indices must meet to be suitable for result-based schemes. The two most important criteria are 1) representativeness for the target habitat or species, and 2) simplicity of assessment in the field (see Table S6 for details).

Most indicator lists and indices proposed for result-based schemes

[8] In our systematic review of proposed biodiversity indicators (not for identifying implemented schemes; see Section 3.2), we focused on indicators proposed in the scientific literature, which were peer-reviewed by other independent researchers (as a quality criterion). Additionally, focusing on peer-reviewed articles is a common approach (e.g., Poulsen et al., 2015; McCary et al., 2016; Dardonville et al., 2020; Van Ewijk and Ros-Tonen, 2021). Moreover, focusing on peer-reviewed articles ensures that compared to other formats, such as peer-reviewed extended abstracts in conference proceedings, sufficient information was available. Furthermore, we focused on English articles as it is the most common language of peer-reviewed articles, and we assume that novel findings, ideas, and design of indicators for result-based payments are published in such format. While focusing on English is common (and studies in the field of medicine have shown that exclusion of other languages than English does not necessarily cause a bias (e.g., Morrison et al., 2012)), we note that non-English articles exist that propose biodiversity indicators (e.g., Tasser et al., 2019; Kaiser et al., 2009; Ruff et al., 2013). Furthermore, we selected the time between 2000 and 2021 as it provides an important picture of the recently proposed biodiversity indicators and their time trend and captures the relevant literature (Herzon et al., 2018). Finally, we want to highlight that our strategy of eligibility criteria resulted in a rich and diverse set of articles about biodiversity indicators for result-based schemes.

[9] We focus on implemented schemes in Europe as only proposed schemes in Europe were found (see Section 4).

[10] Thus, pilot projects, schemes in a test phase, or terminated schemes were excluded.

[11] Note that the available information varied considerably between implemented schemes.

[12] Note that Bertke et al. (2008) presented two case studies. Their case study two is, for example, also used by Klimek et al. (2008) to design a result-based scheme with a conservation auction mechanism.

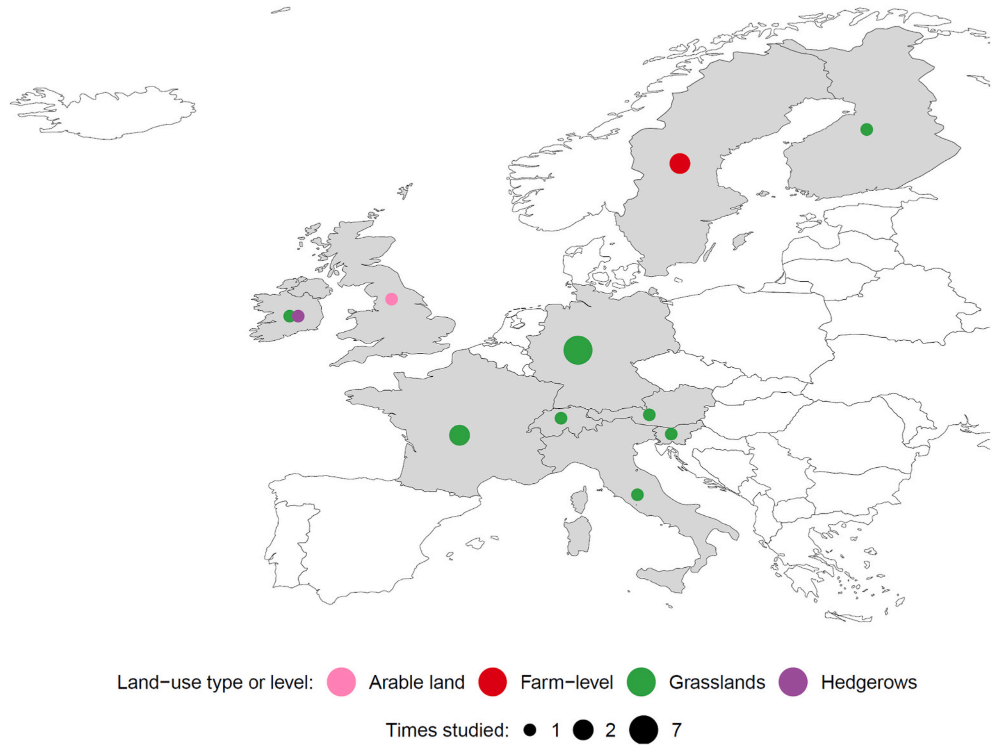

Fig. 1. Resulting frequency from our systematic review of the scientific literature of how often a land-use type or level was studied per country. One study can include more than one country.

use vascular plants – often forbs.[13] Mobile indicators, such as birds, are used only exceptionally at the species-level since it is difficult to put their presence into relation to a particular field or farm (Bertke et al., 2008). Moreover, the chosen plants are often at least partly classified as rare or endangered and, depending on the particular objective of the scheme, should represent a certain target habitat (e.g., species-rich grasslands with low land-use intensity). In schemes targeting biodiversity on the landscape- or farm-level, indicator lists or indices can represent the quality of land-use types and structures and the overall landscape structure or landscape diversity (Hasund, 2011; Hasund, 2013; Tasser et al., 2019). In the following presentation, we first present proposed unidimensional indicator lists and then composite indices.

4.1. Proposed unidimensional indicator lists

The land-use type that most studies with unidimensional indicator lists focused on is grassland; others are hedgerows (Ruas et al., 2021) and arable land (Chaplin et al., 2021). All of the studies focusing on one land-use type using unidimensional indicator lists chose plant species or species groups as the most suitable indicators. Moreover, while most studies designed new indicator lists, some refined existing indicator lists or adapted existing lists to a new region (e.g., Höft et al., 2007). Besides the primary objective of conservation and promotion of biodiversity (i.e., species diversity), which all studies have in common, the proposed schemes can be differentiated by the secondary objectives (Table 1). Thus, we separated unidimensional indicator lists into three groups: 1) indicator lists to detect species-rich grasslands, 2) indicator lists to detect species-rich grasslands with low land-use intensity, and 3) indicator lists balancing agronomic and ecological objectives (Table 1). In the case of arable land, the target is the promotion of farmland birds and pollinators by providing food crops and nectar-rich flowers.

4.1.1. Indicator lists to detect species-rich grasslands

Wittig et al. (2006) define the conservation of species diversity and endangered species as their only target. For this purpose, they provide a list of 43 vascular plant species and mention that four indicator species from the list have to be present on the grassland for it to qualify for payment.

4.1.2. Indicator lists to detect species-rich grasslands with low land-use intensity

All studies except two aimed explicitly at indicator lists for detecting species-rich grasslands with low land-use intensity (such as low fertilizer input (e.g., Ruas et al., 2021) or infrequent mowing (e.g., Höft et al., 2007)). Those studies differ in their underlying policy objectives. For example, Kaiser et al. (2010) specifically targeted the conversion of formally species-poor grasslands with high land-use intensity to species-rich grasslands with low land-use intensity. Matzdorf et al. (2008) targeted agricultural species-rich grasslands with low land-use intensity and excluded grasslands that are very wet or very dry because they are often protected under other policies given their often high conservation value (Matzdorf et al., 2008). Contrasting to Matzdorf et al. (2008), Šumrada et al. (2021) focused on grasslands of high nature value.

The number of indicator species and thresholds differed between studies, ranging from 24 to 71 species and one to four thresholds (Table 1). For example, Höft et al. (2007) compiled a list of 30 indicators, and Bertke et al. (2008) a list of 40. Those two studies proposed similar schemes, with three payment levels: to reach the first level, at least eight different dicotyledonous species that indicate low land-use intensity must be present on the grassland. The next level is reached if two more plants from a list of indicator species can be observed. The third level of payment is reached if four additional species from the list can be observed (Höft et al., 2007) or two species indicating rare grassland communities (Bertke et al., 2008). Ruas et al. (2021) focus on species that can be controlled by the farmers' management decisions.

[13] Note that here forbs refer to broadleaf herbaceous plants that are non-grass-like herbaceous plants and herbs refer to plants that do not have above-ground woody growth (see Pell and Angell, 2016).

Table 1
Summary of the proposed schemes.

Study	Country, Region	Secondary Objective	Indicators	Unidimensional list vs. composite index	Threshold for Payment*
Proposed schemes for grassland					
Wittig et al. (2006)	Germany, Lower Saxony	–	43 plant species or species groups	Unidimensional	4 indicator species (in unspecified transects)
Höft et al. (2007)	Germany, Mecklenburg-Western Pomerania	Low land-use intensity	1. Undefined forbs 2. 30 plant species or species groups	Unidimensional	1. 10 forbs 2. 10 forbs +2 indicator species 3. 10 forbs +4 indicator species
Matzdorf et al. (2008)	Germany, Brandenburg	Low land-use intensity	30 plant species or species groups	Unidimensional	4 indicator species
Bertke et al. (2008) (case study one)	Germany, Lower Saxony	Low land-use intensity	31 plant species or species groups	Unidimensional	1. 4 indicator species 2. 6 indicator species
Bertke et al. (2008) (case study two)	Germany, district Northeim in Lower Saxony	Low land-use intensity	40 plant species or species groups	Unidimensional	1. 8 forbs 2. 8 forbs +2 indicator species 3. 8 forbs +2 species indicating rare grassland communities
Kaiser et al. (2010)	Germany, Brandenburg	Low land-use intensity	27 plant species, grouped into four moisture groups	Unidimensional	4 indicator species per field
Magda et al. (2015)	France	Balancing agronomic and ecological objectives	37 plant species	Unidimensional	4 indicator species on 3 sub-transects
Birge et al. (2017)	Finland, Uusimaa	Low land-use intensity	24 plant species or species groups	Unidimensional	7 indicator species
Kaiser et al. (2019)	Germany, Brandenburg	Low land-use intensity	71 plant species, weighted according to a specific goal	Unidimensional	1. 5 indicator species 2. 8 indicator species 3. 11 indicator species 4. 14+ indicator species
Tasser et al. (2019)	Austria, France, Germany, Italy, Switzerland (alpine regions)	Low land-use intensity	- Flower color index - Diurnal butterfly abundance - Structuring degree of agricultural patches - Patch diversity index	Composite	–
Šumrada et al. (2021)	Slovenia, Kras	Low land-use intensity	57 plant species or species groups, grouped in positive and negative indicators**	Composite	1. 4 positive indicator species present in the meadow + total coverage by indicator species of at least 20% 2. 9 positive indicators with total coverage of at least 40%
Ruas et al. (2021)	Ireland, County Sligo, and County Wexford	Low land-use intensity	32 positive plant species or species groups, 3 negative plant species or species groups**	Unidimensional	–
Proposed schemes for arable land					
Chaplin et al. (2021)	UK, Norfolk, and Suffolk	1. Promotion of farmland birds 2. Promotion of pollinators	1. 11 seed-bearing crops, which serve as bird food 2. 20 nectar-rich plants	Unidimensional (two lists)	5 thresholds (presence of 1, 2, 3, 4, 5+ indicator species) 1. Species-specific thresholds for winter-bird food 2. Percentage of the cover of nectar-rich plants in the 2nd year***
Proposed schemes for hedgerows					
Ruas et al. (2021)	Ireland, County Sligo and County Wexford	–	71 to 72 positive indicator species, 22 to 23 negative indicator species**	Unidimensional	–
Proposed schemes for farm systems					
Hasund (2011), Hasund (2013)	Sweden, Selaö and Vetlanda	Promotion of public goods	7 indicator units composed of several weighted variables 1. Arable field indicator (Qualitative hectares) 2. Permanent grassland indicator (qualitative hectares) 3. Linear elements indicator (qualitative meters); e.g., headlands, stone walls, ditches 4. Point field elements indicator (qualitative number); e.g., ponds, field islets, and redundant traditional field buildings 5. Forest edge indicator (qualitative meters)	Composite	–

(continued on next page)

Table 1 (*continued*)

Study	Country, Region	Secondary Objective	Indicators	Unidimensional list vs. composite index	Threshold for Payment*
			6. Bio-rich tree indicator (qualitative numbers) 7. Historic relic indicator (qualitative numbers)		

* While several studies refer or mention specific thresholds not all use data or expert knowledge to propose new thresholds.
** While those authors included negative species and species groups in their lists, these were not connected to payments.
*** Percentage was assessed but not explicitly defined as a threshold for payment.

Their final modified list of 32 positive and three negative species reflects grassland with low land-use intensity and semi-natural grasslands. However, Ruas et al. (2021) did not define a threshold that triggers payment as they focused on the influence of management on indicator species.

Kaiser et al. (2019) propose an adaptable index, i.e., a weighted index that "reflects adequately the most valuable grasslands in terms of conservation". Their list includes 71 species or species groups that indicate low land-use intensity and includes endangered or threatened species, such as *Veronica spicata* or *Filipendula vulgaris*. Depending on the exact goal of the scheme (e.g., habitat conservation, low land-use intensity, or promotion of species diversity in general), the species can be weighted differently. From these weighted species, indicators can be calculated that are compared to the thresholds. Kaiser et al. (2019) argue that their approach reflects the total species diversity much more accurately than other schemes that extrapolate the total species diversity based on the number of indicator species instead of their weighted value. The thresholds that need to be reached to qualify for payment depend on policy objectives. Yet, the authors propose up to four levels of payment.

4.1.3. Indicator lists balancing agronomic and ecological objectives

Magda et al. (2015) described the selection process of indicator species involving various stakeholders (e.g., farmers and conservationists) for a French scheme. The result was the proposition of an indicator list that balanced agronomic and ecological objectives. Thus, the lists also considered species with high agronomic value, such as red clover (*Trifolium pratense*) (Magda et al., 2015). The resulting indicator list included 37 species, and a threshold of 4 was suggested.

4.2. Proposed composite indices

Four studies proposed using a composite index. A two-dimensional index for grasslands is proposed by Šumrada et al. (2021). Besides the minimal number of different indicator species that need to be present, these indicator plants need to cover a minimum area per field. The first payment threshold is set at four species, which need to be present in a meadow with a total coverage of at least 20%; for the second level, at least nine indicators need to be present with a total coverage of at least 40%. Furthermore, Šumrada et al. (2021) developed two indicator lists reflecting low land-use intensity and favorable conservation status considering two distinct soil types with different vegetation and, thus, distinct indicator species.

Tasser et al. (2019), who also focus on grasslands, propose that four unidimensional indicator lists are aggregated to one composite index. The four indices are 1) a flower color index which counts the number of different colored flowers in grassland, 2) diurnal butterfly abundance, 3) the structuring degree of agricultural patches, and 4) a patch diversity index (Shannon diversity index).[14] Tasser et al. (2019) suggest that the composite index reflects the complexity of biodiversity better and could be used for a result-based scheme but do not propose how it could be implemented in an agri-environmental scheme as, for example, no thresholds for payment were defined.

Hasund (2011, 2013) integrates biodiversity conservation into an agri-environmental scheme for public goods (Table 1).[15] It includes the whole farm, ranging from the biodiversity on the level of land-use types and elements to the diversity of the landscape structure. He defines a composite index consisting of seven indices, including an arable field index, permanent grassland index, linear elements index, point field elements index, and forest edge index. Each index consists of variables representing different aspects of biodiversity. In the case of grassland, these variables measure physical features related to the presence of biodiversity, cultural heritage, and social qualities of pastureland and traditional meadows. Examples are the percentage of invading brushwood or the type of grassland (traditional meadow, semi-natural pasture, other maintained grassland). Each of these variables is weighted according to its value for the public good (normative decision); for example, traditional meadows are weighted higher than semi-natural meadows. Subsequently, all weighted variables are summed up in the permanent grassland index. If there is no active mowing or grazing on the permanent grassland, the index is multiplied by zero; if it is still managed, it is multiplied by one. Consequently, no payments are distributed for the index if a factor is zero. In contrast to other result-based schemes, no threshold for payment is defined. Instead, continuous payments are used based on the composite index. Moreover, in the scenario provided by Hasund (2011 and 2013), the payment is automatically triggered depending on a farmer's score but without any auctioning or contracting processes.[16]

4.3. Selection and validation of proposed indicators

Most studies based the initial selection or adjustment of indicators on expert opinions and selection criteria. These criteria include, for example, land-use intensity (related to the number of cuts and nutrient addition) and recognition by farmers (Matzdorf et al., 2008; Birge et al., 2017). Other studies included next to experts also other stakeholders in the selection of indicators, and such stakeholders included public authorities, farmers, and representatives from nature conservation organizations (Bertke et al., 2008; Magda et al., 2015; Tasser et al., 2019). Furthermore, several studies used data to test their biodiversity indicator list, by correlating the recorded number of indicator species with the total number of plant species, number of plant species found in grasslands with low land-use intensity, number of threatened plant species, and/or combination of these variables (Wittig et al., 2006; Höft et al., 2007; Bertke et al., 2008; Matzdorf et al., 2008; Kaiser et al., 2019; Tasser et al., 2019; Birge et al., 2017). Two studies also validated how well each selected indicator predicted plant species diversity (Kaiser

[14] The Shannon diversity index considers both the number of species and abundance.

[15] Hasund (2011, 2013) uses the term public goods in his study because public goods such as clean drinking water, provision of food for pollinators, and attractive landscapes are promoted through and provided by biodiversity. We note that the other indices and indicators also include aspects of the provision of public goods.

[16] The payment designs proposed by Hasund (2013) might not be in line with EU regulations (Hasund, 2013).

et al., 2010; Kaiser et al., 2019). For example, Kaiser et al. (2019) used as a proxy plant species diversity in this validation, amongst others, an index that combines information about the number of species in grasslands with low land-use intensity and threatened species. Interviews have also been used to investigate if farmers can self-assess the proposed indicators, as well as the acceptance by farmers of result-based schemes and the options for their implementation (Hasund, 2011; Hasund, 2013; Magda et al., 2015; Birge et al., 2017; Šumrada et al., 2021; Chaplin et al., 2021).

While several studies mention thresholds, few tested the implication of those and motivated their choice (Höft et al., 2007; Matzdorf et al., 2008; Kaiser et al., 2019). Höft et al. (2007) selected a threshold that most likely identifies species-rich grasslands with low management intensity. In contrast, Kaiser et al. (2019) selected their first threshold at five species for their adjusted indicator list based on what a threshold of four (common in Germany, see Section 5) would have implied for the old indicator list. Additionally, they also showed the implication of their three other proposed thresholds on plant diversity.

4.4. Proposed indicator assessment in result-based schemes

All studies, except for Kaiser et al. (2019), propose that farmers do self-assessment of indicator plants during the flowering season for grasslands, usually starting in May and before the first cut. Thus, those studies emphasize the importance of a small number of easily recognizable indicator plants to make the assessment possible for farmers (Table S6).[17] On the other hand, Kaiser et al. (2019), proposing an indicator list that includes a large number of species, state that experts must do the assessments since “farmers cannot reliably identify 71 indicator species quickly”. Such involvement of experts would lead to higher costs for policymakers if the experts are paid by the government. Furthermore, Hasund (2011, 2013), who designed a scheme for whole-farm systems, highlight three tools that can be used by policymakers to monitor indicators, i.e., field-surveys (e.g., for vascular plant diversity), geographic information systems (e.g., for land-use and size of the elements like fields), and aerial-photo surveys (e.g., tree and bush coverage).[18]

5. Results: implemented schemes and their biodiversity indicators

This section presents long-term schemes currently implemented in several European countries (Fig. 2, Table 2). The section focuses on countries that have already been previously presented in this review (i.e., Austria, France, Germany, Ireland, Sweden, and Switzerland).

5.1. Implemented schemes with unidimensional indicator lists

We grouped the presentation of the implemented schemes using unidimensional indicator lists by those focusing on 1) land-use type and 2) single species.

5.1.1. Indicator lists focusing on land-use type

Most implemented schemes, which focus on land-use type and farm-level, aim also to conserve grasslands. Such schemes exist in the German states of Baden-Württemberg (Seither et al., 2015), Bavaria (LfL (Bayerische Landesanstalt für Landwirtschaft), 2022a), Hesse (selected regions) (Preusche et al., 2019), Lower Saxony and Bremen (Most et al., 2014), Rhineland-Palatinate (Horn, 2016), Saxony (LfULG (Landesamt für Umwelt, Landwirtschaft und Geologie Sachsen), 2018) and Thuringia (Hochberg et al., 2014), in different states in France (e.g., Underwood, 2014; DRAAF Nouvelle-Aquitaine, 2022), and in the whole country of Switzerland (Swiss Federal Council, 2013, FOAG (Swiss Federal Office for Agriculture), 2014a, 2014b, 2014c). Pilot projects or field trials have been conducted in several other European countries or are currently being developed (Result Based Payments Network, 2022).

Vascular plant species or species groups are used as indicators in all cases. The vast majority of indicator species are forbs; however, in some cases, graminoids (i.e., sedges, rushes, or grass species) are included (e.g., FOAG, 2014a; Preusche et al., 2019). In Germany, lists of indicators are developed for each state to account for regional differences. The number of indicator species per list ranges between 30 and 36 (the number of indicator species will increase with the new CAP reform; see Section 8.1). In Switzerland, different lists have also been established, i.e., for meadows (separated into north and south of the Alps and within those areas are again divided based on the biodiversity potential; the number of indicators ranges between 36 and 46) (FOAG, 2014c), and for alpine grassland (71 species or species groups) (FOAG, 2014a). The Swiss cantons (federated states) can adapt lists according to cantonal conditions. In France, the lists are developed by the state, region, or even regional park and Natura 2000 sites (Underwood, 2014). The lists contain 20 indicator species or species groups (e.g., DDT des Hautes Pyrénées (Direction départementale des territoires des Hautes Pyrénées), 2020, DRAAF Nouvelle-Aquitaine, 2022).[19]

The payment thresholds and the number of those differ between implemented schemes. The Swiss grassland schemes (alpine grassland and meadows) contain only one threshold, which is at six indicator species. In Germany, depending on the state, two to three thresholds exist. In all German states, the minimal number of indicators that must be present is four; however, the other thresholds differ amongst states (German Federal Ministry of Food and Agriculture, 2021). In France there is one threshold for payment of four indicator plants in all cases that we identified (e.g., DDT des Hautes Pyrénées (Direction départementale des territoires des Hautes Pyrénées), 2020, DRAAF Nouvelle-Aquitaine, 2022).

In all German states except Hesse, farmers self-assess their fields. In Hesse, the assessment is done by experts who survey the field before contracting and again every year during participation (Preusche et al., 2019). Since not all species bloom simultaneously, some German states propose to assess the same fields up to three times per flowering season to facilitate the process (e.g., Thüringen). Assessment is explicitly limited to one survey in other states, such as Rhineland-Palatinate. In Bavaria, a yearly assessment is only “recommended” to be able to optimize management, although irregular control surveys are conducted in all states. All German schemes assess the indicators by walking along a transect across the field and documenting all indicator species within a 2 m distance. In some states, the transects are assessed as a whole, and in others, divided into thirds or halves. In Saxony, the number of divisions is adjusted to the size of the field. A minimal number of indicator species has to be present along each transect to receive remuneration. Amongst German states, the required frequency of the indicator species varies. In Thuringia, at least three individuals of each species must be present for remuneration. In Bavaria, infrequent species or those only observed in one small area are not supposed to be counted since it might not be possible to find them again. In Switzerland, farmers can claim that indicators are present in certain fields and enroll those fields. Officials control those enrolled fields surveying representative areas of the grassland with a radius of 3 m (Swiss Federal Council, 2013).

[17] Several studies surveyed farmers’ capability of recognizing species and found that farmers were capable or confident after training in recognizing them (Wittig et al., 2006; Bertke et al., 2008; Birge et al., 2017; Šumrada et al., 2021).

[18] We note that information about how indicators should be assessed in practice is often missing or vague. For an example of such an assessment, see Kaiser et al. (2009).

[19] The French schemes are often developed for small areas such as parks or Natura 2000 sites. Thus, only a non-representative selection of schemes was screened. The number of species per list and payment thresholds were identical in all cases.

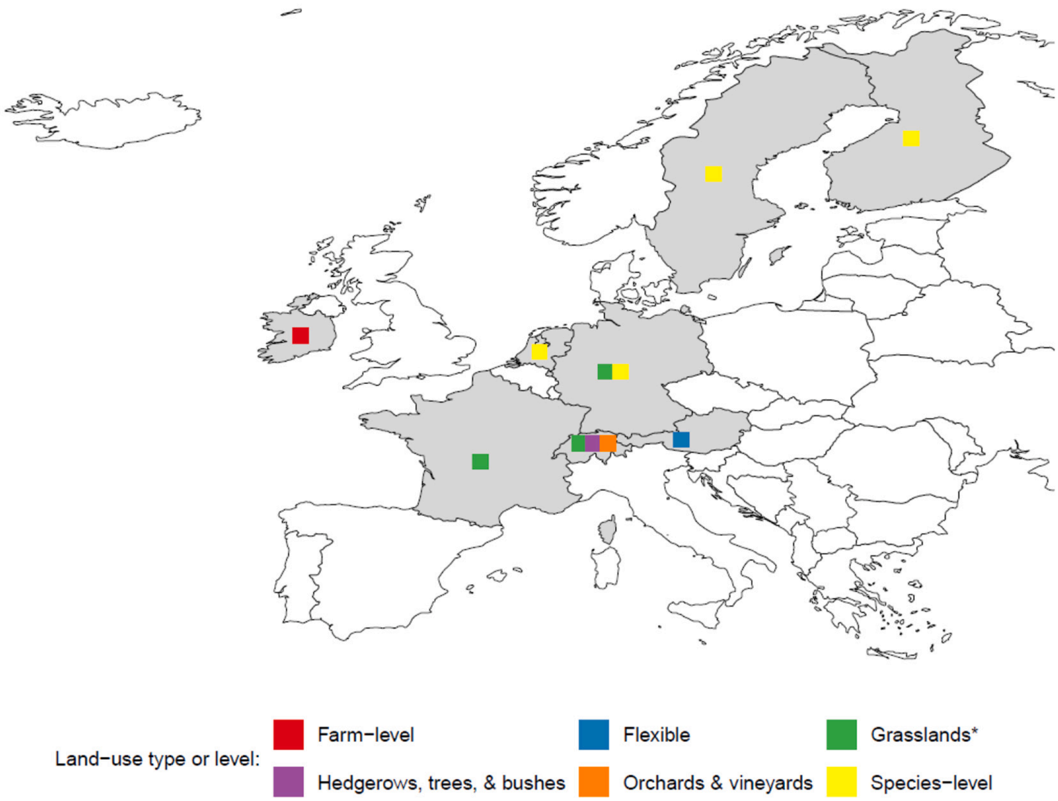

Fig. 2. Existence of implemented schemes per country and indication of the targeted land-use type or level. Note that this is not a complete representation of all implemented result-based schemes. *Grasslands focused schemes can also include structural elements and wood pasture (see Table 2).

We did not identify schemes for arable land. However, in Switzerland, a result-based scheme exists for hedgerows, trees, and bushes along rivers, in which payments are distributed according to the number of species (Swiss Federal Council, 2013).

5.1.2. *Indicator lists focusing on single species*

Several schemes in Germany, Finland, Sweden, and the Netherlands (Underwood, 2014) aim to conserve single species. In some German regions, like North Rhine-Westphalia (Hellwegbörde/Soest) (ABU, 2021) and Bavaria (Würzburg/Franconia) (LBV, 2022), hybrid schemes for harrier nest protection in arable fields have been implemented, with nests of different harrier species in cereal fields as indicators (European Commission, 2022b). Similar schemes are implemented in other German states and the Netherlands, as well as for other bird species such as lapwing or black-tailed godwit who brood in grassland (Jeromin and Evers, 2018).

A purely result-based scheme was implemented in 1996 to protect the endangered wolverine and lynx population in the Sami reindeer herding area in northern Sweden (Zabel et al., 2014). The certified offspring on the reindeer herders' pastures serve as an indicator. The herders are compensated for slightly more than the potential number of reindeers each offspring is likely to prey on during its lifetime (Zabel et al., 2014). The payments are made to the herders' village as a common payment that the inhabitants then distribute amongst each other as they please. Monitoring is carried out by a trained representative from the village who then shows the location of dens or lairs to a ranger from the county managing authority for verification (Unell, 2022). A similar scheme that aims to protect the golden eagle was implemented in Finland in 1998 (Herzon, 2022).

In some German states, high-stem fruit trees are protected by hybrid schemes, such as in Bavaria. (LfL, 2022b, Underwood, 2014). In these schemes, farmers need to follow certain management restrictions and receive payments per high-stem fruit tree once they have reached a certain height and diameter of the crown (LfL, 2022b).

5.2. *Implemented schemes with composite indices*

In addition to the diversity of flowering species, several implemented result-based schemes take other aspects into account, such as different structuring or landscape elements within one land-use type. These schemes differ in complexity. A scheme that covers the whole farm's biodiversity, similar to the program proposed by Hasund (2011, 2013), does not exist. However, there are schemes like the one proposed by Tasser et al. (2019) that aggregate several indices into one index. Examples include the Swiss scheme for pastures and wood pastures, which includes measuring plant species diversity in grasslands using one out of three indicator lists depending on the region and altitude and a threshold of six indicator species (FOAG, 2014b).[20] In addition, the pasture must contain a minimum amount of structural elements, including hedges, brushes, single trees, or piles of rocks (FOAG, 2014b). Two other Swiss schemes using composite indices are those for orchards with high-stem fruit trees and vineyards (FOAG (Swiss Federal Office for Agriculture), 2016a, 2016b). For vineyards, a list of weighted indicator species has been established, and a weighted list of structuring elements such as hedgerows, small water bodies, or single trees (FOAG, 2016b). A vegetation value is calculated from the species present within and at the edges of the vineyard. Similarly, a structuring value is calculated based on the presence of weighted elements in the vineyard and within an area of 10 m surrounding the vineyard (FOAG, 2016b). Payments per hectare are distributed if a certain threshold is met for both values (vegetation and structuring). For Swiss vineyards, only result- but no action-based payments are distributed, which is different from Swiss Grasslands

[20] The scheme includes three lists of indicator species depending on region and altitude; 66, 57, and 41 species or species groups.

Table 2
Summary of the implemented result-based schemes.

Country, Region (Reference)	Objective	Indicators	Unidimensional list vs. composite index	Threshold for Payment
Switzerland (FOAG, 2014a, 2014c)	Protection of biodiverse grassland	Vascular plant species	Unidimensional	6 indicator species on circular areas with a radius of 3 m
Switzerland (FOAG, 2014b)	Protection of biodiverse pastures, protection of biodiverse wood pastures	Vascular plant species, structuring degree	Composite	6 indicator species on circular areas with a radius of 3 m and at least 1 ha of high structuring degree
Switzerland (FOAG, 2016b)	Promotion of diversity of plants and habitats in vineyards	List of weighted indicator species List of weighted structuring elements (e.g., hedgerows and water bodies)	Composite	Minimal number of points for vegetation and structuring elements
Switzerland (FOAG, 2016a)	Promotion of diverse habitats in orchards	- Structuring elements (e.g., water bodies and piles of rocks) - Nesting aids for birds, bats, and bees - Indicator species on grassland	Composite	1 nesting aid per 10 trees + high quality of grassland OR 1 nesting aid per 10 trees +1 structuring element per 20 trees (at least 3 structuring elements in total)
Switzerland (Swiss Federal Council, 2013)	Promotion of habitats such as hedgerows, trees, and bushes in fields and along rivers on farmland	Indigenous tree species	Unidimensional	5 different tree species per 10 m
Germany, several regions*	Protection of biodiverse grassland	Between 30 and 36 vascular plant species or species groups	Unidimensional	Different minimal numbers of species and 2 to 3 payment levels
Germany, several states (e.g., LfL, 2022b)	Protection of high-stem fruit trees	High-stem fruit trees of a certain size	Unidimensional	Minimal size per tree
Germany, several states (ABU, 2021, LBV, 2022)	Protection of three harrier species	Birds' nests	Unidimensional	Yield lost per protected nest
Ireland, the Burren (Burren Programme, 2022)	Conservation of the heritage, environment, and communities of a unique limestone landscape	10 scoring criteria composed of several weighted indicators, e.g., amount of dung present next to a water source, number of plants species in grassland	Composite	A 10-point scoring system, thresholds vary depending on the years of participation
Sweden, northern Sweden (Zabel et al., 2014)	Protection of large carnivores, lynx, and wolverine	Observed new offspring	Unidimensional	Reindeers lost per new offspring
Including France, several states, and parks (Underwood, 2014)	Maintenance of Mediterranean upland grazing areas with mosaic structures of grassland, scrub, rocks, trees, wetlands, or habitats	Indicators designed per site (e.g., percentage of a scrub cover or minimal area of bare peat soil in bog areas)	Composite	Set at the parcel level
Including France, several states, and parks (e.g., DDT des Hautes Pyrénées, 2020, DRAAF Nouvelle-Aquitaine, 2022)	Protection of species-rich grassland	Vascular plant species, mostly flowers	Unidimensional	4 indicator species per field
Austria (ENP, 2022)	Specific objectives per farm or parcel	Indicators are defined specifically per farm or parcel	Composite	Set at farm level

* Seither et al., 2015, LfL, 2022a, Preusche et al., 2019, Most et al., 2014, Horn, 2016, LfULG, 2018, Hochberg et al., 2014.

(Swiss Federal Council, 2013). The scheme for orchards aims at creating habitats for different animals. Besides species diversity in the grassland within the orchard (as defined in Section 5.1.), indicators such as nesting boxes, piles of rocks, or water bodies were defined, of which a minimum number must be present within the orchard to fulfill the criteria for payments (FOAG, 2016a).

One landscape-level scheme is the Irish Burren Programme, which aims to protect a unique limestone landscape on the mid-western coast of Ireland (Burren Programme, 2022). The Burren Programme is a hybrid scheme that includes a result-based payment for winter pastures and lowland grasslands (DAFM, 2018). For the result-based payment, ten criteria were defined, including grazing intensity, amount of litter (dead vegetation), damage around feed sites and water troughs, as well as the extent of bare soil and erosion (DAFM, 2018). To evaluate these ten criteria, indicators are defined for each criterion. The program advisors do the scoring (Burren Programme, 2016). For example, the percentage of sward grazed shorter than 5 cm is included to judge the criterion of 'grazing intensity', while the amount of dung present at the drinking point indicates the impact on natural water sources (thus, linked to the criteria 'damage around feed sites and water troughs'). Like other schemes, a list of indicator species is used to judge the conservation value of grasslands. Unlike in other implemented schemes, these indicator species are weighted according to the frequency of occurrence, i.e., species that frequently occur in grassland are weighted lower than rare species (Burren Programme, 2016). Payments are calculated based on the total score of all ten scoring criteria (DAFM, 2018). There are five payment levels per hectare, whereby the lowest payment level is only enumerated during the first two years of participation. Underperformance (a reduction of the score of more than 20% compared to the first year) or damage caused to habitats or archaeological sites result in recovery of the payments already distributed.

Another scheme that is still in its pilot phase is the "*Results-Based Nature Conservation Plan*" in Austria.[21] It considers local characteristics (ENP (Ergebnisorientierter Naturschutzplan), 2022) and is not limited to a certain land-use type, habitat, or species. Rather, the scheme targets each level ranging from species to farm level. Indicators are defined by an expert in collaboration with the farmer. The scheme aims at promoting biodiversity where a successful outcome is most promising and reasonable and meets the farmers' interests. Thus, for each farmer, a unique scheme specific to the land is designed (ENP, 2022).

[21] Note that we included the Austrian scheme as it runs since 2015, is continued after 2023 under the name "Result-Based Management" within the Austrian Program for the Agricultural Environment (*ÖPUL*) and is extended to 650 farms that can participate from 149 farms participating in 2021 (Mondat, 2021; EBW, 2022).

6. Comparison of proposed and implemented biodiversity indicators

Considering both proposed and implemented schemes, we find that most schemes use simple, unidimensional indicator lists for one land-use type or species (Fig. 3a). Thus, they focus rather on relatively small systems (i.e., species-level or land-use type) compared to larger systems (i.e., farm- or landscape level). A few indicator lists or indices on the level of land-use type are more complex than the rest, with the scheme proposed by Tasser et al. (2019) using the most complex of those. The implemented Burren Programme and the proposed scheme on the farm-level by Hasund (2011, 2013) are the most complex overall (Fig. 3a). The Austrian scheme covers a wide gradient of complexity depending on farmers' preferences as it is flexible in its design.

Furthermore, most schemes are calibrated to a larger regional area and not specific to smaller regional conditions (e.g., soil type, climate, and topography) (Fig. 3b). The schemes focusing on grasslands most adapted to local environmental conditions is the scheme proposed by Šumrada et al. (2021) targeting two distinct grassland types. The scheme proposed by Hasund (2011, 2013) is designed for the whole country of Sweden; thus, it is the scheme that is amongst the least adapted to smaller regional characteristics, whereas the implemented Burren Programme in Ireland and the Austrian scheme are adapted to a very distinct land-use type or designed individually per farm, respectively. Overall, we observe three patterns of proposed and implemented scheme designs: most schemes 1) use rather simple indicator lists 2) are calibrated to larger regional areas and 3) focus on smaller systems.

Furthermore, we observed that older studies propose more often using unidimensional indicator lists. In comparison, newer studies more often propose that biodiversity should be measured based on several other aspects besides plant species diversity to represent the complexity of biodiversity better, and that indicators were be adapted to conditions at smaller regional scales (e.g., Tasser et al., 2019; Šumrada et al., 2021). An exception to this trend is the study by Ruas et al. (2021), which aims to understand how management influences indicator species rather than designing a new scheme. Moreover, Chaplin et al. (2021) proposed two unidimensional indicator lists that are not adapted to local conditions, but their design of the scheme is still novel as it focuses on arable lands. While a shift to more complex and adapted indicator lists or indices can be observed for implemented schemes as well, the majority of the implemented schemes still tend to focus on the species level.

7. Discussion

The decision of what aspect of biodiversity an indicator should represent and the thresholds for when farmers are paid remains a

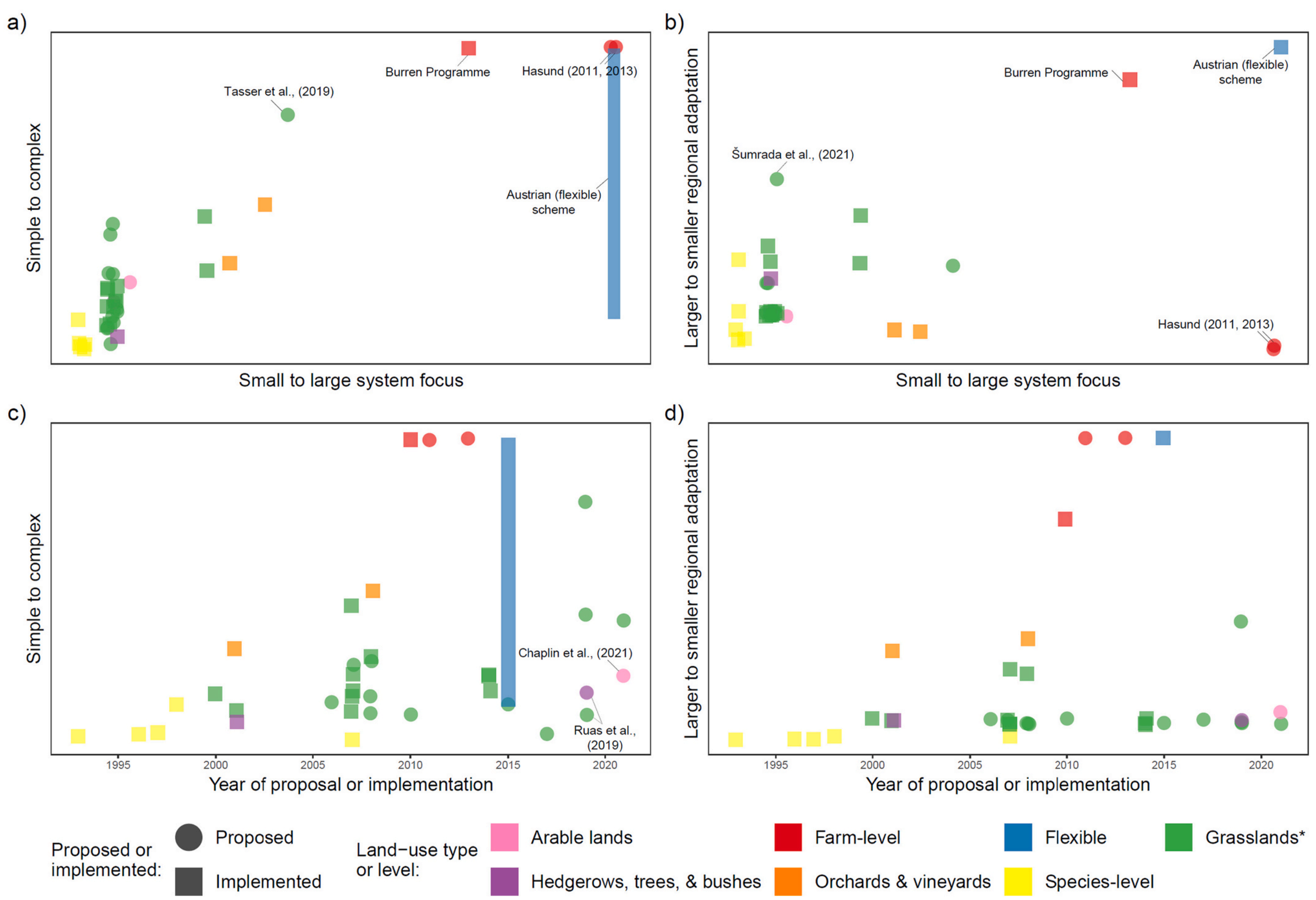

Fig. 3. Overview of the complexity, regionality, system focus, and development over time of schemes and their indicators. Panel a) shows complexity and system focus, b) regionality and system focus, c) complexity over time, and d) regionality over time. Complexity depends on indicator lists/indices and thresholds. Regionality refers to the level of adaptation, i.e., to the smaller vs. larger regional areas. System focus refers to whether the scheme and its indices focus on small (smallest = species level) or large systems (largest = farm-level across land-uses). The ranks in the figure are based on a relative comparison of one scheme and its indicators to the other schemes and their indicators. *Grasslands-focused schemes can also include structural elements and wood pasture (see Table 2). Ruas et al. (2021) did not propose any threshold, therefore, we evaluated the complexity as they would have proposed one threshold. The regional scales; we only include one representation of each for simplicity. For Germany, we included seven state-level schemes. We slightly shifted the scheme indications from their exact coordinates when indications were overlapping.

normative judgment depending on policy objectives, costs, and impact (e.g., Matzdorf et al., 2008; Hasund, 2011). To inform policymakers and improve the biodiversity status, the design of biodiversity indicators for result-based schemes needs to consider how to best represent biodiversity in its complexity and its practical acceptance by farmers. Having indicator lists and indices that consider various aspects of biodiversity and the regional biodiversity potential can possibly better reflect biodiversity. For grasslands, this can, for example, be reached by choosing biodiversity indicators that are, first, designed to reflect not only the number of species but also those of the target habitat (e.g., grasslands with low management intensity) and threatened species and, second, validated based on those criteria. Kaiser et al. (2019) put such an approach forward, which can also be weighted according to policy goals and without changing much of the 'traditional' design of existing schemes. However, their biodiversity indicator list has the drawback of including 71 indicator species, which can reduce farmers' acceptance as field identification can be difficult for farmers or increase costs if it requires botanists (see Section 4.4). Here, future digital solutions, such as smartphone apps, can help to improve monitoring (see Section 8.2).

Moreover, other proposed (e.g., by Hasund (2011) and Tasser et al. (2019)) and implemented indicators and indices (in the Irish Burren Programme as well as a new Irish program (see Section 8.1)) represent several dimensions of biodiversity (e.g., plants, butterflies, landscape elements), which can help improving biodiversity. However, such proposals come with additional monitoring costs, which need to be weighed against their benefits. Bringing these costs down will be important for wider applications of schemes with such indicators, for example, by using satellites, drones, or simulation models (see Section 8.2). Also, considering the regional and ecosystem context can be important to improve biodiversity. For example, the Swiss scheme for species-rich meadows differentiates between two regions (north and south) and within each region between high and medium biodiversity potential. It still needs to be investigated to what degree a differentiation should be made to be i) beneficial for biodiversity and ii) practically feasible. However, if the ecosystems and biodiversity potentials differ between regions (and sub-regions), such consideration could be beneficial for representing biodiversity better. If policymakers decide to consider more local conditions, simulation models might help in the future to provide such information to each farmer (see Section 8.2).

Along with choosing biodiversity indicators, choosing the thresholds to trigger payments is crucial. These thresholds are usually set to a minimal indicator value, such as the minimal number of indicator species per transect, plot, or field. However, they also can be set to a maximal value, such as for a negative list of indicator species. Schemes can vary in the number of thresholds; for example, amongst the implemented schemes with unidimensional indicators, the maximum number of thresholds was three (e.g., in Hesse), for those based on composite indices five, and for proposed schemes with unidimensional indices four (Kaiser et al., 2019). Generally, the higher the number of thresholds, the more precisely it is likely to reflect the biodiversity level of an agroecosystem (e.g., Kaiser et al., 2019). Alternatively, to pay farmers based on thresholds, the number of indicator species could be used to define a "continuous" payment. We identified only two examples using continuous indicators, i.e., the proposition by Hasund (2011, 2013) and the implemented Irish Burren Programme. A higher number of thresholds or using a continuous indicator to trigger payments, can be more precise in measuring biodiversity and encourage to 'produce' higher biodiversity levels than one or few indicators. However, such schemes can also come with higher costs to policymakers and different payment structures. Thus, the choice of the number of thresholds depends on policy objectives.

In the case of composite indices, policymakers need to consider if payments are given based on sub-indices or the composite index. If the payments are provided based on the composite index, the question is if per sub-index, a minimum threshold needs to be achieved or not. For example, the Irish Burren Programme defined five thresholds based on the composite index. The choices policymakers need to make for composite indices and their threshold are complex but should be transparent so that farmers can easily understand them.

When choosing thresholds, policymakers should also consider that some systems (such as grasslands) only slowly respond to changes in management (e.g., Smith et al., 2003). Thus, adding lower thresholds in purely result-based schemes for the first year(s) could make it easier for farmers to achieve the predefined results and participate in a scheme. We identified the only example of such design in the Irish Burren Programme, where the lowest threshold is only valid in the first two years of enrolment. Moreover, models that predict future outcomes based on management adjustment in a given environmental context could be used for a transition period (see Section 8.2). However, whether considering the adjustment time is necessary and to what degree depends on the objectives of a scheme, i.e., whether they aim to conserve existing agroecosystems (such as species-rich grasslands) or to restore them (e.g., from species-poor grasslands with high land-use intensity to species-rich grasslands with low land-use intensity) (e.g., Wittig et al., 2006). In this context, it is also important to consider if and to what degree increasing the number of indicators, thus, reaching a threshold, is under farmers' control (Ruas et al., 2021).

8. Future prospects

8.1. Planned result-based schemes under the CAP reform 2023–27

With the reform of the EU Common Agricultural Policy for 2023–27, substantial additional funds are assigned to the 'Green Architecture', including in forms of 'enhanced conditionality', agri-environmental climate schemes, and the new "Eco-schemes" (Pe'er et al., 2022). In the proposed national CAP Strategic Plans, several member states planned the implementation of result-based schemes (European Commission, 2022a). Countries that planned such schemes to protect biodiversity are, for example, Austria, the Czech Republic, Germany, Ireland, the Netherlands, and Romania. We provide a short description of a few planned schemes (see European Commission (2022c) for an overview of the national CAP Strategic Plans). Austria plans to implement a hybrid scheme for grasslands, where result-based payments depend on whether at least five species are present from a list of over 45 species that are common in species-rich and very fertile grasslands (BML, 2021). With the CAP 2023–27 reform, result-based payments are planned in all German states (part of the Eco-schemes), with a threshold of four regional species that indicate grassland with low land-use intensity but with varying indicator lists and the number of indicators (e.g., 68 indicator species in Brandenburg[22]) (BZL, 2022; GoB, 2022). In states and regions that already had result-based schemes with more than one threshold, such as Baden-Württemberg and selected regions in Hesse, those multi-threshold schemes seem to continue (with the payments related to the four species threshold being then paid under the Eco-scheme) (LLH, 2022, MLR, 2022, personal correspondence[23]).

Ireland plans to incorporate a hybrid scheme for farmers within their new Agri-Climate Rural Environment Scheme (DAFM, 2022). The result-based payments within this hybrid scheme are based on a composite index, and it will be based on a pilot project conducted in 2021 and 2022 (DAFM, 2022; Teagasc, 2022). In the pilot program, farmers could enroll between 2 and 10 ha of land and were paid based on a score ranging between 0 and 10 that should indicate the sustainability of agricultural grasslands. The score is constructed from either the "low-input grassland scorecard" or the "multi-species ley scorecard" (Teagasc, 2022). The low-input grassland scorecard consists of different aspects, including

[22] The first assessment of those indicators is planned to be done by experts (Bauernzeitung, 2022).

[23] The contact was with an employee of the Hessian Ministry for the Environment, Climate Protection, Agriculture and Consumer Protection.

positive and negative indicator species, their cover, evidence of damaging activities to the field, and structural elements (e.g., water-courses, hedgerows, and dry-stone walls) and their conditions (REAP, 2021a). Whereas the multi-species ley scorecard focuses on leys and includes points for the number of sown legumes and herbs, balanced vegetation structure, structural elements, and their quality, the cover of negative indicators species, and evidence of damaging activities to the field (REAP, 2021b).[24]

We see increasing interest in result-based schemes and that the planned result-based schemes in the EU differ in their approaches, ranging from schemes using vascular plant species with varying number of indicators and thresholds to those using composite indices. We also see that indicator lists similar to those proposed (Kaiser et al., 2019) are planned as an example of evidence-based policy making.

8.2. Possibilities to improve indicators and scheme design

The emergence of methodological, technological, and other advancements can help to improve the design and monitoring of biodiversity indicators. These advancements include using simulation models, digital solutions, and eDNA-barcoding.

8.2.1. Modeling indicators and results

Modeling can contribute in two ways to design indicators for result-based payments. First, by defining the most suitable indicators for a specific area based on a modeled biodiversity potential depending on the local environmental conditions. For this, farmers could, for example, insert spatial data, such as soil characteristics and climate into an app that then returns a list of biodiversity indicators[25] (following Bartkowski et al., 2021).[26] This would allow defining biodiversity indicators more closely linked to the area's environmental conditions than most current approaches where indicators are defined on larger regional scales (e.g., at the state-level). These indicators could be on the land-use type- (i.e., indicator plants) or farm-level (i.e., size of patches or landscape diversification) and focus on biodiversity by itself or provision of specific ecosystem functions.[27] Moreover, modeled indicators could be more flexible when adjusting to climatic changes. However, whether farmers would accept such indicators requires further investigation.

Second, models could be used to simulate the plot-specific outcome of biodiversity indicators depending on farmers' land-use and management decisions (Bartkowski et al., 2021).[28] Here, farmers could insert their land-use and management options next to environmental data into an app. Moreover, modeled outcomes could facilitate the inclusion of mobile species (such as birds) into result-based schemes as location-specific observations can be unreliable (e.g., Zipkin et al., 2010). The use of simulation models and apps for assessing indicators can reduce costs (including transaction costs) and risks for farmers (as payments are not distributed according to physical results but according to model calculations), hence, increasing farmers' willingness to participate in a scheme (Bartkowski et al., 2021). On the other hand, complex modeled assessments compared to physical assessments of indicators can be more abstract and less transparent, which can reduce farmers' willingness to participate in schemes.[29]

Whether modeled indicator lists and indices or outcomes will be preferred compared to the currently used methods for result-based payments depends on the precision of the model prediction of biodiversity (indicators) as well as on the required data input. In grasslands, for example, increasing plant species diversity can take several years and depend on many biotic and non-biotic factors (e.g., Smith et al., 2003; Kleinebecker et al., 2018; Clark et al., 2020), which can make the prediction of outcomes difficult. Sufficiently precise and data parsimonious models that would predict biodiversity outcomes to trigger farmers' payments are currently unavailable to our knowledge. Predicting other outcomes than biodiversity (indicators) for result-based schemes, such as soil functions or abatement of nutrient runoffs at the plot-level, might be more likely to be feasible in the near future (Sidemo-Holm et al., 2018; Bartkowski et al., 2021).

Finally, simulation models could also be used to model outcomes at the landscape-level, which is often assumed to be highly relevant for reaching biodiversity goals (e.g., Marja et al., 2022). In turn, such an approach could theoretically also be linked to landscape-level payments (see Ehlers et al. (2021) on the discussion of digitalization and payments at the landscape-level). For example, if multiple farmers apply together as a cooperative for result-based payments (see, e.g., Terwan et al. (2016) for action-based payments at the landscape-level). However, efforts are needed to investigate how such schemes can be designed and implemented in practice and whether precise enough predictions at the landscape-level are even possible.

8.2.2. Digital solutions to facilitate assessments

Digital solutions are so far rarely considered for assessing biodiversity indicators and indices for result-based schemes; however, they might be implemented at low costs. The digital options include using smartphone apps, drones, and satellites.

User-friendly smartphone apps already on the market could help identify plants with high accuracy and little time requirements. For example, the app "Flora Incognita" can identify 4851 plant species with an accuracy of 83% based on only one uploaded image and an accuracy of 93% based on several images (Mäder et al., 2021). Moreover, this app also provides information about prediction accuracy. The accuracy reached in the species assessments for results-based schemes would likely be even higher because the number of species that need to be recognized is limited (e.g., up to 49 species (groups) for meadows in Switzerland or 71 in the proposed scheme by Kaiser et al. (2019)) and species in most current implemented and proposed schemes (for grasslands) are also selected to be easily identifiable. The methods used in these apps are often based on deep learning (Mäder et al., 2021). Thus, the accuracy would improve with more pictures of the same plants. The required minimum prediction accuracy of apps to be used in schemes finally depends on the decision of policymakers. Furthermore, by time- and geotagging and uploading the plants' images onto a database, the presence of the plants on the field can be verified, costs can be reduced, and payments can directly be triggered. Slow internet in rural areas might restrict the current use of such apps (e.g., Finger et al., 2019), hence, such apps will benefit from increasingly available fast mobile internet in rural areas in the future. In the meanwhile, apps could benefit from recognizing species offline or indicating if the picture quality is high enough that the species are likely to be identified.

Currently, cameras and sensors attached to drones are used in agricultural research, for example, to estimate nitrogen content in plants (e.g., Walter et al., 2017; Finger et al., 2019; Argento et al., 2021) or to distinguish plants from soil (e.g., Hamuda et al., 2016). One main

[24] Other planned schemes are those in the Netherlands and Romania, aiming to conserve rare farm animals and local breeds of risk of abandonment (MADR, 2021; MANFQ, 2021). The Netherlands plans to pay farmers when at least five livestock units of rare cattle breeds or one and a half livestock units of rare goat and sheep breeds are on the farm (MANFQ, 2021). Note that these schemes are not directly linked to our research question (i.e., see eligibility criteria in Section 3.1).

[25] Such a list of biodiversity indicators could also be a sub-list from a list of biodiversity indicators for a larger region.

[26] Bartkowski et al. (2021) suggested modeling environmental results for paying farmers to protect and enhance soil functions.

[27] Note that amongst ecosystem functions and biodiversity provision, tradeoffs can exist.

[28] We classified schemes that are based on modeled results also as result-based as they are explicitly based on site-specific outcomes.

[29] For example, experience with index insurances showed that farmers prefer simpler over more complex options (e.g., Patt et al., 2010).

challenge is distinguishing between different plants (e.g., Yang et al., 2021b). Until now, woody species in grassland can be detected with high accuracy (Oddi et al., 2021), but identifying other plants such as forbs or graminoids, with exceptions, remains difficult (Hung et al., 2014; Michez et al., 2016; Yang et al., 2021b). However, the fast evolution of such technologies might allow the identification of more species in the near future (Librán-Embid et al., 2020) as well as benefit from the limited number and easily identifiable species that need to be recognized under result-based schemes. An approach that can be applied in the short-term is the manual identification of indicator species on images taken with drones. Sun et al. (2018) flew a drone equipped with a camera 2 m above a grassland. The resolution of the images was high enough to identify most species (Sun et al., 2018). It would also be possible to take the images during the flowering seasons and evaluate them later, potentially saving time compared to ground-based field surveys (Sun et al., 2018).[30] Moreover, such an approach might be especially suitable for large-scale monitoring of heterogeneous grasslands and could measure species abundance next to the number of different species (Sun et al., 2018).

Satellite imagery is generally unsuitable for identifying species because the resolution is too low, though it is sufficient to evaluate ecosystem diversity or landscape structure (Librán-Embid et al., 2020). Thus, satellite and drone images are viable options to assess field sizes, borders between fields and forests, water bodies, and hedgerows. For some elements (e.g., riparian strips), such images might even allow the assessment of ecological quality (Novoa et al., 2018). Moreover, satellite and drone images are well-established and might be implemented at low costs.

8.2.3. eDNA-barcoding

An alternative option to efficiently identify indicator species in grassland could be the analysis on a genetic level. eDNA-barcoding is a method that allows the identification of a great number of species within a sample by using one or several genetic markers (Saddhe and Kumar, 2018). A big advantage is that the sampling time is irrelevant because no flowers are needed to identify the plants in contrast to visual techniques. Two major hurdles that would have to be overcome are developing suitable markers and sampling methods that are cheap and practical enough to be applied in result-based schemes. Although markers for plant communities exist (Creer et al., 2016), their accuracy might still be limited (Saddhe and Kumar, 2018). However, since the number of indicators for result-based policies is limited, an option might be to use a bigger number of more sensitive markers. Possibilities for an efficient sampling method could be sampling a cross-section of the haystack or sampling along transects of a field. Another method tested recently by Palumbo et al. (2021) is the sampling of cow manure. However, while eDNA-barcoding has potential, it requires substantial advancements (e.g., in terms of occurrence, costs, and usability) before it can be applied to monitor biodiversity indicators for result-based schemes.

9. Conclusion

We provided an overview of the current state of proposed and implemented biodiversity indicators for result-based agri-environmental schemes by reviewing and comparing those indicators. Moreover, we presented examples of planned result-based schemes under the CAP 2023 to 2027 reform and future prospects of design and assessment of those indicators drawing on technological advances. We found that indicators in proposed and implemented result-based schemes range from single species to whole land-use types and from unidimensional to composite indicators. The schemes using these indicators target the conservation of single species, ecosystems, whole farms, or landscapes. Most proposed and implemented schemes use vascular plants as indicators of biodiversity-rich grassland. These schemes are simple to implement and comprehensible for all stakeholders. However, biodiversity indicator lists and indices with lower complexity and generalization over too large regions can reduce the representation of biodiversity in its complexity.

Our review highlights important policy implications for the design of result-based schemes and choosing between biodiversity indicators. First, policymakers need to ask themselves which aspects of biodiversity they want to represent by their biodiversity indicators. Covering more aspects of biodiversity will often come at higher costs. However, in some cases, integrating a more nuanced biodiversity perspective in the indicator design can be inexpensive, e.g., considering the number of species of a certain target habitat (e.g., grasslands with low land-use intensity) and threatened species next to simply the number of species. Furthermore, while most schemes are based on vascular plants for their indicators, policymakers can extend this by considering other taxa and structural as well as landscape elements. Moreover, while the acceptance of indicators by farmers is important, so is their evidence-based selection. Second, policymakers need to clarify if their objective is to conserve existing or restore lost biodiversity. Depending on these objectives, different indicator lists and indices are required. When the objective is to restore grasslands, it is important to consider that it is in farmers' control to increase the number of indicators and that responses might take time. Schemes with lower thresholds in the first year(s) when farmers enter them could be an option to consider the lagged response of outcomes. Third, setting the number of thresholds and the threshold values is an inherent normative decision. Policymakers face the trade-off that a higher number of thresholds can increase biodiversity while also cost increases. Finally, with digitalization and more available data, new tools for policymakers to design and assess indicators are developing – even if many of them will take some time before they are ready for use. Tools that could, with some effort, soon be ready for use in result-based schemes are smartphone apps that enable farmers to self-assess indicators. Policymakers should consider all these implications when designing new result-based schemes, such as under the CAP reform 2023–27.

Our study highlights several important future research areas: First, more propositions of result-based schemes for other land-use types than grasslands. Second, more propositions of how the number of thresholds and their value can be selected. Third, suggestions of how biodiversity indicators can include higher levels of complexity while maintaining a cost-efficient and effective design. Fourth, expanding the perspective to species' functional values and ecosystem functions. This expansion could help restore and conserve ecosystems and reach policy objectives. Five, clarify how new digital technologies, such as smartphone apps, can be implemented in practice, and evaluate farmers' willingness to participate in schemes based on such technologies.

Authors' contributions

Noëmi Elmiger and Sergei Schaub conceived the ideas. Noëmi Elmiger and Sergei Schaub collected the data. Noëmi Elmiger synthesized the data. Noëmi Elmiger and Sergei Schaub led the writing of the manuscript. Sergei Schaub led the revision of the manuscript. All authors contributed critically to the drafts and gave final approval for publication. Noëmi Elmiger and Sergei Schaub equally contributed to the paper.

Declaration of Competing Interest

The Authors declare that there is no conflict of interest.

Data availability

Data will be made available on request.

[30] Economically quantifying those benefits will be important future tasks.

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Appendix A. Supplementary data

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