Biodiversity indicators as a tool to assess sustainability levels of agro-ecosystems, with a special consideration of grassland areas

Biala K., Peeters A., Muys B., Hermy M., Brouckaert V., García V., van der Veken B., Valckx J.

in

Molina Alcaide E. (ed.), Ben Salem H. (ed.), Biala K. (ed.), Morand-Fehr P. (ed.). Sustainable grazing, nutritional utilization and quality of sheep and goat products

Zaragoza : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 67

2005
pages 439-443

Biodiversity indicators as a tool to assess sustainability levels of agro-ecosystems, with a special consideration of grassland areas

K. Biala*', A. Peeters**, B. Muys***, M. Hermy***, V. Brouckaert**, V. García**,B. Van der Veken*** and J. Valckx*****

*Institute for Land Reclamation and Grassland Farming (IMUZ), DOB Wroclaw, Poland
**Laboratoire d'Ecologie des Prairies, UC Louvain, Belgium
***Laboratorium voor bos, natuur en landschap, KU Leuven, Belgium

SUMMARY – The impact of agricultural practices on biodiversity is unquestionable. Biodiversity indicators can therefore be used for assessing both positive and negative effects of different agricultural activities and management strategies on the environment. Consequently, they can be applied as a powerful tool for assessing sustainability levels in agro-ecosystems. Biodiversity can be considered at the level of genetic, species and ecosystem (community) diversity. For agriculture it can be also expressed as planned (agricultural) and associated (para-agricultural and extra-agricultural) biodiversity, which reflect different functions of plants, animals and micro-organisms in agro-ecosystems. Diversity planned by the farmer is represented *i.a.* by different varieties of crops or livestock breeds. Associated biodiversity appears spontaneously within production systems. Para-agricultural biodiversity plays an important role in agro-ecosystems, including beneficial as well as invasive organisms. Extra-agricultural biodiversity fulfils an important heritage function. Potential indicators are identified for all the above-mentioned biodiversity categories at different spatial scales: field, farm and landscape.

Key words: Sustainability, indicators, grassland, agricultural biodiversity, para-agricultural biodiversity, extra-agricultural biodiversity.

RESUME *– "Indicateurs de biodiversité comme outil pour déterminer les niveaux de durabilité des agro-écosystèmes, avec une considération spéciale des secteurs de prairies". L'impact des pratiques agricoles sur la biodiversité est indiscutable. Des indicateurs de biodiversité peuvent être utilisés pour évaluer les effets positifs et négatifs des différentes activités et des stratégies de gestion agricoles sur l'environnement. Ils peuvent être utilisés comme des outils performants pour estimer les niveaux de durabilité des agro-écosystèmes. La biodiversité peut être envisagée au niveau de la diversité des gènes, des espèces et des écosystèmes (communautés). En agriculture, on peut aussi distinguer la biodiversité planifiée (agricole) et associée (para-agricole et extra-agricole), ce qui reflète les différentes fonctions des plantes, des animaux et des micro-organismes dans les agro-écosystèmes. La diversité planifiée par l'agriculteur est représentée entre autres par les variétés des cultures et les races des animaux d'élevage. La biodiversité associée apparaît spontanément dans les systèmes de production. La biodiversité para-agricole joue un rôle important dans ces systèmes, elle comprend des organismes bénéfiques et invasifs. La biodiversité extra-agricole remplit une importante fonction patrimoniale. Des indicateurs potentiels sont identifiés pour toutes les catégories mentionnées ci-dessus à différentes échelles spatiales : parcelle, ferme et paysage.*

Mots-clés : *Durabilité, indicateurs, prairie, biodiversité agricole, biodiversité para-agricole, biodiversité extra-agricole.*

Introduction

The concept of sustainability applied to agriculture developed mainly as a result of negative impacts of intensive farming systems on the environment and the quality of life of rural and neighbouring communities. Intensive farming systems are based on genetically uniform crops and livestock breeds, vulnerable to pests and diseases. High yields are obtained through dependency on external inputs (especially fossil energy, fertilizers and pesticides) which can cause decreased air, water, soil and food quality (Altieri, 1999). Intensification and specialisation also bring about landscape changes, resulting in its homogenisation and destruction of traditional landscape elements and, consequently, loss of habitats. Marginal areas, on the other hand, are threatened with cessation

of agricultural practices and land abandonment. All these factors lead, directly or indirectly, to loss of genetic, species and community biodiversity.

Growing awareness of environmental issues led to the recognition of the importance of maintaining and enhancing biodiversity not only in nature reserves but also in agro-ecosystems, where it performs numerous services. It not only supports the primary function of agriculture, production of food and raw materials, but also provides services indispensable to ecosystem functioning, such as nutrient cycling, protection and enrichment of soils, regulation of local climates and hydrological processes, pollination and regulation of the abundance of undesirable organisms (Altieri, 1999). Moreover, biodiversity offers scientific, cultural, aesthetic and recreational services, which increase the quality of life of the whole society. Therefore, together with other natural resources, it is perceived as a part of "natural intergenerational capital".

As the impact of agricultural practices on biodiversity is recognised, biodiversity indicators can be used for assessing both positive and negative effects of different agricultural activities and management strategies on the environment. Consequently, they can be applied as a powerful tool for assessing sustainability levels in agro-ecosystems.

Categories of biodiversity in agro-ecosystems

Biodiversity can be considered at the level of genetic, species and ecosystem (community) diversity. For agriculture, however, it can be also expressed as planned (agricultural) and associated (para-agricultural and extra-agricultural) biodiversity, which reflect different functions of plants, animals and micro-organisms in agro-ecosystems.

Agricultural diversity

Agricultural or planned diversity is deliberately incorporated into the system by the farmer (Vandermeer *et al*., 1998). Species and genetic diversity of crops, forage plants, temporary grasslands and livestock ensures maintenance of production and increases stability of the agro-ecosystem, which is namely less susceptible to pest and diseases outbreaks and to adverse weather conditions. Moreover, such diversity diminishes reliance on a single enterprise (Collins and Hawtin, 1998), thus positively influencing socio-economic stability and reducing the effects of severe changes in consumer demand. Genetic diversity within species forms a reservoir of genes available for genetic improvement. The choice of local species, varieties and breeds, especially those which are on decline, prevents their extinction and genetic erosion (Maljean and Peeters, 2001). At the landscape level, crop and temporary grassland diversity adds to habitat variability and heterogeneity and increases the ecotone effect, therefore supporting the existence of beneficial fauna and enhancing positive para-agricultural biodiversity.

Simple and easily obtainable indicators of planned diversity at the field, farm and landscape level include the number of varieties and species of crops, and livestock breeds (OECD, 2001). The rarity can be expressed as the proportion of local varieties or breeds in their total number (Piveteau, 1998). At the landscape and regional level an important indicator is the area of crop varieties with genetic resistance to pathogens and pests (Wascher, 2000). An indicator of community diversity at the field and farm level for temporary grassland is the proportion of forage mixtures. Community diversity indicator for the landscape level can be derived from the Shannon Index and takes into account the number of fields grown with different crop species or grassland plots. In intensive farming systems it can be expected that values obtained for these indicators will be low, whereas high values will pertain to more sustainable agriculture.

Para-agricultural biodiversity

Associated biodiversity consists of organisms, which appear independently in the agro-ecosystem (Vandermeer *et al*., 1998) from surrounding environments and whose diversity and abundance is strongly influenced by the agro-ecosystem management. Some of these species play a decisive role, forming what is known as para-agricultural (Maljean and Peeters, 2001) or functional (Altieri, 1999)

biodiversity. They particularly include species which have a positive effect on production, such as photosynthetic organisms that produce fodder, microorganisms which play a role in organic matter decomposition or nitrogen fixation, parasites and predators of pests, pollinators and earthworms.

Semi-natural grasslands and rangelands are an extremely important component of para-agricultural biodiversity as they support all previously listed biodiversity services and are the most diversified communities on European farmland. They constitute a habitat and a source of food for livestock, ensuring the production of livestock products. Their existence, however, is threatened not only by intensification but also by land abandonment.

No feasible indicators for measuring genetic para-agricultural diversity have been suggested so far. The choice of indicators for the species and community level should focus on functional groups of species. Of these, earthworms appear to be a very valuable indicator. Their biomass or abundance can be measured relatively easily. Moreover, they recover relatively quickly in response to more extensive agricultural practices (Paoletti, 1999b). Another group of animals which can constitute a reliable indicator of sustainability are arthropods, mainly carabids, spiders and staphylinids (Duelli and Obrist, 2003). There are easy standardized methods for their collection and comparative interpretation (Duelli *et al.*, 1999). The value of these indicators is heightened through their applicability to all spatial levels. Due to their importance for agro-ecosystem biodiversity, semi-natural grasslands should be included in any indicator system (OECD, 2001; van Dijk, 1996), combining both quantity and quality aspects. Relevant indicators for the field and farm level include plant species richness and diversity, including forage plants and for the farm and landscape level, the number of grassland plant communities (associations or alliances). The area of semi-natural grasslands is an indicator used for assessing sustainability of agriculture for example in Great Britain (MAFF, 2002) and in France (Piveteau, 1998) and is particularly appropriate for landscape and regional level.

Extra-agricultural biodiversity

Extra-agricultural biodiversity consists of spontaneously appearing organisms, linked to varying degrees with the farming system, but with a less important role in its general functioning (Maljean and Peeters, 2001) than the para-agricultural biodiversity. However, many species in this category have an enormous heritage value, including rare plants, insects (butterflies, dragonflies), birds and mammals, including 'flagship' species, capable of provoking public concern and actions when threatened with serious decline or extinction.

The presence and abundance of rare plant species are good indicators at the field and farm level, while animal species, such as meadow birds and butterflies can be useful at the landscape level. Both are valuable indicators of the presence of high ecological value habitat in an agro-ecosystem (Wascher, 2000).

Species populations trends are an easily implemented and interpretable indicator of biodiversity change (Wascher, 2000). Birds are suggested as good indicators, as habitat loss through intensification and specialisation result in the significant decline in their populations (Donald *et al.*, 2001) and they are comparatively easy to observe and identify. Populations of key farmland birds are included in various sustainability assessment indicator systems (OECD, 2001; Piveteau, 1998; MAFF, 2002). Among invertebrates, butterfly species richness and abundance can be used as an indicator, as they are sensitive to changes in habitat quality (Collinge *et al.*, 2003), but their sampling is more time-consuming than birds. Similarly to para-agricultural biodiversity, semi-natural grasslands also add to enhancing and maintaining extra-agricultural biodiversity.

Habitat diversity and connectivity

One of the main quality aspects and, consequently, an indicator of high biological diversity in agricultural landscapes is a high level of structural complexity (Wascher, 2000). The importance of connectivity between habitats, provided by corridors in the landscape, such as hedgerows, field margins or woodland strips for the abundance and distribution for various biota has been well documented (Paoletti, 1999a; Hinsley and Bellamy, 2000; Ouin and Burel, 2002). Habitat indicators are especially relevant for para- and extra-agricultural biodiversity.

Indicators particularly suitable for the farm and landscape level are the ratio of cropped to uncropped land (including linear features) as well as the length of linear habitats per km^2. Boundary diversity can be a farm and landscape level indicator of the spatial complexity and land use changes, showing lowest value when all the boundaries represent the same type (Wascher, 2000). Data for the indicators are easily available from land use maps or aerial photographs.

Conclusions

There is a common agreement that no single biodiversity indicator can be devised and that their choice depends on the motivation for a particular evaluation (Duelli and Obrist, 2003). Indicators presented in the paper are relevant to various crucial functions provided by biodiversity in agro-ecosystem, leading to its stability and sustainability. They are valid for various biodiversity categories and spatial scales. Moreover, they meet the criteria of ease of interpretation and measurability as well as responsiveness to spatial and temporal changes. Their analysis, however, leads to the conclusion, that the optimum set of biodiversity indicators for sustainability assessment in agriculture can be developed through combination of direct and indirect, biotic and habitat diversity measurements.

Acknowledgements

This research is supported by the Belgian Federal Office for Scientific, Technical and Cultural Affairs (OSTC).

References

Altieri, M. (1999). The ecological role of biodiversity in agroecosystems. *Agric. Ecosys. Environm.*, 74: 19-31.

Collinge, S.K., Prudic, K.L. and Oliver, J.C. (2003). Effects of local habitat characteristics and landscape context on grassland butterfly diversity. *Cons. Biol.*, 17: 178-187.

Collins, W. and Hawtin, G.C. (1998). Conserving and using plant crop biodiversity in agroecosystems. In: *Biodiversity in Agroecosystems*, W. Collins, C.O. Qualset (eds). CRC Press LLC, Boca Raton.

Dijk, G. van (1996). Land use policy and plant conservation, especially regarding grasslands. In: *Proceedings of the 1st Planta Europa Conference on the Conservation of Wild Plants*, Newton, J. (ed)., Hyères, France, September 1995.

Donald, P.F., Green, R.E. and Heath, M.F. (2001). Agricultural intensification and the collapse of Europe's farmland bird populations. *Proc. R. Soc. London* B, 268: 25-29.

Duelli, P., Obrist, M.K. and Schmatz, D.R. (1999). Biodiversity evaluation in agricultural landscapes: Above-ground insects. *Agric. Ecosys. Environm.* 74: 33-64.

Duelli, P. and Obrist, M.K. (2003). Biodiversity indicators: The choice of values and measures. *Agric. Ecosys. Environm.*, in press.

Hinsley, S.A. and Bellamy, P.E. (2000). The influence of hedge structure, management and landscape context on the value of hedgerows to birds: A review. *Journ. of Environm. Management*, 60: 33-49.

MAFF (2002). *Towards sustainable agriculture (a pilot set of indicators).* www.defra.gov.uk/farm/sustain/pilotind.pdf

Maljean, J.-F. and Peeters, A. (2001). *Integrated farming and biodiversity: Impacts and political measures*. Council of Europe, STRA-CO/AGRI (2001) 27.

OECD (2001). *Environmental indicators for agriculture. Vol. 3: Methods and results.* OECD, Paris.

Ouin, A. and Burel, F. (2002). Influence of herbaceous elements on butterfly diversity in hedgerow agricultural landscapes. *Agric., Ecosys., Environm.*, 93: 45-53.

Paoletti, M.G. (1999a). Using bioindicators based on biodiversity to assess landscape sustainability. *Agric. Ecosys. Environm.*, 74: 1-18.

Paoletti, M.G. (1999b). The role of earthworms for assessment of sustainability and as bioindicators. *Agric., Ecosys., Environm.*, 74: 137-155.

Piveteau, V. (1998). *Agriculture et environment*. Institut Français de l'Environment.

Vandermeer, J., Van Noordwijk, M., Anderson, J., Ong, C. and Perfecto, I. (1998). Global change and multi-species agroecosystems: Concepts and issues. *Agric. Ecos. Environm.*, 67: 1-22.

Wascher, D.M. (ed.) (2000). *Agri-environmental indicators for sustainable agriculture in Europe*. European Centre for Nature Conservation, Tilburg.