Payment by results as an approach to enhance effectiveness of pollinator promoting subsidies

Deliverable D4.4

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Safeguard
Safeguarding European wild pollinators

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Summary

In this deliverable, we first summarize the results of three case studies on the application of PBR in Switzerland (original study carried out within the Safeguard project), UK (Chaplin et al. 2019) and Romania (Page et al. 2019). We then focus on the key knowledge gaps hampering the applicability of PBR schemes in practice: evidence that simple pollinator indicators provide meaningful information about pollinator biodiversity. For this purpose, we performed a large synthesis study using primary data from across Europe to identify effective indicators of wild bee diversity across different habitats. Based on the promising results of this analysis we proposed a flexible protocol to measure these indicators in the field. We focused on wild bees as they are the most taxonomically complex and challenging group of pollinators and represent the most dominant and important taxa for crop and wild plant pollination across agricultural landscapes. Although butterflies are considered good potential bio-indicators as they are easy to identify, previous research indicates that they have little predictive power to explain the diversity of other pollinator taxa. Concerning hoverflies, we could not find a body of literature sufficient to perform a robust synthesis study at the European scale. Here, we collated a large dataset of published and unpublished primary data on bee communities sampled in different habitats across Europe. Our general aim was to identify indicators of high species diversity communities. Using a quantitative meta-analysis, we tested whether simple metrics such as the total wild bee abundance (excluding *Apis mellifera*) or the abundance of bumblebees could predict the species diversity of wild bees. We also tested whether the sampling method (direct observations with transects vs. trapping) and the habitat type modified the performance of the candidate indicators across Europe. The meta-analysis showed that total abundance of wild bees was a very strong predictor of total wild bee diversity across different habitats and sampling methods. The average correlations within habitats were all above 0.75. The indicator performance was consistent across different environments and sampling methods. Using bumblebee abundance as indicator of total wild bee diversity was also supported by our analysis. However, the correlations were lower than those related to total abundance. Averaged correlations varied between 0.47 and 0.65 depending on the habitat and sampling method. We also observed a trend for stronger correlations in forest than in other habitats and in transects compared to pan-traps. We found a trade-off between predictive power and implementation easiness for the two candidate indicators. Concerning the sampling method, as PBR schemes are usually aimed to improve habitat quality at the local scale (e.g. a single meadow, margin, or pasture), we suggest to use transect counts. If it is possible to properly train the famers, total abundance of bees should be preferred, while if training is a constraining factor, the abundance of bumblebees can be used. However, one should consider that the predictive power of this indicator is not sufficient to detect subtle changes in species diversity. Finally, we provide practical guidelines on how to implement the indicators at the regional scale.

List of abbreviations

PBR	Payment-by-results

1. Introduction

Agro-environmental measures (AEM) have been an important tool to try to halt biodiversity decline across agricultural landscapes (Burton and Schwarz, 2013). Still, traditional AEM, which pay for measure implementation have shown mixed results over the years and their cost effectiveness was put into question (Burton and Schwarz, 2013; Chaplin et al., 2021; David Wuepper and Robert Huber, 2022; Matzdorf and Lorenz, 2010; Uthes and Matzdorf, 2013). Payment-by-Results schemes (PBR) have been proposed as a potentially more effective approach (but see (Verhulst et al., 2007). PBR schemes seek to improve environmental outcomes by imposing a set of key indicator species which the farmers need to achieve in order to be eligible for the payment (Uthes and Matzdorf, 2013). In this case, the farmer has to meet a certain ecological outcome, instead of applying a certain farming practice (Chaplin et al., 2021; Schroeder et al., 2013). Since their introduction, the popularity of the PBR schemes has increased among farmers and the general public is also more inclined to accept spending money for the PBR because the farmers receive the money only if they achieve the expected results (Burton and Schwarz, 2013; Schroeder et al., 2013)

There are multiple reasons why PBR schemes have gained attention over the years. Since the results and payment are linked farmers have the control and responsibility to deliver the set results using their own land management options. Hence, they feel that they play a major role in the conservation, which could promote behavioral changes and improve the outcome of the payment scheme (Chaplin et al., 2021; Matzdorf and Lorenz, 2010). In PBR, the farmers also have the flexibility to use any management method in order to achieve the desired results. This can make the payment scheme an integral part of the farming process, not just another set of rules that need to be followed (Chaplin et al., 2021; Uthes and Matzdorf, 2013). Moreover, the PBR schemes can motivate farmers to innovate in order to achieve higher environmental outcomes and to receive a higher payment, thus increasing the cost effectiveness of the scheme (Burton and Schwarz, 2013; Chaplin et al., 2021; Matzdorf and Lorenz, 2010). Another reason why farmers might opt for PBR schemes is because they perceive them as less risky as opposed to action based payment schemes. If the indicator species are well defined and the farmers receive a certain degree of training, then they can also self-monitor their fields reducing the monitoring costs (Burton and Schwarz, 2013; Chaplin et al., 2021; Schroeder et al., 2013).

Indicators are therefore a central component of PBR schemes. Indicators should be cost effective tools that are easy to measure but still provide meaningful information to decision makers (Siddig et al., 2016). Within a biodiversity context, this means that indicators should be species or species groups that are easy to recognize and to quantify and whose abundance correlates well with overall species richness of sites. For PBR schemes to effectively enhance biodiversity or species richness of the targeted species group, the choice of indicators is of upmost importance (Matzdorf et al., 2008; Wittig et al., 2006). Task 4.4 aims to develop new indicators for pollinators using flagship species and test the performance of these indicators for predicting pollinator community response in terms of abundance and diversity. We build upon experiences from existing PBR schemes running in Romania, Switzerland, UK and Germany. Indicators should be relatively easy to be measured by farmers or other operators with only a minimal training (Matzdorf et al., 2008; Wittig et al., 2006). We found that most research carried out in with respect to pollinator indicators specifically focus on this particular aspect: the ability of citizen scientists to identify pollinator indicator species or species groups (Le Féon et al., 2016; Mason and Arathi, 2019; O’Connor et al., 2019; Ratnieks et al., 2016; Roy et al., 2016). Results of these studies suggest that volunteer recorders can identify the selected indicators in the different region and provide data that can produce meaningful results, although the quality, taxonomic resolution is generally lower than data collected by scientists. This in turn reduces the reliability of observed trends and relationships with environmental variables. Surprisingly little attention has been given to the question whether a selected indicator species or species group correlates well with overall biodiversity of pollinators (Segre et al., 2023).

In these deliverable, we first summarize the results of three case studies on the application of PBR in Switzerland (original study carried out within the Safeguard project), UK (Chaplin et al. 2019) and Romania (Page et al. 2019). We then focus on the key knowledge gap hampering the applicability of PBR schemes in practice: evidence that simple pollinator indicators provide meaningful information about pollinator biodiversity. For this purpose, we performed a large synthesis study using primary data from across Europe to identify effective indicators of wild bee diversity across different habitats. Based on the promising results of this analysis we proposed a flexible protocol to measure these indicators in the field.

2. Regional case studies

In the next sections we will present three case-studies and to analyse and identify limitations of current PBR schemes for pollinator conservation.

2.1. Swiss case study – The potential of the Swiss payments by results scheme for meadow extensification in promoting bee pollinator diversity

2.1.1. Background and aim of the study

In Switzerland, ecological focus areas (EFAs) have been implemented in the framework of the Swiss agri-environment scheme in a tiered approach from 1993 (action-based) and 2001 (result-based) onwards. Result-based EFAs have the same minimum management requirements as action-based EFAs, but can be voluntarily improved by farmers to achieve minimum local-scale biodiversity targets, which is assessed based on the presence of plant indicator species considered to reflect the ecological quality and potential of a local EFA to promote biodiversity (see Table 1). Thus, farmers receive additional subsidies if a minimum number of indicator plants occur in a local focal meadow considered to indicate overall high plant species richness, ecological quality and high potential for promoting biodiversity (BLW, 2013).

However, it remains unclear whether the expected higher ecological quality of extensively managed meadows in Switzerland fulfilling the additional criteria of the payments by results scheme also more effectively promotes pollinators diversity compared to the basic action-based meadow extensification scheme or conventionally (intensively) managed meadows not under any scheme. The aim of this study was to address this research gap. In essence this study therefore indirectly examined whether scoring higher on the presence of plant indicator requirements was reflected in the pollinator community.

Table 1: Management prescriptions for the studied basic action-based Swiss agri-environment scheme meadow extensification (i.e., extensively managed meadows) and criteria for additional direct payments through a results-based scheme (payments by results) based on the presence of required plant indicator species indicating high ecological quality and potential value for biodiversity.

AES meadow type	Action-based criteria	Criteria PBR scheme
Extensively managed meadow	No use of fertilizer and pesticides, mown at least once each year but not earlier than a set date (15th of June in the Swiss lowland study region), the cuttings must be removed.	Required plant indicator species present in the core area of a focal meadow. At least six of plant species listed (see list and decision tree shown in Appendix 1) must be present.

2.1.2. Methods

The study was conducted in a total of 28 agricultural landscapes in the Northern Swiss Plateau in the canton of Aargau. Landscapes represent the typical mosaic-type agricultural landscapes consisting of grasslands, crops, semi-natural habitat remnants (e.g., forest remnants) and settlements. Bees were sampled through standardized transect walks in each of three types of permanent meadows: (i) intensively (conventionally) managed meadows, (ii) extensively managed meadows managed according the basic action-based scheme for meadow extensification of the Swiss agri-environment scheme and (iii) extensively managed meadows under the payments by results scheme, for which farmers received additional subsidies if focal meadows achieve minimum quality requirements based on the presence of a list of plant indicator species (Table 1). Intensively managed meadows in the study regions are fertilized, typically receiving 150–200 kg ha^{-1} nitrogen each year and are mown up to five or six times per year if weather conditions are suitable, the first cut mostly taking place in May (Albrecht et al., 2023). Bees were sampled in a total 54 intensively managed meadows, 17 extensively managed meadows under the action-based basic scheme and 53 meadows under the payments by results scheme. Up to eight (sub-)transects of 40 m length and 2 m width were walked during a total of 4 min and 30 sec per 40 m sub-transect (excluding the time required for the handling of collected bees) per meadow type and landscape during two sampling rounds in June and July 2022. All bees that could not be identified in the field were collected and identified at the species level by an expert bee taxonomist. To account for slightly varying numbers of transects walked per meadow type and landscape, standard rarefaction methods using the *R* package *iNEXT* (Hsieh et al., 2016) were used to estimated bee species richness. Generalized linear mixed-effect model analysis (using a negative binomial error distribution to account for overdispersion in the data) with meadow type as explanatory variable and landscape ID as random factor was used to analyse the data.

2.1.3. Results

A total of 1927 wild bee individuals representing a total of 64 species were sampled. The average estimated species richness was highest in the results-based scheme meadows, and lowest in the intensively managed meadows, while the basic action-based scheme showed intermediate mean estimated species richness values (Fig. 1). Preliminary results from linear mixed-effect model analysis indicate a significant effect of meadow type on estimated species richness (log-likelihood ratio test: $P < 0.001$). However, variation in estimated bee species numbers was relatively high within each meadow type, and statistically significant differences were only found between the payments by results scheme meadows compared to intensively managed meadows (Tukey post-hoc test: $P < 0.001$).

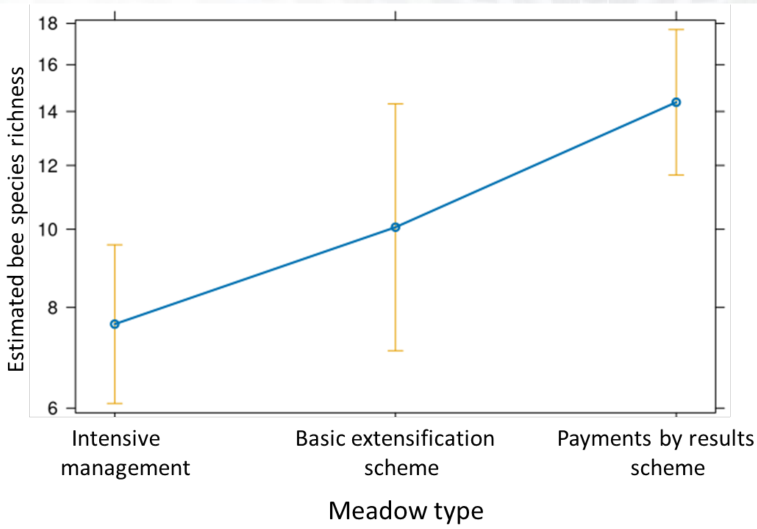

Figure 1. Estimated mean (± 95% confidence intervals) number of wild bee species in each of the three studied meadow types: (i) intensively managed meadows ("intensive management"), extensively managed meadows managed according to the prescriptions of the basic action-based agri-environment scheme for meadow extensification ("basic extensification scheme") and (iii) extensively managed meadows under the payments by results scheme ("payments by results scheme"; based on the presence of required plant indicator species; see Table 1).

2.1.4. Conclusions

The preliminary results of this case study suggest that the Swiss payments by results scheme for meadow extensification is associated with a higher bee pollinator diversity than the basic action-based scheme when compared to intensively managed meadows, with an almost twice as high estimated number of species found on average in meadows under the results-based scheme compared to intensively managed meadows. However, it needs to be noted that also the meadows under the results-based scheme had to fulfill the basic management prescriptions for extensively managed meadows (e.g., no fertilizer input, delayed firs cut) of the action-based scheme, but additionally harboured the required indicator plant species considered to represent plant-species rich meadows of high ecological quality. Furthermore, the present study focused on assessments of pollinator diversity in meadows during the summer months for which meadows play a particularly important role in providing floral resources for bee pollinators as this period is typically associated with most pronounced floral resource scarcity when most woody flowering plants and crops are not anymore flowering (Ammann et al., 2024; Bertrand et al., 2019). Nevertheless, future studies should assess the role of the studied meadow types also during spring. Moreover, it remains to be explored, which factors contributed to the local presence of these plant indicator species in an extensively managed meadow, for example whether management intensity was lower in such payments by result scheme meadows (e.g. further delayed first cut, reduced mowing frequency; or management was adapted in any other way by farmers to achieve an increased ecological quality), or to what extent rather local environmental conditions and given meadow properties (e.g. exposition, slope, soil and microclimatic conditions) contributed the presence of these indicator plant species. Finally, it remains to be explored whether alternative sets of indicator species could be more suitable to assess the potential of meadow to promote pollinator diversity.

2.2. UK case study – PBR Pilot for agri-environment schemes including species rich grassland and provision of pollen and nectar resources for pollinators (Chaplin et al. 2019)

2.2.1. Background and aim of the study

This pilot trial was carried out by Natural England and the Yorkshire Dales National Park Authority. It ran for three years with data collection taking place in 2017 and 2018. The aim of the study was to test the performance of a results based payment scheme against a set of control sites for several agri-environmental schemes. Specifically, the project quantified the environmental performance of the scheme, tested the accuracy of farmer self-assessment and explored the cost effectiveness of the result-based approach. The study involved comparing agri-environment schemes for four environmental outcomes including ‘habitat for breeding waders’, ‘provision of winter bird food’, ‘species rich hay meadows’ and ‘provision of pollen and nectar resources’. Here we focus on approaches and results associated with the latter two outcomes as these are potentially directly relevant to pollinators.

2.2.2. Methods

The study took place in East Anglia, Norfolk and Suffolk for the ‘provision of pollen and nectar resources’ PBR trial, and Wensleydale, North Yorkshire, for the ‘species rich hay meadow’ PBR trial. A call for expressions of interest for participant farmers was made within each region and 11 farms with 19 suitable habitat plots for species rich grassland, and 11 farms with 11 plots were selected for the pollen and nectar, were identified for the trial. Using a range of existing data sources within the target area boundaries, a series of control plots were also identified which included the same habitats but with no PBR scheme introduced. Participating farmers were then introduced to the PBR scheme and provided extensive advice on maximising environmental outcomes from each habitat type. Advice and training was provided through face to face farm visits, farm walks and training events.

Farmers were then asked to apply management approaches they thought appropriate to maximise the quality of the habitat. The objective for pollen and nectar plots was for good cover of flowering plants, minimising the amount of bare ground and grasses, as well as a wide range of different flowering species which produced pollen and nectar attractive to a wide range of pollinators at different times of year. For the species rich hay meadows, the objective was to maintain or enhance the diversity of plant species through sustainable agricultural management.

Farmers were then required to apply a protocol to self-assess the outcomes. For this PBR scheme the relative success of habitat management was based on metrics of the plant communities recorded in each habitat. For the pollen and nectar plots, farmers were required to deploy 10 random 1m quadrats across the plot and record the presents or absence of a predefined list of plant species, as well as record % cover of all flowering plants in each quadrat. For the species rich hay meadows, farmers were asked to walk a diagonal transect across the site, stopping 10 times to record the presents or absence of key positive and negative indicator plants species. In addition, they were asked to score damage and disturbance to the plots. A score was then calculated based on the results generated and a payment structure adopted with equally spaced payment rates, tiered for each habitat type. During the project researchers carried out the same survey approaches on the study and control plots to allow for comparison. Participants were also asked to complete a survey at the end of the project to provide feedback.

2.2.3. Results

Pollen and nectar plots involved in the PBR scheme performed better than the control sites with 15% higher scores on average (Figure 2). The species rich meadow sites exhibited an average 24% increase in quality score relative to the controls over the 2 years with improvements on all but 2 sites. Scores recorded by farmers and researchers were similar, with pollen and nectar provision and hay meadows (Table 2) resulting in the same payment tier 68% and 66% of the time respectively.

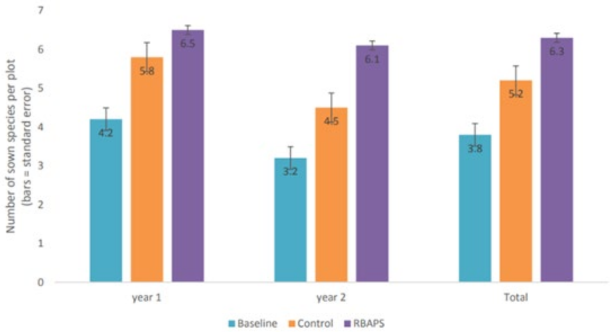

Figure 2 Number of target species recorded per pollen and nectar plot recorded before the study began and in PBS scheme and control sites.

Table 2. Mean percentage presents and absence of indicators recorded in species rich hay meadows by farmers and researchers (advisors) in year 1 and 2 of the PBR scheme.

Indicator species	% occurrence			
	Year 1		Year 2	
	Adviser	Farmer	Adviser	Farmer
Sweet vernal grass	91.1	76.2	97.4	93.2
Red clover	86.3	84.6	94.7	91.1
Ribwort plantain	72.6	67.7	74.7	77.9
Yellow / hay rattle	60.5	57.7	64.7	69.5
Pignut	48.4	57.7	80.0	75.3
Hawkbits	26.8	24.6	31.6	27.9
Eyebrights	18.9	23.1	20.5	23.7
Vetches	5.8	21.5	8.9	8.4
Greater burnet	5.3	6.2	5.8	5.8

2.2.4. Conclusions

This conclusion reflects points raised by the researchers and their implications for a PBR scheme focussed on pollinators. Firstly, it was identified that proxy indicators need to be extensively tested in the field to ensure they reflect the desired environmental outcomes. In this case they are referring to plant communities but the same is also true for pollinators. Robust metrics of pollinator communities would be necessarily recorded whether this was measures of abundance, richness or the use of pollinator indicators species.

Secondly, it was concluded that some measures, such as % cover in this study, are more subjective and more likely to vary between individuals carrying out the recording. When surveying insect pollinators such subjective measures are less common. For example, presence or absence of indicator species, species richness and abundance cannot be considered subjective.

Thirdly they conclude 'result indicators which are very sensitive to weather conditions should only be used where potential management interventions are available to directly influence these characteristics'. This is particularly pertinent to a PBR scheme based on recording pollinators. Pollinator activity is very weather dependent with fewer species and individuals recorded in poor weather (cold and/or wet). This factor would certainly have to be taken into consideration for a pollinator PBR scheme for example by setting minimum weather conditions under which assessment can take place.

Finally, the need for extensive training and advice to deliver the self-assessment process was highlighted. The same would be true for assessing pollinators. Training for many elements of a scheme would be straightforward including carrying out transects or timed observations and completing recording sheets. However, pollinator species identification could present a barrier, and in some regions would be more challenging than for plants. This could be addressed through the use of broad pollinator groups or recognizable species, but the relevance of these as proxy would need to be quantified.

2.3. Romanian case study – PBR Pilot for agri-environment schemes including species rich grassland and provision of pollen and nectar resources for pollinators (Page et al. 2019)

2.3.1. Background and aim of the study

A Payment by Results pilot project took place in Romania between 2015 and 2019. It was implemented by the ADEPT Foundation and it focused on two areas where High Nature Value Grasslands are present at a landscape level, Târnava Mare, which is a continental biogeoghraphic region and Pogany Havas, which is an alpine biogeographic region. Moreover the areas have been well-studied over a 10 year period from both ecological and socio-

economic points of view. In addition, the measures implemented in the pilot phase of the PBR scheme are a direct solution to some of the threats identified by the National Rural Development Programme (NRDP).
The key need of both areas selected for the pilot phase is to maintain and support traditional random/small-scale/mosaic management, this implies that farmers need the payment infrastructure which will allow them to adapt to annual variability of seasons. The previous iteration of our NRDP (2007 – 2014) did not take into account this need of the farmers, which resulted in payment schemes with requirements that hindered too much the activity of the farmer (ex. fixed dates for activities at a landscape level). This lead to the farmer's incapability to respect the requirements of the payment scheme or for them to actually lose money, because the payment scheme would not compensate them enough. This scenario could have been avoided by applying a results based payment scheme, instead of a management based one.
The objectives of the pilot study were:

- To design, develop, use and test result-based remuneration schemes to conserve and enhance biodiversity.
- Increase the understanding of the factors that contribute to the success or failure of such schemes.
- Identify opportunities and conditions for increasing the use of such schemes in Romania and in the EU more widely, especially in future CAP Rural Development programmes.
- Demonstrate the potential of these schemes to achieve ecological targets, using monitoring of indicators in pilot measure participant and control grasslands.
- Increase the understanding of the benefits of PBR schemes within the rural community.
- Promote PBR schemes within the Romanian Ministry of Agriculture & Rural Development (MARD) and Ministry of Environment (MoE), based on results achieved.

2.3.2. Methods

First step of the project was to create a floristic inventory from which to select indicator species. In total 321 transects were carried out in both regions, in both hay meadows and pastures, which were identified by stratified random sampling, assisted by a GIS expert. In the end, indicator species were selected only for hay meadows because of the following reasons:

- these are the grassland habitats with the highest plant species richness and at the greatest threat of land use change
- they have more homogeneous vegetation, making them more suitable for assessment with results indicators
- they are smaller and have generally only a single owner (compared to communal ownership of many pastures), making them more suitable for the limited budget and intensive supervision of each owner/manager within this pilot scheme.

After all the refinements to the list of indicator species were made, the list contained 30 floristic species. The selected species only grow in hay meadows managed at low intensity and are associated with high plant and animal species richness as well as good quality hay. Moreover, the species are easy to recognized by the farmers and if two or more species were looking similar then they were grouped together and the group counted as a single indicator. The locations were monitored for three years, in order to ensure the robustness of the selected species.
The payment was divided into three levels, depending on the number of indicator species found on the transect (5, 8 and 10 indicator species). The farmer with 10 indicator species would get a higher pay/parcel, while the farmer with 5 species would get less. This graded payment scale was selected in order to help to prevent decline of moderately species-rich

grasslands and also provide an added incentive to maintain the most ecologically valuable areas in good condition. For the calculation of compensation it was assumed that the higher the number of indicator species, the greater the cost incurred by the farmer. The calculations were based on income foregone and additional costs if ideal management was carried out, and transaction costs – the costs to the farmer of learning the methodology, plant identification, and doing his own controls, as required under the measure.

The monitoring methodology followed by the farmers was the same as the one used by specialists to determine the indicator species. The transect was 100 m along the longest diagonal of the parcel (excluding the first 3 m from the edge of the parcel) and then the transect is divided into 3 sections of equal distance. The indicators were recorded within 1 m on either side of the transect. In order for the farmer to be eligible for payment each section of the transect must contain at least 5 indicator species (Fig. 3).

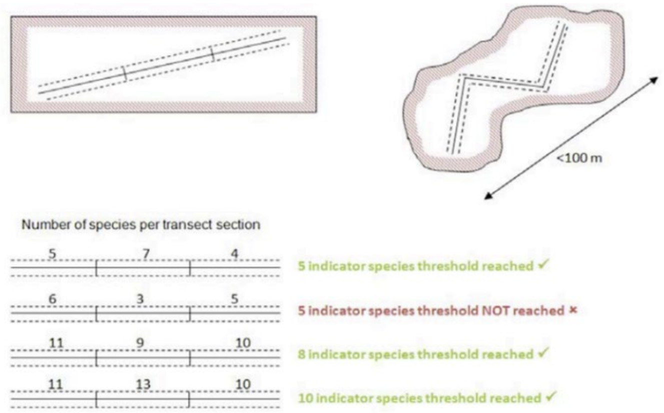

Fig. 3. The monitoring methodology and indicator thresholds.

2.3.3. Results

The monitoring of parcels under PBR agreements, and control parcels, has revealed that the number of indicator species is strongly linked to general nature value of the parcels, general species diversity of the parcels, and habitat condition of the parcels. This is reassuring as it means that the indicator species can be used as a broader gauge of species diversity and habitat condition.

Regarding the year to year results from the field, there were some fluctuations, in some cases up to seven species between years. Also, there were differences between the indicator species found each year: there are variations between years, between different survey times in the same year, between surveyors, and between transect positions in the same parcel. Moreover, there was a wide range in accuracy of the farmers' surveys. On average, farmers overestimated the number of indicator species on their parcels in the second year and underestimated in the last year. But overall the number of indicator species increased from one year to another (Figure 4).

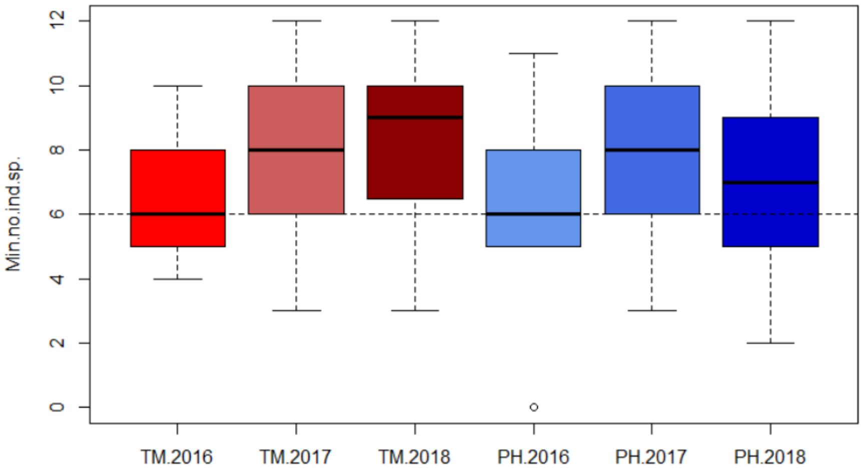

Fig. 4. Minimum number of indicator species found in the transects that were surveyed in every project year (TM: N=44, PH: N=111): The horizontal line in the boxplot is the median value, the box is 50% of the values, the dotted line is the median value from 2016 for comparison.

In general, farmers enjoyed learning the species, but there was natural variation in their ability to recognize them. This should be considered in scheme design with regard to providing expert advice and farmer training. Experts walked the transects with the farmers in the Târnava Mare region and in the Pogany Havas the farmers walked the transects by themselves. Overall, 60% of the farmers estimated the plants within 3 species from the experts, but some of the farmers were consistently inaccurate (Figure 5).

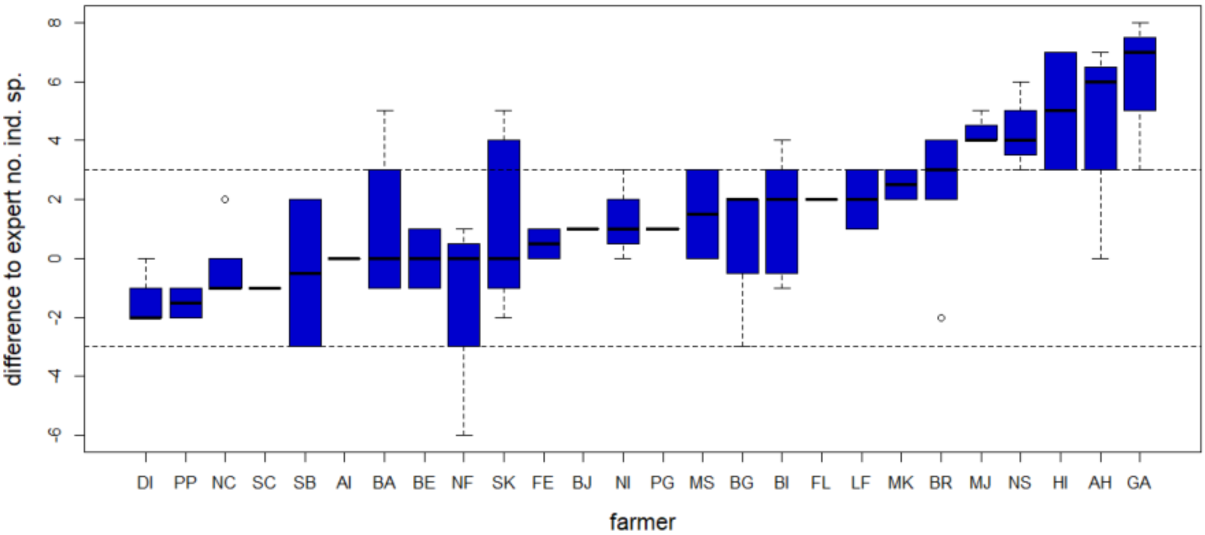

Figure 5. Difference between the number of indicator species recorded by the farmers and by the experts, sorted by farmer. Most farmers were within 3 species of the estimate of the expert (dotted lines).

2.3.4. Conclusions

The indicator species list that is used for the project must be practical (i.e. it should not too long, nor should there be too many different regional lists), but also appropriate to distinguish the most species-rich grasslands. This requires optimisation of the selection, maybe over multiple years before the full implementation of the project. For example, in 2018 it was discovered that for the Pogany Havas region two plants should be excluded and perhaps six new ones should be added. This suggests that changes in the indicator species list should be taken into consideration even in the last phases of the pilot study.

2.4. General conclusions on the implementation of current PBR schemes

From the three case studies we learnt that i) current PBR schemes focus only on plants, (ii) pollinator-relevant plants should be good proxies for pollinator benefits but they do not represent the direct expected results of schemes aiming at increasing pollinator diversity, (iii) effective indicators for bee diversity are missing. We tried to fill this operational gap in the implementation of PBR schemes for pollinators by developing easy-to-use indicators based on pollinator taxa. We focused on wild bees as they are the most taxonomically complex and challenging group of pollinators and represent the most dominant and important taxa for crop and wild plant pollination across agricultural landscapes. Butterflies are considered good potential bio-indicators as they are easy to identify. However, previous research indicates that they have little predictive power to explain the diversity of other pollinator taxa (Segre et al., 2023). Concerning hoverflies, we could not find a sufficient body of literature to perform a robust synthesis study at the European scale.

3. Development of effective indicators of wild bee diversity across Europe

3.1. Introduction

Pollinators and wild bees in particular are a highly diverse group. Only in Europe, there are around 2.000 bee species and some of the genera are a complex of species with difficult or uncertain taxonomy. Hence, applied conservation is often constrained by the availability of trained taxonomists. The hurdle of pollinator identification and the associated costs reduce our ability to monitor and evaluate the effectiveness of conservation interventions (Breeze et al., 2021). For instance, PBR schemes are considered effective tools but they are often constrained by the difficulties in measuring the results in terms of biodiversity improvements. Similarly, projects of habitat restoration or enhancement such as European LIFE projects require monitoring to measure the extent of the project effectiveness.

Against this background, developing indicators can aid conservation planning and decision support systems for policy makers (Fraixedas et al., 2020). Good indicator species should be easy to identify, cheap to monitor, but also sensitive to environmental changes (Segre et al., 2023). In the case of pollinators, it is particular interesting to find bio-indicators of species-rich communities as these are often linked to the occurrence of rare species but also to improved pollination services (Dainese et al., 2019; Simpson et al., 2022). Putative bioindicators of wild bee diversity are species richness of flowering plants while other pollinator taxa such as butterflies are often not correlated with wild bee diversity (Segre et al., 2023). However, plants can be also difficult to identify and their flowers that greatly facilitate easy identification are often only present for a limited amount of time. Hence, it would be useful to identify and test indicators among wild bees. Many wild bee species tend to depend on similar resources, namely a continuous supply of nectar and nesting sites and are also sensitive to similar environmental pressures such as pesticide use or habitat degradation through soil eutrophication or vegetation disturbances. Hence, we expect to find a strong cross-taxon congruence in the occurrence and abundance of different wild bee species.

If we consider wild bees, there are several putative indicators that can be easily used by non-experts. First, the total abundance is an important variable per se since it is often strongly correlated with species richness and it is directly linked to pollination service (Fijen et al., 2018). Moreover, the estimation of total abundance in transects or in trap catches is a relatively easy task and requires little training also for non-experts as it requires that an operator is able to distinguish Apiformes from other hymenopterans. Second, also amongst wild bees there are several common species or genera such as bumblebees that can be used as a flagship group. In particular monitoring of bumblebees can be easily implemented in citizen science projects or similar initiatives as they can be easily identified as a group (Comont and Ashbrook, 2017).

A second requirement for a good indicator is the time and costs associated to the measures. Monitoring of wild bees is usually carried out using two methodological approaches: i) transect surveys and ii) trapping using pan-traps. While transect counts are usually preferred for monitoring population trends focusing on abundance fluctuations, pan-traps are considered superior in detecting rare species and they are more effective in estimating species richness. Moreover, pan-traps are less prone to subjective differences between operators while direct observations using transects strongly depend on the ability of the personnel involved. On the other hand, the effectiveness of pan-traps is strongly influenced by the number of flowers in the direct vicinity, while the observation efficiency in transect surveys is not influenced by flower availability (O'Connor et al., 2019).

Here, we collated a large dataset of published and unpublished primary data on bee communities sampled in different habitats across Europe. Our general aim was to identify indicators of high species diversity communities. Specifically, we tested whether simple metrics such as the total wild bee abundance or the abundance of bumblebees could predict the species diversity of wild bees. We also tested whether the sampling method (direct observations with transects vs. trapping) and the habitat modified the performance of the candidate indicators across Europe.

3.2. Methods

We collected primary unpublished and published data from different sources. Each dataset included a species by site matrix with the species abundance pooled across multiple rounds of sampling in a single year. *Apis mellifera* was excluded from all the analyses. If one study sampled multiple habitats or multiple year, we created a separate matrix for each habitat and year combination. Based on the original habitat description, we reclassified the habitats in the following categories: crop (both annual and perennial), ecotone (field margin, hedgerow, forest edge), grasslands (semi-natural grasslands, pastures, meadows), forest (both interior, forest openings) and urban habitats. For each dataset, we retrieved the sampling methods (transect counts or trapping using pan traps) and the region where the sampling was carried out at the NUTS2 or NUT3 level.

Then, we measured the strength of the relationship between different measures of community abundance and wild bee species diversity. First, we visually estimated the linearity of the relationship within each dataset. Second, we estimated a Pearson correlation index between i) total wild bee abundance vs. bee species richness, ii) bumblebee abundance vs. bee species richness. To test the strength of this relationship across datasets we used a weighted meta-analysis. The Pearson's product–moment correlation coefficient (*r*) from each case was normalized using Fisher's *z* transformation as an effect size, where the sample size was the number of sampling sites. The variance was estimated using the sample size (1/n-3) (Peng et al., 2019). In the meta-analysis models described below, we weighted the effect sizes by their inverse variance.

Selected publications often performed more than one sampling for instance over different years or habitats, and thus reported more than one effect size. This clustering of effect sizes at any organizational scale violates model assumptions of independence and can affect the overall meta-analytic estimates. To examine the variation in effect sizes, and to account for non-independence of observations, we used multi-level meta-analytical models, which are equivalent to linear mixed-effects models. We accounted for clustered effect sizes by including random (nesting) factors (Bishop and Nakagawa, 2021).

We included as crossed random effects the dataset ID and the unique identifier of each dataset. For each dataset, we tested the following moderators as fixed effect: (1) sampling method (pan-trap vs. transect); (2) habitat type. We used AIC and likelihood ratio test (LRT) to compare models including moderators with the null model. We reported the results of the omnibus test and interpreted the model coefficients and confidence intervals of each moderator level, separately. Then, we examined the significance of variation in effect sizes attributed to each moderator variable using Q statistics. To visualise model results, we displayed the overall mean effect alongside with 95% confidence intervals (CI).

3.3. Results and discussion

We collected data across 1898 sites in 10 countries for a total of 691 species. Nineteen datasets used pan-traps as sampling methods while 35 used standardized transects with direct observations of pollinators on flowers.

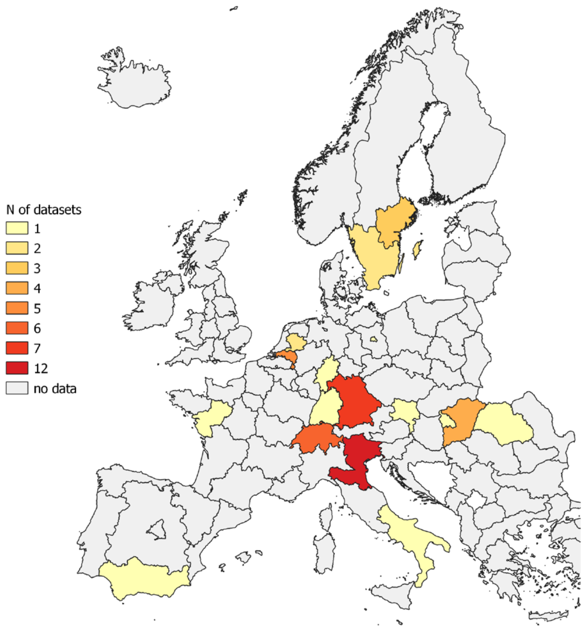

Figure 6 Geographical distribution of the datasets at the NUT1 level.

The meta-analysis showed that total abundance of wild bees was a very strong predictor of total wild bee diversity across different habitats and sampling methods (Figure 7A and B). The average correlations were all above 0.75. Both habitat and sampling method moderators were not significant indicating that the indicator performance was consistent across different environments and sampling methods.

Using bumblebee abundance as indicator of total wild bee diversity was also supported by our analysis. The correlations were lower than those related to total abundance (Figure 7C and D). Averaged correlations varied between 0.47 and 0.65 depending on the habitat and sampling method. We also observed a trend ($P<0.1$) for stronger correlations in forest than in other habitats and in transects compared to pan-traps.

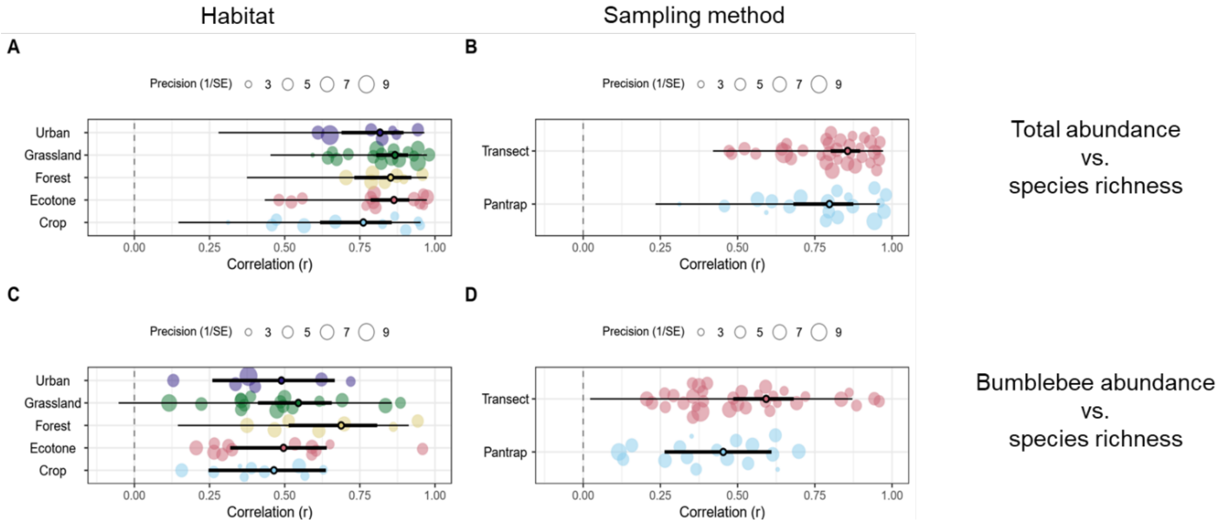

Figure 7 Forest plots showing the strength of the relationships between different measures of community abundance and wild bee species richness

For the first two indicators, we also tested the interaction between habitat and sampling method. This analysis should be considered with caution since the number of datasets per combination was relatively low to estimate an average effect size (Figure 8). Concerning total abundance, we found a low correlation for crop habitat using pan-traps compared to the other habitats (Figure 8A). Concerning bumblebee abundance, we generally observed weaker correlations for pan-traps than transects across all habitats (Figure 8B).

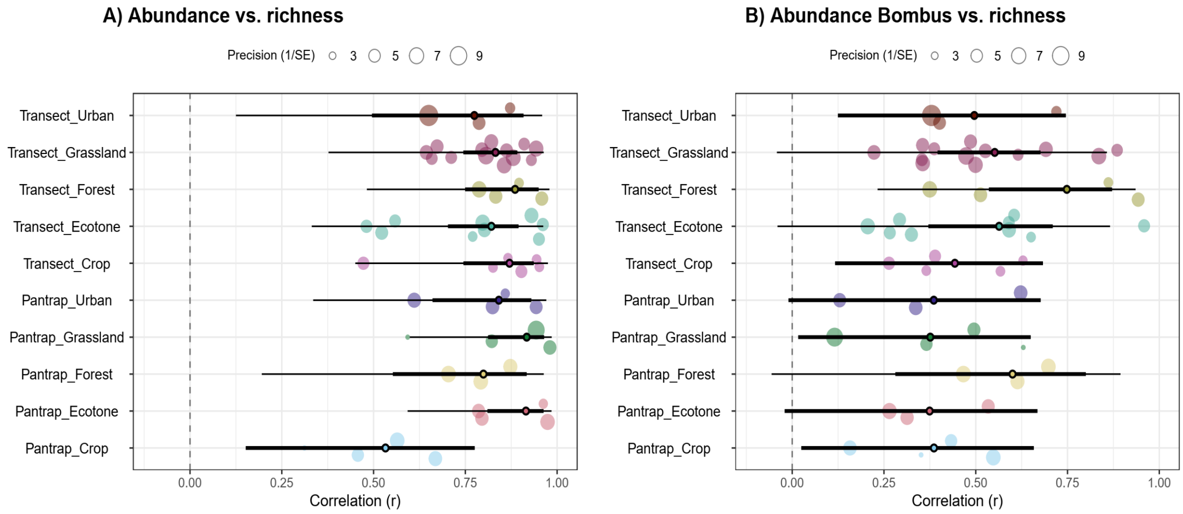

Figure 8 Forest plots showing the strength of the relationships between different measures of community abundance and wild bee species richness, testing the interaction between habitat and sampling method.

3.4. Conclusions and implications for PBR schemes

We found strong predictive power of total abundance and abundance of bumblebees for total wild bee diversity across all habitats, including those more relevant for PBR schemes (PBR are expected to be implemented in grasslands, crops and field margins). Total abundance worked well with both pan-traps and transects and exhibited correlations above 0.75. The minimum correlation observed was 0.47. Bumblebee abundance performed better using transects than pan-traps with correlations ranging from 0.13 to 0.92 and exhibiting larger variability.

Hence, the most robust indicator of wild bee diversity was the total abundance of wild bees. This indicator is relatively easy to measure in both pan-traps catches and during transect sampling. The use of bumblebee abundance is a much simpler indicator to implement than total wild bee abundance since these species are clearly identifiable from the other wild bees. However, its predictive power was lower than the total abundance of bees and its use is restricted to transect counts as bumblebees are often seen to avoid pan-traps and therefore their abundance estimates could be less accurate than in transects. Bumblebees performed really well in forest habitats, while the candidate agricultural habitats for PBR exhibited lower predictive power. However, correlations were around 0.5 which can still be considered sufficient values for a good indicator (Corcos et al., 2021).

The next step would be to evaluate the ability of farmers to measure both indicators in the field using both transect and pan-traps. Below, we tried to present pros and cons of using the indicators with both sampling methods.

Pan traps have several well-known limitations and biases (Westphal et al., 2008). However, they can also provide species resolution data independent of expertise and require less person effort to achieve equivalent sample sizes when compared to transects. They could also minimize noise in the data from different levels of recorder knowledge or changes in recorders over time (O’Connor et al., 2019). Pan-traps can be also deployed during the entire flowering season being independent from the presence of flowering plants (Breeze et al., 2021; Klaus et al., 2024). However, there are also several negative sides of using pan-traps. First, pan-traps can kill a large number of individuals that can create some ethical issues for the people involved in the schemes, although no negative effects of such lethal sampling has been observed on pollinator communities (Gezon et al., 2015). Second, while transects provide a

measure of pollinator diversity more related to the local availability of flowers, catches in pan-traps reflect more the quality of the landscape surrounding the local site.
Although transect counts can be more subjective and require more advanced sampling skills and knowledge than pan-traps, the use of our indicators would strongly facilitate these measures also for non-experts. Pan traps would also take more time for farmers compared to transects where observations can be done directly in the field. Compared to dead specimens found in pan-traps, with transects farmers can see living bees in all their colors, understanding their behavior and their functional link to wild plants and crops.

We therefore found a trade-off between predictive power and implementation easiness for the two candidate indicators. As PBR schemes are usually aimed to improve habitat quality at the local scale (e.g. a single meadow, margin, pastures), we suggest to use only transect counts. If it is possible to properly train the famers, total abundance of bees should be preferred, while if training is a constraining factor, the abundance of bumblebees can be used. However, one should consider that the predictive power of this indicator is not sufficient to detect subtle changes in species diversity.

4. Guidelines on how to implement the indicators at regional scale

Irrespective of the indicator selected, we can provide practical guidelines to implement the pollinator indicator monitoring for PBR schemes. First, schemes are usually implemented at the regional scale (e.g. NUT2 or NUT1) and for a specific habitat (e.g. grassland, field margin, hedgerow). Once the indicator is selected, the first step requires to identify 5-10 high diversity reference sites that represent the ideal target for the biodiversity outcome in the region.

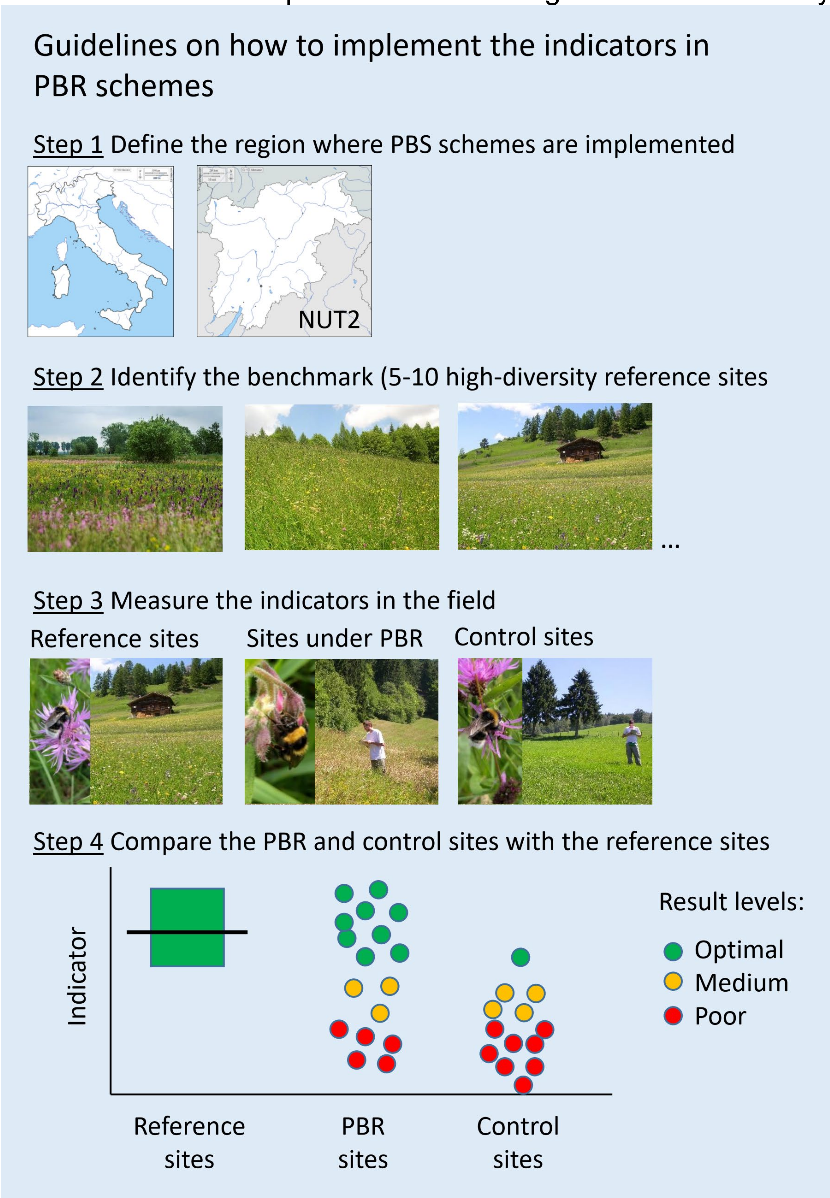

Figure 9 Guidelines on how to implement the identified indicators in a PBR scheme at the regional scale
(Meadow pictures from Lorenzo Marini, Bumblebee pictures from Andree Cappellari).

These sites provide a dynamic benchmark to evaluate the performance of the sites under PBR schemes. In the monitoring phase would be also useful to include some control plots to test the performance of the PBR scheme. As pollinator communities are highly dynamic, both species richness and abundance can vary dramatically between years. Hence, each year reference sites, controls and the sites under PBR should be monitored. Based on the indicator values in the reference sites, different a priori result levels can be created to evaluate the performance of the PBR sites. A critical step here is the variability in the reference sites. The higher the variability, the more sites should be monitored to estimate the benchmark. The level of the payments can be more accurate if total wild be abundance is selected while they should be broader if bumblebee abundance is selected.

For both indicators, the sampling should be repeated three-four times under good weather conditions (temperature above 20°C and sunny weather). The total abundance should be computed by pooling the same number of sampling rounds. Ideally the sampling should be performed within specific sampling windows selected based on weather conditions. Bumblebee sampling is less sensitive to poor weather conditions than total wild bee abundance.

Finally, it is very important that the sampling effort is equal across all sites in term of space and time. We suggest to use two short transect 25 m x 2.5 m for 15' repeated three times. The choice of the sampling windows should be guided by the phenology of the key flowering plants in the focal region starting in late spring (e.g. *Sambucus nigra* flowering in Europe).

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