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An Analysis of Ecological Indicators Applied to Agricultural Ecosystems: What to Retain to Shape a Future Indicator for Pollinators †

Sergio Albertazzi [1], Elisa Monterastelli [2], Manuela Giovanetti [1]*, Simone Flaminio [1], Emanuele Luigi Zenga [1], Laura Bortolotti [1] and Marino Quaranta [1]

[1] CREA Research Centre for Agriculture and Environment, Via di Corticella 133, 40128 Bologna, Italy; sergio.albertazzi@crea.gov.it; manuela.giovanetti@crea.gov.it; simone.flaminio@crea.gov.it; emanuele.zenga@crea.gov.it; laura.bortolotti@crea.gov.it; marino.quaranta@crea.gov.it
[2] Independent Researcher, Via di Corticella 85, 40128 Bologna, Italy: elisa.monterastelli@gmail.com
Correspondence: manuela.giovanetti@crea.gov.it

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Abstract: Biodiversity loss has been demonstrated to have direct impacts on human welfare. However, policymakers need to refer to commonly accepted standards to monitor biodiversity, especially to direct fund granting. Intending to collate information for the creation of a reliable pollinators' one, we screened available indicators. Our first criterion was selecting indicators applied in agricultural contexts and legitimated by a regulatory agency. Further, we included indicators referring to any arthropod taxa and officially recognized at least by national bodies. We compared survey scale, monitoring scheme, type of environment, sampling effort, expected arthropod population, taxonomic level of data. As a common approach, we identified the combination of a territorial analysis by remote tools (e.g., GIS) and animal taxa surveys. The strength of indicators including arthropods emerges in the simultaneous inclusion of biotic and abiotic components. However, most of them just refer to confined environments (e.g., grasslands, riversides). Pollinators' sensitivity to changes at the micro-habitat level is widely recognized, even helping to distinguish different methods of agricultural management. To develop a biodiversity indicator based on pollinators, we suggest improving knowledge on local pollinator species and their environmental requirements, coupled with wide (in time and space) national monitoring programs..

Keywords: biodiversity; agroecosystems; arthropods; environment; pollinators; indicators; RDPs measures

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1. Introduction

The biodiversity of the agroecosystems is becoming a crucial component in European legislation since it represents a key to tackle food security, human and environmental health, and climate change. A specific objective of the CAP post-2020 (European Common Agriculture Policy 2014-2020) is "to contribute to the protection of biodiversity, strengthen ecosystem services and preserve habitats and the landscape"[1]. Measuring biodiversity in agricultural systems is not effortlessly. For RDPs (EU countries Rural Development Programmes) actions to sustain biodiversity, FBI (Farmland Bird Index) and HNV (High Nature Value) farming were the adopted indicators [2]. However, they encountered some objections; therefore, HNV farming will not be integrated into the next CAP post-2020 [3], while the FBI, even if retained, proved to be poorly tied to local RDP measures [4]. So far, there is no tool to assess the impact of RDPs on biodiversity at the farm-level, despite an intensive research effort to identify suitable indicators [5].

Pollinators are desirable candidates to contribute to indicators applied to monitor the trend of biodiversity loss [6]. Their role in agroecosystems is recognized of crucial importance: they perform services in support of food production [7] and indirectly inform on pollutants and environmental quality [8]. Furthermore, the decline that pollinators are undergoing [9] can precisely impact agriculture produce [10]. The EU Biodiversity Strategy for 2030 focus on the decline of pollinators to reverse this trend [11] and a European group of experts is working on the methodologies to be adopted by a wide EU Pollinator Monitoring Scheme at a continental level [12]. Following the 2018 European Pollinator Initiative [13], the 2019 Directive on the conservation of biodiversity of the Ministry for Environment, Land and Sea Protection of Italy [14] provided funding and enhanced research on pollinator populations in Italian National Parks, with special acknowledge of threats driven by agricultural practices. ISPRA highlights the complexity of approaching pollinators as indicators with some in-situ sampling and by applying a simple-level taxonomic recognition [15]. Our research group is involved in two projects: the European LIFE 4 POLLINATORS, led by the Alma Mater Studiorum (University of Bologna), and the national BeeNet, led by CREA (Research Centre for Agriculture and Environment), both related to pollinators in agricultural environments. One of the objectives of the first is evaluating agroecosystems in the intensely-cultivated area of the Po Valley [16] through pollinator monitoring and direct involvement of farmers. The second is applying a large monitoring scheme on honeybees and wild bees at the regional level all over the country. Data should all contribute to testing a pilot indicator (in progress), that also acknowledges EU recent guidelines on pollinator monitoring. While carrying out data collection, these projects face gaps in our comprehension of pollinators' ecology, especially that of bees (Apoidea, [12]). Missing information on species-specific requirements are frequent, as confirmed by the European red list: about 56% of species are indicated as "data deficient" [17]. Therefore, we suggest that a potential starting point to address a future pollinator-based indicator is identifying and analyzing the structure of other indicators applied to investigate biodiversity.

Greening measures have been implemented to counteract biodiversity loss, especially through fund granting. However, evaluating the resulting impact of these actions, and consequently, the financial effort linked to them, has not been successful so far. Our long-term goal is to define an indicator based on pollinators and able to highlight the power of greening measure and RDPs contribution. This indicator should therefore inform policymakers by highlighting and sustaining effective measures. To achieve that, we are presenting an analysis of existing indicators, underlining their power and their weakness, and discussing what to retain.

2. Methods

In temperate latitudes, the pollination service is carried out mainly by insects [12]. Among existing indicators, we considered those including the evaluation of biodiversity in agroecosystems and arthropods as bio-indicator organisms. There are numerous indexes/indicators proposed to evaluate the agroecosystem. We applied another filter, selecting those that have been legitimated (through a protocol approved by a scientific regulatory agency) or officially recognized (through their inclusion in regulation and therefore considered the official method in the given context; Figure 1).

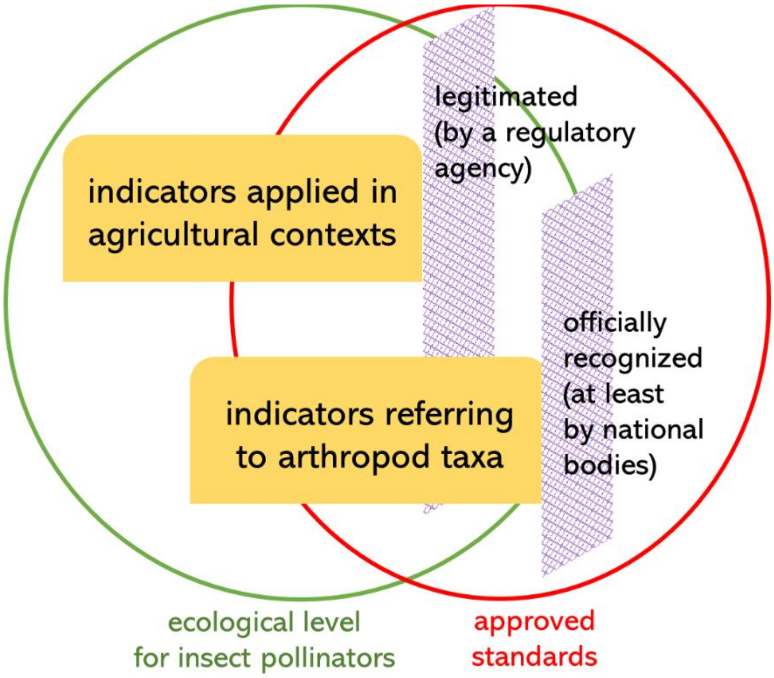

Figure 1. Criteria we applied to select existing indexes/indicators to be compared, to contribute to developing a future biodiversity indicator based on pollinators. On the one hand, indicators need to be suitable for agroecosystems, or for investigating arthropod taxa so to maintain similarity with insect pollinators of temperate areas. On the other, indicators need to have already passed a "political" filter: legitimated by a regulatory agency and/or officially recognized by (at least) a national body, to ensure a proven interest from a legislative point of view.

The following are the definitions we will employ further on.

Index and indicator. We define "index" an instrument that returns a value to describe a measurable phenomenon (e.g., the sampled population against the expected one). "Indicator" is a more complex and often composed instrument, aimed at evaluating a phenomenon not directly measurable.

Key criteria. a) the evaluation of biodiversity in agroecosystems and b) arthropods as bio-indicator organisms. We surveyed reports of the European Environment Agency (EEA); the indexes and/or indicators included in the Italian "Testo Unico Ambientale" (D. Lgs. no. 152/2006) [18], a text adopting numerous European directives on environmental issues; protocols drawn up by ISPRA; and finally, Italian regional legislation [19].

Legitimated vs. officially recognized. To be legitimated, an index/indicator need to be tested by a scientific regulatory agency, that possibly further create and publish an official protocol for its implementation: it is therefore the result of a technical-scientific approach. To be officially recognized, an index/indicator need to be included in an existing regulation: it is the results of authorization for its use in a legal framework.

We proceeded by a bibliographic search, through official websites of the regulatory agencies: the scientific ones that are responsible for the development and legitimation of indicators, and the political ones responsible for the recognition of biodiversity indicators in regional, national, or European legislation.

We analyzed each index/indicator by the following parameters:

1. *Taxonomic groups*: the taxa of the subject species and their ecological/biological resemblance with pollinator lifestyles.
2. *Spatial context*: definition of the spatial scale (regional, local, codified habitats, portions of habitats) and of parameters applied to define it, arbitrary or ecological (i.e: the application of a rigid sampling scheme, adaptation of the sampling scheme to territorial characteristics, individual case studies).

3. *Baseline background*: level of ecological/biological knowledge on the subject species, (i.e.: is there is an expected population/list of species typical of a given habitat in the absence of disturbance?).
4. *Sampling effort and level of taxonomic identification*: type of sampling protocol and subsequent taxonomic effort; the taxonomic level of identification; skills required for these activities.
5. *Final output*: quantity and type of outputs (i.e.: descriptive, or class/category).

3. Results

We selected eight indexes/indicators potentially useful for the further development of an indicator on pollinators. Three of them are linked to the first key criterion (the evaluation of biodiversity in agroecosystems) and the other five to the second (arthropods as bio-indicator organisms). The main characteristics of these indexes/indicators are summarized in Table 1.

Table 1. List of selected indexes and indicators, with information on regulatory agencies (European, Italian, or regional) and year of official release.

Indicator/index	Acronym	Legitimated	Officially recognized
Farmland Bird Index	FBI	EEA/2005 [20,21]	CAP (from 2000 to post-2020) [2,3,22]
High Natural Value Farming	HNV farming	EEA/2004 [23,24]	CAP (from 2007 to 2020) [2,22]
Proxy	PrY	EEA/2019 [25,26]	CAP post-2020 [3]
Fresh water macrobenthos index	STAR ICMI	ISPRA/2014 [27]	Directive 2000/60/EC [28]
Grassland Butterfly Index	GBI	EEA/2013 [29–32]	none
Soil Macrobenthos Index	QBS-ar	(CREA, ISPRA)[2] [33–35]	Emilia-Romagna Region (from 2015) [19]
Sirph the Net	STN	ISPRA/2015 [36,37]	none
Ground beetle index	GrB	ISPRA/2005[3] [38–40]	none

Notes: [1] Implicitly officially recognized, as it is included into HNV farming; [2] agencies names in parenthesis since legitimation in progress; [3] ISPRA protocol establishes a standard for sampling but does not establish the indicator.

The result of our analysis for each parameter follows:

1. Taxonomic groups. Among the eight indexes/indicators, we found all taxa of pollinators. As taxa of pollinators, we consider the ones included by the EU recent guidelines on pollinator monitoring: e.g., bees, butterflies, flies. GBI, HNV farming and PrY focused on butterflies; STN and PrY (but the list in progress [41]) on hoverflies and PrY also included bees. However, not all groups were considered at the same level of detail. For butterflies and hoverflies, all species are considered; for bees, only endangered species.

2. Spatial context. The spatial analysis ranges from largely adopted European monitoring plans to individual case studies. FBI, GBI and STAR-ICMI are based on monitoring programs defined respectively by the European Bird Census Council (EBCC), the European Butterfly Monitoring Scheme (eBMS) and the Directive 2000/60 / EC. FBI considers the whole European territory, divided into regular grids. GBI and STAR-ICMI focus on a portion of the continent containing given environments (pastures and hydrographic basins). The other indicators try to standardize individual case-studies by correlating the results with the characteristics of the habitat (SNT, QBS-ar), or by varying the sampling methodology (GrB).

3. Baseline background. Knowing the ecology and biology of target species is very important. PrY considers the rate of extinction risk, while STAR-ICMI and QBS-ar the morphometric adaptations to individual microhabitats. The link of target taxa with the environment in which they live may be expressed by an indirect parameter as the land use

(Corine Land Cover) on a cartographic level. Some indexes are structured to combine with other tools to resume more baseline information, forming a macro-indicator. In the "Testo Unico Ambientale" (D. Lgs. 152/2006), that integrates the Directive 2000/60/CE, the STAR-ICMI index is combined with other biological indexes (on fishes, macrophytes, diatoms) to define the Ecological Index of Biotic Quality (EQB). EQB also include the sensitivity to pollutants and hydro-morphological aspects for an overall assessment of environmental quality.

4. Sampling effort and taxonomic identification. Sampling effort is established by monitoring protocols, while taxonomic identification can be carried out in the field or back in the laboratory. EBCC monitoring plans include a different pool of bird species in each country (230 nesting species in the case of Italy). eBMS investigates 435 European butterfly species, identified at species level directly in the field. Both are coordinated and supervised by regulatory agencies through the work of thousands of trained professional and volunteers. An opposite situation is that of samplings that later require identification in the laboratory through an optical microscope (STAR-ICMI, QBS-ar, STN, GrB). Another parameter that may vary is the type of collected data: abundance (FBI, GBI), or presence-absence (occupancy) (STN, HNV farming, PrY, STAR ICMI, GrB, QBS-ar).

5. Final output. Usually, indexes compare a resulting value with a reference: for FBI the reference is the corresponding value in a given year (2000 for Italy); for HNV farming and PrY the reference is the entire area of the farm. It could also be a given population (STN, STAR ICMI, GrB, FBI). Ideally, the value of the index indicates the disturbance suffered by the environment and recorded by the sampled population. FBI and GBI consider a few species: 23 and 17, respectively (for the latter: 10 generalists and 7 specialists). In some cases, only expert opinion can interpret rough data and estimate the disturbance (GrB). In other cases, indexes transform the data into a well-defined qualitative scale (STAR-ICMI,), or a set of user-friendly values so that also non-experts can compare results on a national / European basis (QBS-ar and STN).

5. Conclusion

Pollinator taxa are different among themselves, in their ecological requirements and their interactions with the landscape. In the framework of a future indicator on pollinators, we depicted as an important variable to be considered that of a cartographic analysis of the territory. It is crucial to choose a level that complies with 1) the reduced mobility of pollinators, and 2) the spot-distribution of RDPs fund granting. Therefore, actual tools that include information on land use into indicators need to be sharpened to greater detail. To overcome the deep gaps in our knowledge on (some) pollinators biology and ecology, we suggest broadening the environmental parameters possibly by building a complex indicator based on several indexes. Among them, those more strictly linked with pollinators should be included (e.g., vegetation type, crops, agricultural practices, climatic context, etc.). We should also care about the relationship between environmental parameters and the target taxa of pollinators. For example, butterflies and hoverflies are linked to vegetation especially as food for the larval stages (not mobile). On the contrary, adult bees are the ones more strictly connected to vegetation and interested in a wider (flight) range. The necessary ability for taxonomic identification has been already recognized as a limiting factor. It may limit the possibility of introducing, into the indicator, the expected population of a species and identifying different ecological weights for each species of taxa. In some cases, a reduced number of species can be selected and included in the indicator. For example, species that showed a sensitivity to the use of pesticides can be the main target, or those differently reacting to given agricultural practices. The ideal situation to achieve in the future would be to integrate information on abundancy and occupancy of sampled species, widening the range of legitimated methodologies.

All the above is feasible if pursuing extensive (both in terms of space and time) monitoring programs, that may also include public awareness-raising from citizen science projects. The latter have been widely adopted in many research fields to increase/facilitate the sampling effort [42]. We compared indexes/indicators tested in the field for a long time and any new indicator is expected to undergo the same path. Many established indicators (QBS-ar, GrB) are equally undergoing a refinement phase even promoted by regulatory agencies and pilot studies. An indicator based on pollinators is achievable and will certainly contribute to measuring the biodiversity of the agroecosystems.

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Abbreviations

The following abbreviations are used in this manuscript:

EU: European Union
CAP: (European) Common Agriculture Policy
RDPs: (EU countries) Rural Development Programmes
FBI: Farmland Bird Index
HNV farming: High Nature Value farming
ISPRA: (Italian) National Institute for Environmental Protection and Research
GIS: Geographical Information System
CREA: (Italian) Council for Agricultural Research and Economics (in this context, with its Research Centre for Agriculture and Environment)
EEA: European Environment Agency
D. Lgs.: decreto legislative (legislative decree)
STAR-ICMI: Fresh water macrobenthos index
GBI: Grassland Butterfly Index
QBS-ar: Soil macrobenthos Index
STN: Sirph the Net (Syrphidae)
GrB: Ground beetle index
EBCC: European Bird Census Council
eBMS: European Butterfly Monitoring Scheme
EQB: Ecological Index of Biotic Quality

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