Assessing biodiversity in arable farmland by means of indicators: an overview

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Abstract: *Maintaining biodiversity is one of the key issues of sustainable agriculture. It is now stated that innovation to enhance biodiversity in arable land requires operational assessment tools like indicators. The goal of the article is to provide an overview of available indicators. Besides measured indicators and simple indicators based on management data, we focus on predictive indicators derived from operational models and adapted to* ex ante *assessment in innovative cropping design. The possibility of use for each indicator type is discussed.*

Key words: *environmental assessment, indicator, model, validation, biodiversity, ecosystemic services*

Maintaining biodiversity is one of the key issues of sustainable development, and agriculture is highly concerned in this perspective. The term was first suggested in 1985 at a conference on biological diversity in the USA and was popularized since the Rio Conference in 1992 (Le Guyader, 2008). It is now commonly accepted that biodiversity can address the biological diversity at different levels: i) the compositional, including the genetic, species, community, habitat diversity, ii) the structural, iii) the functional encompassing processes within that level (Clergué *et al.*, 2005). In the 2000s, the Millennium Ecosystems Assessment (2005) introduced the concept of ecosystemic services provided by biodiversity, like pollination, and pest control.

In arable area the change in land use, the intensification and simplification of cropping systems, as well as the drastic reduction of semi-natural elements (hedges, trees, wet zones, etc.) have led to a significant decrease of biodiversity in arable land (Le Roux *et al.*, 2008). Different options were developed to mitigate negative effect of agriculture intensification, among them extensification and even suppression of chemical input like in organic farming (Hole *et al.*, 2005), reconsideration of field margin management to enhance semi-natural area of farmland (Marshall and Moonen, 2002). It is now stated that this process of innovation to enhance biodiversity in arable land requires operational assessment tools. These tools should evaluate the current state at different scales, identify the causes of biodiversity impoverishment in a diagnosis phase, and assess the effects of innovative solution cropping systems (Bockstaller *et al.*, 2008b). This led many authors to plead for research on biodiversity indicators (Carpenter *et al.*, 2006) which have not to be confounded with bioindicators (Duelli and Obrist, 2003). The latter use a component of biodiversity to assess something else, like the accumulation of a pollutant.

From a general point of view, the term ''indicator'' can refer to many definitions (Heink and Kowarik, 2010) as shown in *figure 1* (Bockstaller *et al.*, 2008b). Those authors set a typology based on the nature of the indicators. Indicators can be basic variables (e.g. amount of input) or simple combination of these variables (balance, ratio) as well as field measurements, the former being also called ''indirect'' and the latter ''direct'' indicator regarding biodiversity (Burel *et al.*, 2008). Indicators can also be derived from model outputs and thus can be considered as ''predictive indicators''. By this way, an indicator can be obtained from the average of model output, transformed into scores or even expressed as the ratio of a model output and a reference value, as for pesticide risk indicators (Bockstaller *et al.*, 2009). This type of indicators expresses an explicit link between input variables addressing the causes, and an output reflecting an effect on environment. Models can be roughly separated in operational models using a limited and available set of input variables and complex models which are too difficult to implement by non-scientists. If measured indicators are totally relevant for *ex post* assessment of the state of biodiversity to evaluate e.g. the results of agri-environmental scheme (Kleijn *et al.*, 2006), they

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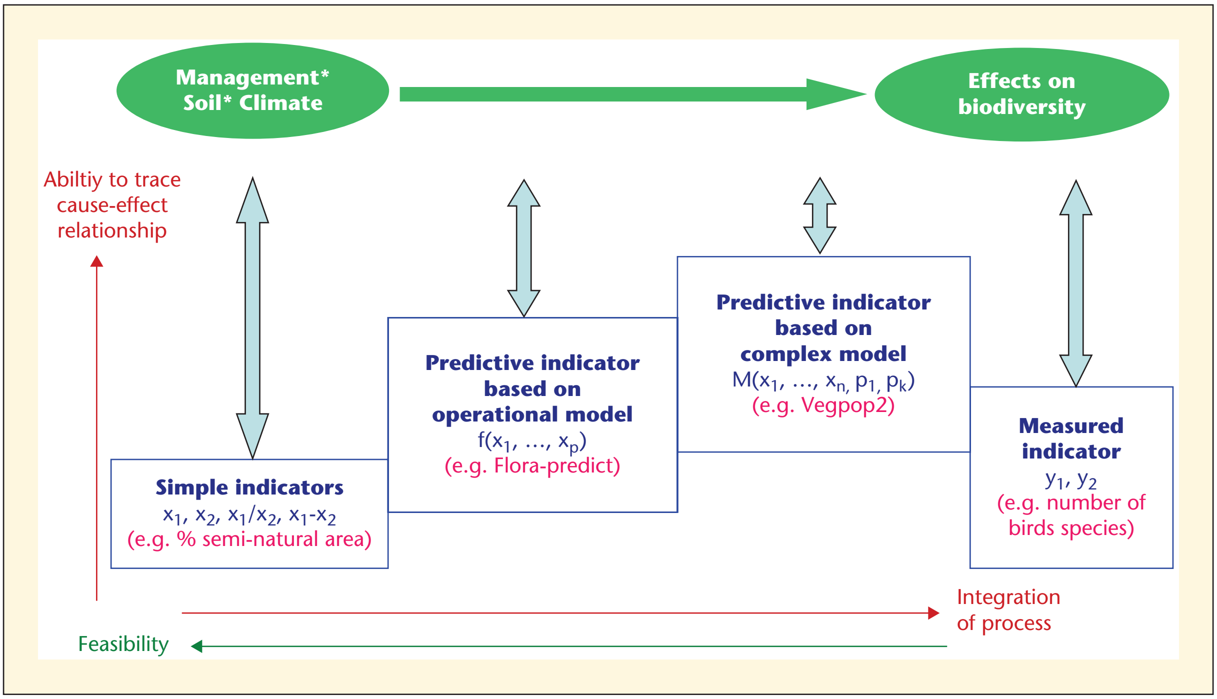

Figure 1. *Typology of indicators base on the construction method and evaluation of their quality (inspired from Bockstaller* et al.*, 2008b)*

do not allow trace the cause. Simple indicators can complete the information on the causes or ''pressure''. Predictive indicators offer a compromise between simple indicators and measured indicators regarding feasibility and degree of integration of process. They can be used for *ex ante* assessment to predict effect of simulated system. Such indicators are necessary for agronomist working on innovative cropping design (Sadok *et al.*, 2008).

Since the 90s, scientific publications on biodiversity indicators have increased to reach 100 articles per year in the last years (Burel *et al.*, 2008). In the last decade, several reviews were published but their scope was beyond agriculture addressing natural land (e.g. Levrel, 2007). Others focused on agriculture but covered only measured indicators and secondary simple indicators derived from management data (Braband *et al.*, 2003; Büchs *et al.*, 2003; Delbaere, 2003; Burel *et al.*, 2008). Clergué *et al.* (2005) gave two examples of models which can be used to derive indicators: Vegepop2 a complex model predicting the effect on field boundary flora and Flora-predict (Amiaud *et al.*, 2005), an operational model for meadow flora. The model Vegpop2 predicts a dynamic of biomass for different species that allows assess the biodiversity, whereas the operational model Flora-Predic provides a probability of presence. This output only indicates the occurrence of species and can be considered as an indicator. This last group of predictive biodiversity indicators remains poorly covered by scientific literature. In this article, we aimed at providing an overview of the available biodiversity indicators covering the three types of indicators, with a focus on this last group of predictive indicators. We illustrate it with recent initiatives concerning predictive indicators addressing biodiversity for different taxa mainly plants, invertebrate and soil microbial communities, this for spatial scale ranging from field to agricultural landscape.

Measured (direct) indicators

Since the 80s, a vast number of measured indictors were proposed in the literature as previously reviewed by Noss (1990) and more recently by Lindenmayer and Likens (2011). Indicators based on species diversity and/or abundance among a given taxon or several taxa (e.g. birds, plants, carabid beetles, etc.) are the most commonly indicators used at different scale from field to national level. An exhaustive review of proposals for different taxa can be found in Burel *et al.* (2008). Species of almost all taxonomic groups have been proposed (Lindenmayer and Likens, 2011). The indicator may address all the species of a given taxon or a given category like the number threatened species given by the Red Lists for a given region (see list given by Delbaere (2003)). It can also focus on the diversity of *keystone* species, i.e. a species supporting the functioning of a ecosystem and the survival of many other species as well as *umbrella species*, i.e. species which needs a large area to survive and offers possibility of existence to many other species (Clergué *et al.*, 2005). However examples of such specific species are scarce in agriculture.

In field experiments testing new designed cropping systems, agronomist assessed biodiversity by some measured indicators like plant diversity (Vereijken, 1997; Pacini *et al.*, 2003). Among invertebrates, indicator based on the diversity of carabid beetle were proposed by many authors because they are relatively easy to assess by simple pitfall although they were criticized as indicator of biodiversity (Duelli, 1997). Döring and Kromp, 2003 analysed the ability of different carabid beetle species to indicate the impact of change of cropping systems from intensive to organic.

At smaller level, soil is one of the major reservoirs of microbial diversity, one gram of soil containing between 3,000 and 11,000 genomes (Torsvik and Ovreas, 2002). Nevertheless, assessing the diversity (in terms of species number) remained a challenge for microbial ecologists, traditional techniques based on isolation and culturing being too selective (Gardi *et al.*, 2009). Molecular techniques like fingerprinting based on 16S rDNA sequences were commonly used to reveal patterns considered as ''a picture'' of the microbial communities. Nevertheless, the evaluation of the microbial specific diversity is poorly informative in relation to soil functioning (Maron *et al.*, 2011). Therefore molecular techniques targeting key microbial genes implicated in ecosystem functions were valuable tools to assess functional diversity (genetic structure, abundance *vs* level of expression of functional microbial genes). The development of multi-parametric indices integrating these data is now needed to better understand the relationships between soil microbial diversity and function.

At higher scale, only one indicator is currently available in France at present time: the diversity and abundance of common birds (about 120 species) which are divided in generalists, farmland, forest and urban areas. Results of the assessment over more than 10 years show a clear decline in farmland specialists. The strength of this indicator is that is can be relatively easy to obtain, species being easy to determine, easy to interpret, the cause of variation being well know, and present a power of communication to the society (Levrel, 2007).

Since diversity cannot be only be reduced to the number of species but also to their abundance and evenness in distribution, several composite indices were proposed, to go further than the species number. *Table 1* shows some examples but more can be found in Magurran (2004) who supplied information about their statistical relevance. Among them, the Shannon index is one the most popular one although some authors criticized its statistical relevance and do not consider it as a true diversity index but as an entropy evaluation (Jost, 2006). The reciprocal Simpson's indicator is a real diversity indicator and its outputs can be more easily interpreted: It is equal to the species number in case of even distribution of species (all species have the same percentage in the sample) and decreases with increase of unevenness. It highlights the number of dominant species in a certain way. In any case, no single index can provide all the information directly. Our proposal is to implement simultaneity a composite index like the reciprocal Simpon's indicator, and at least two other indices to explain the former, like the number of species and an the evenness index.

Simple (indirect) indicators based on management data

Many proposals also exist for this type of indicators. Among the 91 indicators listed for agriculture by Delbaere (2003) more than the half belongs to this type. Considering the general model explaining biodiversity in farmland (Le Roux *et al.*, 2008) we classify them in two groups: i) indicators related to management of farmland at different scales ii) indicators addressing cropping practices, which can be expressed in amount of inputs per area unit or in percentage of area disturbed by fertilizer, pesticides, irrigation, tillage, both being expressed at different scales. *Table 2* gives some examples used in different assessment methods (Bockstaller *et al.*, 2008a; Bockstaller *et al.*, 2009) and information about their validation. By validation we mean here correlation studies between indicator output and measurement of diversity for different taxa. We used data from the work of Billeter *et al.* (2008).

Table 1. *Example of composite indices of biodiversity*

Indicator	**Méthode de calcul**
Species number	$S = \Sigma s_i$ avec s_i : i^{th} species
Shannon Index	$H' = - \Sigma p_i \,.\, \mathrm{Ln}\, p_i$ $^{(a)}$ with p_i = proportion of species i (entre 0 et 1)
Evenness	$E = H'/\mathrm{Ln}\, S$
Simpson's Index	$D = \Sigma p_i^2$
Reciprocal Simpson's index	1/D
Buckland arithmetic Occurrence index:	BuckArith-OI= $100/S\ \Sigma\ O_i\ /R_i$ with O_i = site number where species i is observed R_i = site number where species i was observed

Predictive indicators based on model

Like for other environmental issues (e.g. nitrate leaching), researchers developed mechanistic models to predict the dynamic of population for a given species, its survival probability, and ecological process like predator-prey interaction. They worked mainly in ecology for natural area (Guisan and Zimmermann, 2000) with mechanistic models and also operational static models (Gontier *et al.*, 2006) but few concerned farmland. Besides the Vegepop2 model for field boundary flora (see above Clergué *et al.*, 2005), another model covering a species of farmland, the Corn Bunting deserves attention but remains relatively complex, needing spatial data (Meyer *et al.*, 2007).

However in recent years, some operational approaches were developed with the specific objective to assess the effect of farmland and crop management on biodiversity as shown in *table 3*. Most of the methods were developed in frame of a multicriteria assessment (excepted Sanderson *et al.*, 1995; Keichinger, 2001; Butler *et al.*, 2009). SALCAbd (Jeanneret *et al.*, 2006) was developed to complete the SALCA method based on life cycle analysis. Actually this biodiversity component does not tackle the whole production cycle but only the farm level like the other methods presented in *table 3*. Indicators of this group provide output in form of a probability of presence for one or a reduced number of species, or in form of risk or impact scores. Whereas some models tackle in a explicit way a broad

Table 2. *Example of simple indicators used in environmental methods (Bockstaller et al., 2008a) or proposed in initiative (e.g. IRENA at EU level (EEA, 2005))*

Indicator	**Unit**	**Example of method using the indicator, or list containing it**	**Scale**	**Validation (correlation with given taxon)[a]**
Percentage of area cropped in organic farming	%	IRENA	Region, country	ns[b]
Percentage of area with agri-environmental scheme	%	IRENA	Region, country	ns[b]
Percentage of semi-natural area	%	DIALECTE, IDEA	Farm, landscape, region, country	Herbs, birds, bees, bugs, hoverflies, carabids, spiders,
Habitat diversity	None		Farm, landscape, region, country	Bees
Percentage of area with high value nature	%	IRENA, KUL[c], REPRO[c]	farm-landscape	Not studied
Hedgerow length in farm	m	RAD	Farm, landscape	Not studied
Percentage of well-managed hedgerows	%	Projet OTPA	Farm, landscape	ns[b]
Median size of field	ha	KUL[c], REPRO[c]	Farm, landscape	ns[b]
Average number of crops per farm	none		Farm, landscape	Bees, bugs, carabids
Crop diversity	None (Shannon index	KUL[c], REPRO[c]	Farm, landscape	ns[b]
Percentage of area cropped intensively	%		Farm, landscape	ns[b]
Pesticide use	Number of treatments/ha,			
g of active ingredient/ha		Fields, farm, landscape	No correlation	
Pesticide use	Treatment frequency index	DIALECTE, IDEA, KUL[c], REPRO[c]	Fields, farm, landscape	ns[b]
Percentage of non sprayed area	%	DIALECTE,	Farm, landscape	ns[b]
Nitroen fertilizer use	kg N/ha		Fields, farm, landscape	Birds
Percentage of intensively fertilized area	%	DIALECTE, IDEA	Fields, farm, landscape	Herbs
Percentage of irrigated area	%	DIALECTE, IDEA	Fields, farm, landscape	ns[b]

[a] see Billeter *et al.* (2008). Correlations studies included herbs, woody plants, birds, bees, bugs, hoverflies, carabids, spiders

[b] not studied in Billeter *et al.* (2008)

[c] German methods (see Bockstaller *et al.* (2009))

number of species, for plants (Sanderson *et al.*, 1995) or severa taxa (Butler *et al.*, 2009), most them focus on a few number of species or few taxa without explicit information on species. The IBEA method (Anonymous., 2011) does not address the species level but only biodiversity in general through an ''environment quality'' and a ''genetic diversity'' components.

Behind the calculation of such predictive indicators, different aggregation approaches are used: scoring systems based on equations (Sanderson *et al.*, 1995; Jeanneret *et al.*, 2006; Butler *et al.*, 2009) or functions (Meyer-Aurich *et al.*, 2003), decision tree using fuzzy subsets allowing cope with uncertainty and avoid effect of knife-edge limit of classes (Keichinger, 2001; Sattler *et al.*, 2010). More recently several authors (Sadok *et al.*, 2009; Messéan *et al.*, 2010; Anonymous., 2011)) developed a qualitative approach based on decision tree using the DEXi tool (Bohanec *et al.*, 2008). Tichit *et al.* (2010) worked on a totally different approach, using a dataset and deriving *a posteriori* regressions between a variable assessing the occurrence of bird and different sets of input variables *(table 3)*.

Discussion

This article aimed at providing an overview of the biodiversity indicator available to agronomists working on cropping systems at field and to other stakeholders working on higher scales.

Table 3. *Examples of predictive indicator with their main characteristics*

Name **Reference**	**Taxonomic gro^{2}up (species)**	**Species number**	**Expresion of result**	**Aggregation function**	**Input variable or component**	**Scale**
VEM Sanderson *et al.*, (1995)	Plants	534	Probability of presence between 0 and 1	Calculation of suitability index from the British National Vegetation Classification A probability of presence is derived from this index	e.g. grazing (yes/no) Slurry application (yes/no) Mineral fertilization (kg N/ha)	Fields, farm, landscape
Keichinger, (2001)	Pheasant Partridge Field hare Wild rabbit	1 1 1 1	Score between 0 (maximum impact) and 10 (no impact)	Decision tree with fuzzy subsets for global indicators and components	Soil cover Crop diversity Machine use Pesticide risk Irrigation Semi-natural area	Farm, landscape
Meyer-Aurich *et al.*, (2003)	Amphibian Partridge	Not explicit 1	Disturbance impact scored between 0 (none) and 1 (high)	Continuous function	e.g. number of tillage perturbation amount of nitrogen number of herbicides	Field, farm, landscape
SALCA bd Jeanneret *et al.* (2006)	Plants Mamamals Birds Amphibians Snails and slugs Spides Carabid beetle Orthoptera Bees and bumblebees Butterflies	Not explicit	Score between 1 (negative impact) and 5 (positive impact)	Each cropping practices scored and calculation of an average value	Scale	Field, farm
Butler *et al.* (2009)	Birds Bumblebees Butterflies Mamals Broadleaf plants	63 14 23 44 190	Risk score between 0 (none) and 3 to 6 (high)	Scoring system: assessing impact on species needs (e.g. diet, forage habitats)	e.g. Spring to autumn sowing Increased agrochemical inputs Loss of non-cropped habitat Land drainage	Regional
MASC Sadok *et al.* (2009)	None	No	4 qualitative classes	Decisison tree based on decision tree (DExi software)	Crop diversity Non sprayer area Treatment frequency index[a]	Cropping system
DEXiPM Messéan *et al.* (2010)	Flying natural enemies Polllinators Soil natural enemies Weeds Flora of semi-natural area	Not explicit	5 qualitative classes	Decisison tree based on decision tree (DExi software)	e.g Deep tillage, Treatment frequency index[a], Habitat management for soil natural ennemies	Cropping system and neighboring habitat
Sattler *et al.* (2010)	Birds Amphibian Mamal Hoverfly Field flora	1 1 1 Not explicit Not explicit	Between 0 (low) and 1	Decision tree with fuzzy subsets	e.g. cropping practices, Herbicides treatment frequency index[a], fertilization (kg N/ha)	Field
Tichit *et al.* (2010)	Birds	2	Occurrence of bird (yes/no)	Logistic regression function	11 management and 11 habitats variables	Field
IBEA Anonymous, (2011)	None	None	5 qualitative classes	Decisison tree based on decision tree (DExi software)	e.g. Mineral fertilization (kg N/ha) Treatment frequency index[a] Area with tillage	Farm

[a] Sum of ratio actual pesticide rate/recommended rate. Here the index is calculated separately for fungicides, herbicides, insecticides.

We organized the presentation in three groups of indicators according to their type of construction. As it was pointed out by several review articles, a very large number of measured indicators are available using many taxonomic groups. The implementation of such indicators requires taxonomic knowledge what is the main hindrance to their implementation for non-specialists like many agronomists. This led some authors to propose parataxonomic approach which assess the diversity by sorting living organisms into morphologic groups (Duelli and Obrist, 2003). This approach remains very controversial (Abadie *et al.*, 2008). Lindenmayer and Likens (2011) analysed in a very exhaustive way the use of measured biodiversity indicator. They pointed out the lack of justification for the choice of the species and the poor predictive quality of many measured indicators. Some authors tried to validate measured indicators. At European level no group species could be correlated to the diversity of all taxa (Billeter *et al.*, 2008), although such test across different ecosystems is not relevant according Lindenmayer and Likens (2011). At field level, a comparison of individual taxa of invertebrates with the whole diversity of invertebrates accross taxa yielded the best correlation for heteroptera and aculate hymnoptera (bees, wasp and ants), (Duelli and Obrist, 2003). Arena, coleotera (among them carabid beetles), syrphidae or red list species showed a poor correlation.

Such considerations led several authors to state that assessment of biodiversity should rest on several taxa (e.g. Carignan and Villard, 2002; Duelli and Obrist, 2003). In any case, biodiversity indicators are often expressed in composite indices like those presented in *table 1*. The Shannon indicator is the most popular but does not seem to be the most relevant (Jost, 2006). A major drawback is that such indicators are only quantitative and do not take into account the nature of species. An increase of biodiversity can also be due to invasive species (Lamb *et al.*, 2009). Those authors tested the ability of several indices to show changes of biodiversity. Traditional indices like the Simpson and Shannon indices (see *table 1*) yielded poorly in comparison with the Buckland arithmetic Occurrence index. In the approach of van Wenum *et al.* (1999) in the Netherlands, which assesses biodiversity at farm level, each species is weighted by a factor addressing its rarity.

Although there is a growing agreement to assess not only biodiversity but also the linked ecosystemic services like pollination (Le Roux *et al.*, 2008), those are assessed in very indirect way by assessing the diversity of species involved in the service. This is the case for biological control. But possibility of predation between predator guilds limits the interest of species diversity, which is a very complex concept (Straub and Snyder, 2008). Measurement of amount of captured prey by a predators, or determination of stomach content of predator with help of molecular biology (King *et al.*, 2008) are useful to assess the service in experimental conditions. The implementation of such techniques in routine to derive an indicator remains questionable for the moment.

The second group of simple indicators based on management variable are more easy to assess than measured ones and are therefore used in several multi-thematic environmental assessment method (Braband *et al.*, 2003). Their predictive quality remains in general poor although Billeter *et al.* (2008) found some correlations with the diversity of some taxa (*table 2*). But the correlations were observed for a very broad range of conditions regarding landscape structures, farming systems. Such indicators do not take into account interactions between management and pedo-climatic conditions and do not refer in an explicit way to species. In any case, simple indicators based on management data are useful to communicate with farmers as they focus on information which farmers know and understand (Tichit *et al.*, 2010). They can be used to analyze results obtained with measured indicators. The Nature Balance is an example of assessment method of biodiversity at farm level combining both types of indicators (Oppermann, 2003).

In the difference with previous reviews on biodiversity indicators in farmland (e. g. Braband *et al.*, 2003; Büchs *et al.*, 2003), our article does not only focus on measured indicators or simple indicators using management data, but also on predictive indicators. In the last decade several initiatives were proposed for assessment of agricultural systems, a majority of them being developed in the frame of multi-criteria assessment method addressing also other environmental issues or even other dimensions of sustainability. Their advantage is that they do not need taxonomic identification while providing information of impacts of crop management factors on one or several species, or a given taxon. Most of them can be used by agronomists working on design of innovative cropping systems.

Like for the other types of indicators, their predictive quality remains a question. Correlations were found by some authors between indicator output and measured diversity of the taxon (Butler *et al.*, 2009, excepted for broadleaf species), at the level of occurrence of species (Sanderson *et al.*, 1995), or with expert judgments (Keichinger, 2001). The development of qualitative approach based on the DEXi tool (Bohanec *et al.*, 2008) should be noticed. The construction of such qualitative models is relatively easy but the methodology requires more methodological investment, especially on the sensitivity (Bergez *et al.*, 2010). No validation was undertaken for these methods based on DEXi. Actullay such indicators constructed with expert-based methods may be limited by uncertainty and subjectivity. While expert-based indicators are built in a ''top-down'' manner, a new trend consists in adopting a ''bottom-up'' point of view by building indicators from observation data. The approach of Tichit *et al.* (2010) is one option. Machine-learning techniques (Shan *et al.*, 2006) such as decision trees is another. They allow produce indicators that are more objective, scientifically sound and still easy to interpret. Uncertainty is still present but can be represented and handled using accurate formalisms such as fuzzy logic. A work on the development of a biological control indicator is ongoing within the Casdar entomophage project (2009-2011)[1]. The availability of adequate dataset is a major requirement for the development of indicators following this methodology.

Conclusion

A vast number of biodiversity indicators are currently available for the agrono-

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[1] http://78.155.145.122/rmtbiodiv/moodle/course/category.php?id=21.

mist and stakeholders who needs to assess the impact of agriculture on biodiversity. A great diversity of indicators goes together with this abundance. The selection of indicators among the three types of indicators given by the typology proposed in this article, will depend on the goal of the assessment work. We recommend to use measured indicators when users aim at assessing efficacy of a policy, of an agri-environmental scheme. But this requires several species to give a ''whole picture'' and a justification of the species choice. Simple indicators can be used by farmers' advicers in a first stage to work with farmers to make them aware of the problem. They can also complete the information given by measured indicators. But it remains a challenge to prove the link between both type of indicators, to highlight the causes of the observed impacts on biodiversity. The third option is to use predictive indicators resulting from an operational model or assessment function linking causes and effect. They are useful for agronomists working on *ex ante* assessment of newly designed cropping systems or to test policy options. Finally, more research is necessary on the validation of all those reviewed biodiversity indicators. There is also a need of new indicators assessing not only diversity *per se* but also the impact of crop and landscape management on ecosystemic services.

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