Review Paper

Biodiversity and ecosystem services in agroecological systems. A review

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Abstract

Objective: To analyze the relationships between biodiversity and ecosystem services in an agroecological context.

Materials and Methods: Different sources of information (114) were consulted and analyzed, referring to the available literature in the fields of biology, agricultural sciences and agroecology, with the purpose of deepening the state of knowledge related to biodiversity and ecosystem services provided by agroecological systems.

Results: This review addresses an updating process constituted by the main efforts in this branch of knowledge and proposes a systematic search of the key topics and approaches that have been developed to understand the services provided by biodiversity as a key principle of agroecology. It also provides a guide for the development of research that allows a comprehensive understanding of the ecosystem services generated by biodiversity management. Analyses of the relationship between biodiversity and ecosystem services in agroecosystems should be part of comprehensive studies in the agroecological context, so that from science it becomes evident which practices are more effective for the sustainability of productions.

Conclusions: Multifunctional, biodiverse ecosystems that implement management practices that optimize land use and efficiently manage ecosystem services should become the paradigm for sustainable agroecosystem management. There is a strong interrelationship between the functioning of biodiversity and the development of ecosystem processes that will subsequently form the basis of production, based on the richness and spatial and temporal variability of species, their performance in the complexity of ecosystems and the maintenance of ecosystem services at different scales.

Keywords: agrobiodiversity, agroecosystems, agroecology

Introduction

The intensification of human activities in the world has led in recent years to the loss of the capacity of ecosystems to produce goods and services capable of satisfying the needs of the population. In this context, agroecology constitutes a paradigm that promotes the enhancement of biodiversity as a key principle to strengthen ecosystem services from the beginning of the agroecological transition in production systems.

The report on the global assessment of biodiversity and ecosystem services points out that nature has been severely affected, including species, their genes and populations, communities of interacting populations, ecological and evolutionary processes (IPBES, 2019), due to anthropogenic actions. Therefore, it is stated that the Earth has entered a new geological epoch, resulting from the transformations that have taken place on the planet, and that respond to a human origin. This new epoch is called the Anthropocene.

Birkhofer *et al*. (2018) indicate that there is a need to improve understanding of the relationships between biodiversity and ecosystem service provision for the development of sustainable agriculture. They propose to identify indicator species for the simultaneous assessment of ecosystem services. Although biodiversity functions are not comprehensively understood, it is valid to highlight that the functionality of species in the agricultural context is more important than diversity per se. Duncan *et al.* (2015) affirm that studies that address the relationships between biodiversity and the provision of ecosystem services and that demonstrate the determining role of biodiversity in the stability and productivity of natural and exploited systems, as well as its contribution to their resilience, are decisive. However, these studies are still insufficient due to the heterogeneity of agroecosystems.

To manage production systems, the ideal is to balance food production, ecosystem services and biodiversity, which requires a change that promotes multifunctionality at the landscape scale (Holt *et*

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al., 2016). Agroecology proposes reincorporating agrobiodiversity (variety mixtures, polycultures, agroforestry, animal integration, among others) as one of its fundamental principles, together with water conservation and harvesting practices, but it also requires ensuring landscape restoration, which guarantees reasonable yields and greater resilience (Altieri and Nicholls, 2020). These more complex agroecological systems, which include multiple components are more likely to have positive food security and nutrition outcomes (Bezner-Kerr *et al*., 2021). The objective of this paper is to analyze the relationships between biodiversity and ecosystem services in an agroecological context.

Materials and Methods

A bibliographic review of different sources of information (114) was carried out, referring to the available literature in the fields of biology, agricultural sciences and agroecology, with the purpose of deepening the state of knowledge related to biodiversity and ecosystem services provided by agroecological systems. A search was conducted for papers indexed in recognized databases such as Science Direct, Springer and SciELO, the search terms were ecosystem services, biodiversity, agroecology.

Of the publications reviewed, 93 were in English, 19 in Spanish and 2 in Portuguese.

Based on the analysis and review of the literature, this study contributes to support and guide future research needs with a holistic approach to manage and understand the functioning of agroecosystems in the agroecological context.

The role of biodiversity in agroecosystems

The definition of biodiversity is complex, in that it refers to the variability of life (CBD, 2000). To this end, the composition, structure and function of organisms are considered. Considering that biodiversity has several components, which are expressed at different scales, its measurement must be treated hierarchically, as it is intrinsically a multidimensional issue, encompassing genes and species, functional forms, adaptations, habitats and ecosystems, as well as variability within and between them (Laurila-Pant *et al*., 2015). All these dimensions of biodiversity are closely interconnected, affect ecosystem status, stability and productivity, as well as ecosystem services (Schneiders and Müller, 2017). This is why knowledge of the relationship between biodiversity components and ecosystem services is essential to understand the functioning of ecological processes in agroecosystems.

According to Gliessman (2022), with increased diversity there is greater microhabitat differentiation, which allows component species to occupy their ideal habitat. In addition, when several species with different needs take part in a farming system with habitat diversity, better resource efficiency can be achieved. Diversity provides opportunities for coexistence and beneficial interactions. For example, open habitats in an agroecosystem may be occupied by many different useful species rather than weeds. In addition, the different populations present may allow overlapping predator/prey relationships to promote biological control. Also, the diversity of the belowground portion enhances a variety of ecosystem services, such as nutrient cycling, regulation of local hydrological processes, and carbon sequestration, which have on-farm as well as off-farm impacts.

There is a broad consensus in many aspects about the effect of diversity on ecosystem functions. That is, greater diversity increases functions, because different species perform different functions and occupy different niches. In addition, plant community diversity and composition have a direct relationship with soil communities, which contribute to various ecosystem functions, so there is a positive relationship between plant biodiversity and ecosystem functioning. This knowledge can be used to design diversification schemes that maximize agroecosystem functioning (Cappelli *et al*., 2022).

However, it is not enough for an agroecosystem to be biodiverse. Its design must be based on knowledge to achieve complex, locally adapted agricultural systems capable of providing food to the population, while being more resilient and constituting a valuable cultural heritage. This is why biologically complex traditional systems are needed to achieve a transition to forms of agriculture that are more ecological, biodiverse, local, sustainable and socially just (Altieri, 2021).

It has been documented that, compared with conventional monocultures, diversified farming systems exhibit substantially greater biodiversity, better soil quality, and greater water holding capacity, and show higher energy efficiency and better resilience to climate change. Concerning conventional monocultures, diversified farming systems show a positive association between crop diversification and agricultural productivity, farmer income, food security, and nutritional richness (Nicholls and Altieri, 2019). In addition, diversification avoids dependence on a single product by expanding offers, for which there are several strategies (table 1) that contribute to the efficiency of the production system.

Multiple studies around the world clearly show how agriculture causes landscape simplification and biodiversity loss, leading to the detriment of ecosystem functions by compromising their provision of services and, probably, reducing the adaptive capacity of these systems to disturbances. Felipe-Lucia *et al*. (2020) point out that land use intensification can increase the provision of ecosystem services, such as food and timber production, but it also drives changes in ecosystem functioning and biodiversity loss, which can ultimately compromise human well-being.

Agroecological practices need to be promoted beyond farm boundaries, which can be based on a bottom-up approach, from agroecological lighthouse farms to networks of farms to amplify the adoption of agroecology at the landscape scale, taking into account the context, with the aim of fostering biodiversity and ecosystem services at larger scales (Jeanneret *et al*., 2021).

The Food and Agriculture Organization of the United Nations (FAO) recognizes biodiversity as one of the 10 elements of agroecology for assessing transitions to more sustainable agri-food systems, so as to ensure food security and nutrition while conserving, protecting and enhancing natural resources. Through diversity planning and management, agroecological approaches enhance the provision of ecosystem services, particularly pollination and soil health, on which agricultural production depends. Diversification can increase productivity and resource use efficiency by optimizing biomass harvesting and water harvesting (FAO, 2018).

Biodiversity and ecosystem services. The concept of ecosystem services became known in the early 1980s. Subsequently, during the 1990s, this concept was introduced into the scientific debate, due to the multiple authors who applied it from different perspectives of analysis. With the Millennium Ecosystem Assessment (MEA) in 2005, the concept becomes known beyond the scientific discourse. Recently, Wang *et al*. (2022) propose that ecosystem services represent the well-being that ecosystem functions create for human society through biological and physical interactions, which resembles the exchange flows between nature and human society.

Subsequently, other initiatives promote the focus on the relationship between biodiversity and ecosystem services, for example, the Common International Classification of Ecosystem Services (CICES), which proposes a conceptual framework for ecosystem services assessments (Czúcz *et al*., 2018). Thus, the concept integrates different scientific disciplines from natural and social sciences, brings together different sectors and stakeholders to discuss natural resource management, and assumes biodiversity conservation and commercial interests.

The Economics of Ecosystems and Biodiversity Report (Elmqvist and Maltby, 2010) focuses its argumentation on the valuation of ecosystem services and points out the need to take into account ecological, social and monetary values. Likewise, with the creation of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), it has been possible to articulate information on ecosystem services for decision-making in the face of certain processes.

Table 1. Main crop diversification strategies, grouped into five categories.

Crop diversification strategies	Definition and details
Agroforestry	The inclusion of ligneous vegetation, like trees and shrubs, with crops or livestock, and both, simultaneously or sequentially on a land unit.
Cover crops	The inclusion of plants cultivated for agronomic or environmental purposes, besides the main crop on a land unit.
Mixed crops	The inclusion of several cultivars of the same species on a land unit.
Intercropped crops	The simultaneous or relay cultivation of multiple crops during a significant part of their growth cycle on a land unit.
Crop rotation	Recurring succession of a set of selected crops, cultivated on a same land unit each season or year, according to a plan.

Source: Beillouin *et al*. (2021)

The main function of biodiversity is to facilitate the functioning and development of ecosystem processes, which will later become the basis for the production of ecosystem services (EEM, 2005; Polania *et al*., 2011). However, there are few references on how different agronomic decisions impact biodiversity and, in turn, the whole set of ecosystem services it provides.

Schneiders and Müller (2017) state that the assessment of ecosystem services must include the entire gradient, from natural to technological solutions, so it is necessary to understand how key functions determine the provision of ecosystem services and how they depend on biodiversity, as well as the effect of reducing these functions through technological variants, which is crucial in the search for nature-based solutions.

The classification of ecosystem services, developed by the initiative that brought together thousands of scientists for the Millennium Ecosystem Assessment (EEM, 2005), is considered a reference in international research and policy documents, in which the ecosystem services approach is applied. This classification groups ecosystem services as summarized below:

1. Provisioning services: these are the material goods and products obtained from ecosystems (food, fiber, timber, firewood, water, soil, genetic resources, oil, coal, gas).
2. Regulating services: benefits resulting from the self-regulation of ecosystem processes (maintenance of air and soil quality, erosion control, water purification).
3. Cultural services: non-material benefits obtained from ecosystems (spiritual enrichment, scenic beauty, artistic and intellectual inspiration, recreation).
4. Support services: these are defined as the ecological services and processes (basic) necessary for the provision and existence of the other ecosystem services (nutrient cycling/soil formation, photosynthesis/primary production, water cycling).

The EEM (2005) made it possible to identify how human intervention in ecosystems can increase direct and indirect benefits for society (increase in crops, for example) and also generate spatial and temporal changes that lead to transformations in ecosystems, their processes and functions, thus affecting human well-being. The views generated in this initiative showed that there are trade-offs between provisioning services and regulating services. Usually, the former are in better condition or are privileged, to the detriment of the latter.

Agricultural practices that aim to promote species richness of individual taxonomic groups can increase multifunctionality (Finney and Kaye, 2017), but the positive effects of agri-environmental schemes on the relationships between multiple components of biodiversity and ecosystem services are unknown (Ekroos *et al*., 2014).

The mechanisms that result in higher productivity in diversified systems are embedded in the facilitation process. Facilitation is an ecological interaction, which occurs when one crop modifies the environment in a way that favors a second crop, and constitutes a tool for restoring diversity and ecosystem functions (Navarro-Cano *et al*., 2019). This is why the farmer's knowledge is essential to design and manage the system, taking advantage of the potential of biodiversity.

However, there are few references on the most appropriate indices for measuring functional diversity. In general, the indices used in ecology are widely applicable and can be used in agroecosystems. For example, the diversity of crops or habitats in an agricultural landscape can be calculated. Yet, they do not provide information on their functional aspects and therefore do not contribute to decision-making on system management to ensure ecological processes. The valuation of biodiversity must take into account the impacts it causes on the development of ecosystem services, since it is considered a regulator of the processes occurring in ecosystems (Quijas *et al*., 2019).

In Cuba, Vázquez-Moreno (2013) proposed and validated a methodology for the diagnosis of biodiversity design and management in the production system. The aforementioned methodology considers several dimensions: species, the complexity of spatial, structural and temporal arrangements, as well as the conservation approach to natural resources, which allows identifying in what sense transformations should be achieved on the farm to strengthen ecological interactions and synergy between biological components, so that integration is thus achieved in its design and management.

Schneiders and Müller (2017) argue that biodiversity restoration and ecosystem services are two sides of the same coin. They highlight the role of biodiversity, as a driver of all existing relationships in social-ecological systems, and emphasize that it is based on very complex schemes of ecological interactions with high mutual interdependence.

In a general analysis on the subject, Harrison *et al*. (2014) indicate that the relationship between biodiversity and ecosystem services can be positive as well as negative. These authors point out that as biodiversity can contribute to multiple services, there will be trade-offs or exchanges among them.

The Economics of Ecosystems and Biodiversity (TEEB) initiative developed a classification list of ecosystem services (table 2).

Biodiversity can play three different roles in ecosystem services: as a regulator of ecosystem processes, as a final ecosystem service, or as an asset (Mace *et al*., 2012). However, because the description of biodiversity is complicated, it is not simple to explain the performance of biodiversity or the impacts of its decline on ecosystem services in general (Elmqvist and Maltby, 2010). For all of the above-mentioned reasons, it is necessary to develop more comprehensive research that takes into account evaluations with multidisciplinary criteria, so that the multiple dimensions and utilities of ecosystem services to generate human well-being are recognized, depending on the context, scale and involved actors (Saarikoski *et al*., 2016). In addition, the effect of good agricultural practices must be considered. This is why the assessment of ecosystem services is a challenge, given the great variety of agroecosystems and their complex interactions.

Agroecology as an enhancer of biodiversity and ecosystem services. Agroecosystems can transition between alternative states, defined by their structural and functional characteristics. Agroecological transitions are a special type of human-mediated transitions, where the various components of the agroecosystem and their interactions are reconfigured through a design process (Tittonell, 2020).

Agroecology has been recognized as a springboard for achieving several sustainable development goals (SDGs), due to its great potential to build agricultural systems that are resilient to climate change, while improving ecosystem services and reducing biodiversity loss (Sethuraman *et al*., 2021). In an agroecological context, innovation is promoted to manage agroecosystems based on better use of resources, which enables the evolution of farms with greater capacity to regulate the system. However, it is not enough for farms to be diversified or complex, and both, but they must necessarily be multifunctional, spatially and temporally, in order to enhance ecosystem services.

The results of a recent bibliometric analysis by Chen *et al*. (2020) indicate that the ecosystem services of forests, agriculture and wetlands are the most discussed in scientific literature. Furthermore,

Table 2. List of ecosystem services.

Provisioning services	Food
	Raw materials
	Fresh water
	Medicinal resources
Regulation services	Local climate and air quality
	Carbon sequestration and storage
	Moderation of extreme events
	Waste water treatment
	Erosion prevention and maintenance of soil fertility
	Pollination
	Biological control
Support services	Habitats for species
	Maintenance of genetic diversity
Cultural services	Recreation and mental and physical health
	Tourism
	Aesthetic appreciation and inspiration for culture, art and design
	Spiritual experience and sense of place

Source: (Elmqvist and Maltby, 2010)

the ecosystem services of all social-ecological systems have been assessed at various scales: national, urban and protected area. These authors highlight that biodiversity has been a critical point, mainly because it is an effective ecological parameter.

Agroecology proposes to reconstruct or strengthen the functional biodiversity of agroecosystems, and both, to improve the interactions among their components, in order to achieve a flow of goods and services from the redesign of food production systems, where processes that enhance ecological functions, crucial for crop production and other benefits to society, are optimized (Sarandón, 2020). In a study by Boeraeve *et al*. (2020), multiple ecosystem services were evaluated in agroecological and conventional farms. It was found that there were significant differences between the types of systems. It was found that agroecology has a clear impact on the delivery of ecosystem services, which tend to function better by providing more regulating services and enhancing synergies. Meanwhile, in conventional systems, provisioning services were better represented.

Generally, in farms towards agroecological transition, yields decrease during the first 3 to 5 years of conversion, but yields in these systems are only 19,2 % (± 3,7 %) lower than yields in conventional systems (Ponisio *et al*., 2015). These researchers also found that two agricultural diversification practices, such as multiple cropping and rotations, substantially reduced the yield gap (from 9 ± 4 % and 8 ± 5 %, respectively). However, they also found that the yield gap was substantially reduced by 9 ± 4 % and 8 ± 5 %, respectively. However, not all agroecological practices have the same influence on agrobiodiversity and the services it provides.

Tamburini *et al.* (2020) evaluated by meta-analysis the impact of various diversification practices on cropping systems, biodiversity and ecosystem services; above and below ground, and found that diversification improved regulating services, without compromising crop yields. Practices targeting aboveground biodiversity boosted pest control and water regulation; while those targeting belowground biodiversity improved nutrient cycling, soil fertility, and water regulation.

Beillouin *et al.* (2021) emphasize that while increasing the diversity of crop species or varieties in agroecosystems represents a very promising strategy for more sustainable land management, contributing to improved yields, enhanced biodiversity and ecosystem services, some crop diversification strategies are more effective than others in supporting ecosystem services. These authors proved that crop diversification improves not only crop yields (average effect + 14 %), it also impacts associated biodiversity (+ 24 %), i.e., the biodiversity of non-crop plants and animals and several supporting and regulating ecosystem services, including water quality (+ 51 %), pest and disease control (+ 63 %) and soil quality (+ 11 %). However, there was substantial variability in the results for each individual ecosystem service among different diversification strategies, such as agroforestry, intercropping, cover crops, crop rotation or variety mixtures. Agroforestry is particularly effective in providing multiple ecosystem services: water quality, pest and disease regulation, associated biodiversity, productivity and long-term soil quality. Varietal mixtures, on the other hand, provide fewer benefits; while the other strategies show intermediate results.

Considering the generated knowledge on the importance of biodiversity for generating ecosystem services in the agroecological context, man as the main actor in the transformation of ecosystems must manage agrobiodiversity in such a way that synergies among ecosystem services predominate and regulatory services are enhanced. This will allow for greater stability and sustainability of the production systems responsible for feeding the population and, in turn, providing a balanced environment.

Conclusions

After analyzing the relationship between biodiversity, ecosystem services and agroecology, there are all the arguments to support the idea that multifunctional, biodiverse ecosystems that implement management practices that optimize land use and efficiently manage ecosystem services should become the paradigm for sustainable agroecosystem management.

There is a strong interrelationship between the functioning of biodiversity and the development of ecosystem processes, which will subsequently form the basis of production, based on the richness and spatial and temporal variability of species, their role in the complexity of ecosystems and the maintenance of ecosystem services at different scales.

Analyses of the relationship between biodiversity and ecosystem services in agroecosystems should be part of comprehensive studies in the agroecological context, so that science can prove which practices are most effective for the sustainability of production.

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Conflict of interests

The authors declare that there is no conflict of interests among them.

Authors' contributions

- Wendy Mercedes Ramírez-Suárez. Generated the idea, searched for bibliographic information, and provided the information needed to prepare this review.
- Jorge Carlos Lopez-Chouza. Contributed with the idea, searched bibliography and drafted the manuscript.
- María de los Ángeles Flores-Acosta. Searched for information, drafted and revised the manuscript.
- Pedro Lázaro Rodríguez-Morejón. Searched for information, drafted and revised the manuscript.
- Saray Sánchez-Cárdenas. Searched for information, drafted and revised the manuscript.

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