ACTA UNIVERSITARIA
Multidisciplinary Scientific Journal

I VOLUMEN 34 I 2024 I

ISSN online 2007-9621

http://doi.org/10.15174/au.2024.4006

Participatory action-research for the restoration of biocultural heritage: case studies from two indigenous communities in Mexico

Investigación-acción participativa para la restauración del patrimonio biocultural: estudios de caso de dos comunidades indígenas de México

Enrique Hipólito-Romero, José María Ramos-Prado, Jorge Ricaño-Rodríguez*

Centro de Eco-Alfabetización y Diálogo de Saberes, Universidad Veracruzana, Zona Universitaria, Xalapa, Veracruz México. C.P. 91090.
Tel (+52) 2288 42 17 00 (ext. 10858). jricano@uv.mx*
*Corresponding author

Abstract

This document describes a theoretical-practical proposal that entails the transformation of an environmentally fragmented, overexploited, and underutilized agricultural matrix. It can also serve to modify non-harmonic landscapes with similar structures and functions observed in natural ecosystems with features such as resilience, strength, elasticity, and fragility. Through a multidisciplinary approach and using mainly productive ecological restoration tools, the theoretical-practical framework, an action plan, and an example of real-life implementation of the restoration of degraded and fragmented biocultural landscapes in two indigenous communities in Mexico that dominate the tropical regions of Latin America are discussed here as top results. Thus, we defined the basis for establishing complementary and retributive agroforestry landscapes with biocultural values and biological and social resilience, to provide economic benefits for local inhabitants and the population in general. It is concluded that biocultural resources and their sustainability may be approached in social terms and dynamic equilibrium, which integrates the essential elements of territoriality.

Keywords: Agroecosystem; biocultural species; landscape restoration; productive ecological restoration; territorial spaces.

Resumen

Este documento describe una propuesta teórico-práctica que implica la transformación de una matriz agrícola ambientalmente fragmentada, sobreexplotada y subutilizada. También puede servir para modificar paisajes no armónicos con estructuras y funciones similares observadas en ecosistemas naturales con características como resiliencia, resistencia, elasticidad y fragilidad. A través de un enfoque multidisciplinario y utilizando principalmente herramientas de restauración ecológica productiva, se discuten aquí como resultados principales el marco teórico-práctico, un plan de acción y un ejemplo de implementación real de la restauración de paisajes bioculturales degradados y fragmentados en dos comunidades indígenas de México que dominan las regiones tropicales de América Latina. Así, se definieron las bases para establecer paisajes agroforestales complementarios y retributivos con valores bioculturales y resiliencia biológica y social, para proporcionar beneficios económicos a los habitantes locales y a la población en general. Se concluye que los recursos bioculturales y su sostenibilidad pueden plantearse en términos sociales y de equilibrio dinámico, lo que integra los elementos esenciales de la territorialidad.

Palabras clave: Agroecosistema; especies bioculturales; restauración del paisaje; restauración ecológica productiva; espacios territoriales.

Recibido: 07 de septiembre de 2023 **Aceptado**: 12 de junio de 2024 **Publicado**: 11 de septiembre de 2024

Cómo citar: Hipólito-Romero, E., Ramos-Prado, J. M., & Ricaño-Rodríguez, J. (2024). Participatory action-research for the restoration of biocultural heritage: case studies from two indigenous communities in Mexico. *Acta Universitaria 34*, e4006. doi: http://doi.org/10.15174/au.2024.4006

Introduction

A harmonious biocultural landscape is a region where the cultural practices of human communities and the biodiversity of the natural environment coexist in balance and mutually benefit. In these landscapes, human activities, such as agriculture, fisheries, and forest management, are designed and implemented to respect and promote the diversity of plants, animals, and other organisms (Maryunani, 2019).

In this context, harmony means that there is a sustainable balance between the use of natural resources and their conservation. Communities work within the limits that ecosystems can support, ensuring that their activities do not degrade the environment or deplete biodiversity. This implies a deep understanding and respect for the signals and cycles of nature, adjusting cultural practices to minimize negative impacts, and maximizing the long-term health and productivity of the ecosystem (Folgueiras-Bertomeu & Sabariego-Puig, 2018).

In a harmonious biocultural landscape, culture and nature are seen as parts of an interconnected whole, where every human action considers its effects on the environment and vice versa. Thereby, environmental conditions influence and shape human practices and traditions (Brydon-Miller *et al*., 2020).

The recovery of harmonic biocultural landscapes from degraded and fragmented areas allows for the preservation of languages, dialects, and native knowledge regarding the use of natural resources and biodiversity (Arts *et al*., 2017; Hong, 2014). Unfortunately, in the past decades national and international development programs have promoted the disturbance and degradation of the original vegetation (eco-ethnocide), fragmentation of secondary vegetation, and a decrease in traditional agroecosystems that maintain sizeable biocultural diversity, particularly in rural communities occupied by ethnic groups (Arts *et al*., 2017).

Worldwide, poorly productive agricultural matrices that produce non-harmonic and fragmented landscapes have been exploited for decades and are underutilized as natural resources without any economic, social, cultural, or ecological benefits for local people (Vandermeer & Perfecto, 2006). Thus, it is necessary to positively transform these matrices of agroforestry systems to meet the needs of local communities with structures and functions similar to those observed in natural ecosystems, which exhibit properties like homeostasis, dynamic equilibrium, resistance to disturbances, and diversity (Burke *et al*., 2023; Cumming & Peterson, 2017).

In this proposed strategy, we highlight the concept of "society for ecological restoration" (Del Amo *et al*., 2010; Society for Ecological Restoration [SER], 2004), which focuses on the assistance, facilitation, and accompaniment of natural regeneration processes, also known as secondary succession. This concept refers to the resilience mechanism of forest ecosystems that controls disturbances and manages the species composition of the vegetation cover. In addition, in the early management period, enrichment with biocultural arboreal species is recommended (Ramos & del Amo, 1992) because it guides and accelerates succession that finally resets conditions similar to those observed initially.

It is essential to mention that resilience mechanisms can direct the recovery of homeostasis with native, functional, and valuable biocultural species through a concept called "productive ecological restoration" (PER) (De Sousa, 2009; Del Amo *et al*., 2010, 2013; Wei *et al*., 2023). In this sense, species conservation, with significance for the inhabitants, reduces disturbance and facilitates the establishment of other species with commercial value (Loh & Harmon, 2005).

For all those mentioned earlier, we have proposed a framework to establish complementary and retributive agroforestry landscapes with biocultural attributes, such as biological and social resilience that provides economic benefits for the indigenous inhabitants and global populations, based on the establishment of agroforestry systems with species of economic importance (Keahey, 2021).

Considering all the foregoing, the primary aim of this study was to guide the ecological restoration of the biocultural heritage of two indigenous communities in Mexico. This research was based on a participatory action-research (PAR) approach methodology that merges research, action, and community participation to foster practical knowledge and social change (Folgueiras-Bertomeu & Sabariego-Puig, 2018). This approach starts with a participatory diagnosis in which the community helps identify issues by sharing their perceptions and insights, engaging community members in identifying, analyzing, and addressing their cultural and environmental challenges.

In addition, it is important to note that data were gathered through surveys, interviews, and observations and then analyzed collaboratively to define key problems and needs. Besides, the methodology involved the implementation of the cosmovision principles of Colombian Ethnic Groups, as described by Bermúdez *et al*. (2005).

Theoretical framework

The notion of 'biocultural heritage' has garnered increasing attention in recent years as a means of articulating a comprehensive and refined framework for conducting landscape research and its subsequent management. This concept strives to embrace a holistic methodology that transcends traditional demarcations between biological and heritage preservation, rural development, and community engagement. In this context, biocultural heritage is delineated as the recognition of cultural landscapes, the culmination of enduring symbiotic connections between biology and society. These connections have molded both the tangible aspects of the landscape, including its biological and material characteristics, as well as intangible elements such as memory, lived experiences, and accumulated knowledge (Karger *et al*., 2021; Loh & Harmon, 2005).

Likewise, ecological restoration is a multidisciplinary and in-depth process, with the objective of restoring ecosystems that are on the brink of degradation. This approach is usually based on a fusion of ecological and social practices that intertwine the intricacies of natural systems and the human fabric that depends on them. Due to the above, this search goes beyond the health of ecosystems and strives to rekindle the well-being of those inextricably linked to these environments. From a position rooted in the sociocultural sciences, this paradigm delves into different philosophical concepts that unify local communities with their natural habitats (Wei *et al*., 2023).

As Burke *et al*. (2023) rightly mentioned, the conceptual framework of PER finds its cornerstone in the foundations of socioecological resilience. Here lies the recognition that human enclaves and ecosystems engage in a dance of interdependence. Thus, the sociocultural sciences underscore the importance of contextualizing restoration strategies within tradition, values, and local knowledge; their effectiveness is a necessary conduit for cultivating cultural consonance and social acceptance (Dhiman, 2022).

Within its intellectual scaffolding, this movement is based on the architecture of socioecological systems theory, the pillars which trace the intricate interplay between human and ecological dynamics. Socioculturality involves searching for patterns of land use and resource allocation, scrutinizing the degradation of ecosystems. Notably, sciences -including anthropology, sociology, and agroecology- take the helm of reviving ancestral resource management practices and the synergies that unite inhabitants with the biodiversity tapestry that surrounds them (Karger *et al*., 2021).

A central aspect of the biological and social perspective related to this topic is the emancipation of local communities, the proclamation of indigenous wisdom about the land, and the wealth it harbors. By virtue of this, the creation of synergies among scientists, restoration experts, and rural communities is essential, as their symbiotic craftsmanship shapes solutions that harmonize ecological vitality and human demands (Chin *et al*., 2021).

PER also embraces the idea of "socioecological coevolution," highlighting how communities and ecosystems converge over time. Their intertwined evolution echoes in the annals of culture, knowledge, and traditions that shape landscapes inexorably as landscapes shape them. Metaphorically, environmental metamorphoses resonate with the heartbeat of communities, reconfiguring their beliefs and existence (Del Amo *et al*., 2010, 2013).

Considering the aforementioned, to collaboratively articulate the PAR process in the restoration of biocultural heritage in indigenous communities of Mexico, it is important to adopt a structured approach that respects and values the perspectives of the native inhabitants (Fine *et al*., 2021; Giunta, 2019).

In this sense, the planning stage of this work began with a participatory diagnosis through meetings, interviews, and workshops with the communities in order to understand their biocultural heritage vision (Folgueiras-Bertomeu & Sabariego-Puig, 2018). Also, common interests were identified by researchers and other actors and local authorities (Brydon-Miller *et al*., 2020).

As we know, traditional knowledge is integrated with scientific research to develop restoration strategies that combine ancestral and modern techniques. This process includes a dialogue of knowledge to merge local wisdom from a scientific perspective, culminating in an agenda of restoration projects ranging from reforestation with native species to the recovery of traditional agricultural practices (Maryunani, 2019).

For this reason, during the action plan of this work, many tasks were executed, including activities like planting native trees and teaching water conservation techniques. These actions reflect the fusion of local and scientific knowledge, adapting to the specific needs of each community. It is worth mentioning that during the observation, the results must be documented, thus evaluating both quantitative aspects as well as the improvement in biodiversity and the strengthening of cultural practices. Therefore, the participation of all stakeholders is crucial to providing a complete perspective on the impact of the actions (Brydon-Miller *et al*., 2020; Giunta, 2019; Keahey, 2021).

Finally, in the reflection stage, the analysis of the effectiveness of the theories and methods used is necessary. This means that the ecological and cultural impact of the community have to be reviewed, adjusting theories and practices for future ecological cycles and verifying the satisfaction of the interests of all parties involved. This approach ensures that the PAR process is effective, contributing significantly to the restoration of biocultural heritage, and promoting sustainability and respect for local traditions and knowledge (De Oliveira, 2023; Fine *et al*., 2021).

In light of the above considerations, it can be emphasized that the harmonious restoration of the landscape is not a mere technical puzzle, but a complex multidisciplinary process that directs the communion between human beings and nature. Likewise, this paradigm shift is not merely an effort but also a resurrection, a renaissance of culture, an increase in sustainable stewardship, and a reaffirmation of the intertwined tapestry of human history with the balance of its environment (Cumming & Peterson, 2017).

Figure 1 shows a representative scheme of the relationship between the basic components that constitute the restauration of biocultural heritage in indigenous areas in Mexico, as well as social, economic, and environmental sustainability.

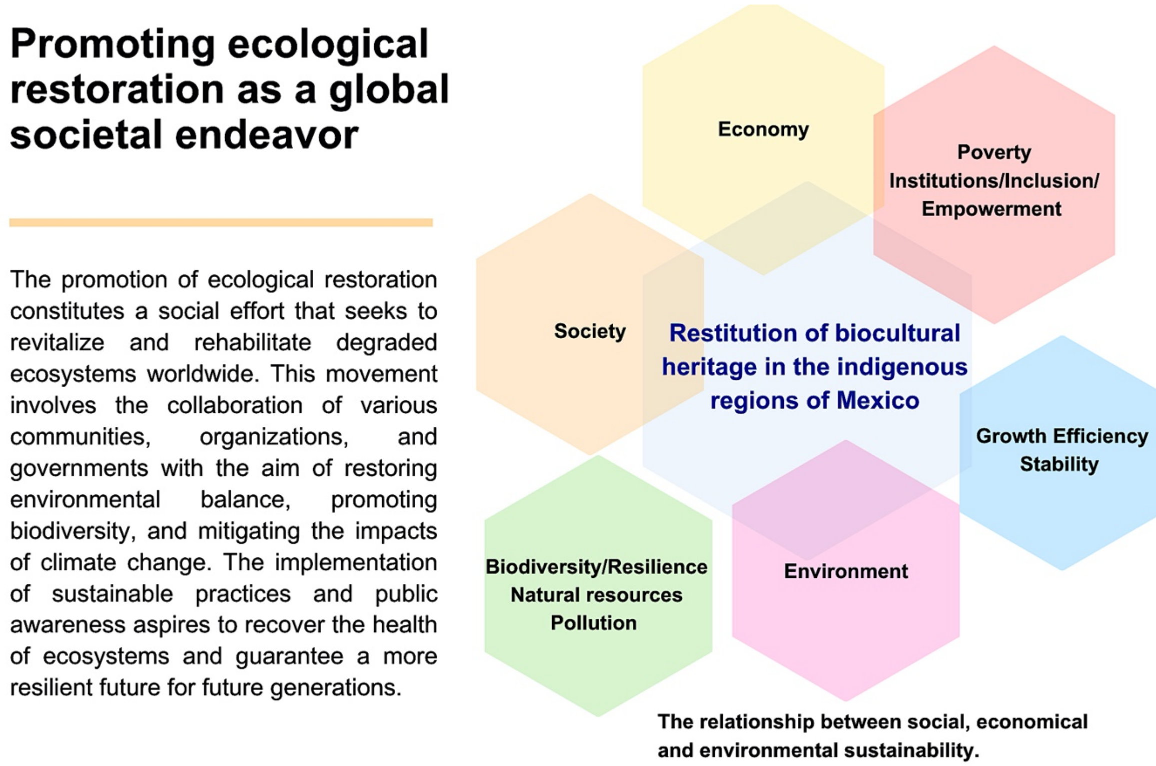

Figure 1. Factors involved in the process of restitution of biocultural heritage in indigenous regions in Mexico.
Source: Author's own elaboration based on Del Amo (2012).

Materials and methods

This initiative focuses on the study of biocultural and productive restoration in two indigenous regions of Mexico through a PAR methodology using a multidisciplinary approach. It involves active and reciprocal collaboration between researchers and indigenous community members who recognize and value their traditional knowledge, perspectives, and needs. The aim of this methodology is to jointly identify ecologically and culturally degraded areas and co-create restoration strategies that combine ancestral practices with innovative and sustainable approaches.

The active participation of communities throughout the process seeks to strengthen the resilience of both ecological and cultural systems, while improving the living conditions of local inhabitants. Through constant interaction and continuous feedback, this action research aims to generate integrated solutions that promote biodiversity conservation and restauration of indigenous traditions, establishing an exemplary model of intercultural collaboration for environmental restoration and community empowerment.

Study zones

This proposal takes place in the native communities of Nuevo Ojital, Municipality of Papantla, Veracruz; and Cerro Camarón, Municipality of San Pedro Ixcatlán, Oaxaca, Mexico. The municipality of Papantla, Veracruz, is located at coordinates 20° 27' N and 97° 19' W, at an altitude of 180 m. a. s. l. (Instituto Nacional de Estadística y Geografía [INEGI], 2007). This municipality is characterized for being the center of the Totonaca culture and one of the main indigenous areas of the country (Boege, 2008; Hipólito-Romero, 2011). It shows a warm sub-humid climate with rainfall in summer (Aw) of medium humidity (40%). The original vegetation corresponds to medium semi-deciduous forest and belongs to the hydrological region Tuxpan-Nautla RH27 (INEGI, 2007).

The primary economic activity of Papantla is the production of vanilla (*Vanilla planifolia* L.). Papantla is globally renowned as "The City that Perfumes the World" due to its production of this product, which is considered among the finest and most prized. Agriculture also plays a significant role in the local economy, with crops such as maize, beans, and citrus fruits being prevalent. Additionally, cultural and ecological tourism has gained importance, driven by the region's rich pre-Hispanic history and attractions like the El Tajín archaeological site and the traditional “Voladores de Papantla” ceremony (Hipólito-Romero, 2011).

Likewise, the municipality of San Pedro Ixcatlán, Oaxaca, is located in the Papaloapan region between parallels 18° 06' and 18° 14' N and meridians 96° 28' and 96° 38' W (INEGI, 2010). The altitude ranges between 0 m. a. s. l. and 1200 m. a. s. l. The ethnic diversity keeps the Mazatec and Chinantec languages alive. The predominant climate in the municipality is hot and humid, with an average annual temperature of 26 °C and an average annual rainfall of 2350 mm. The vegetation type is tropical evergreen forest and belongs to the hydrological region of Papaloapan, with the sub-basins of Presa Miguel Alemán, Río Blanco, and Río Amapa (INEGI, 2010).

The primary economic activities of San Pedro Ixcatlán revolve around agriculture and fishing. The region is known for its production of maize, beans, and coffee, which are staple crops for the local economy. Fishing in the Presa Miguel Alemán also significantly contributes to the livelihood of the community. Additionally, the town benefits from cultural tourism, attracting visitors with its rich indigenous heritage and traditional festivals (INEGI, 2007, 2010).

Identification of ethno and productive inputs of ecological restoration

As previously mentioned, our proposal focuses on the rescue and promotion of cultural landscapes as an alternative to preserve and increase biocultural heritage in the indigenous communities of Veracruz and Oaxaca, Mexico, based on concepts including Ethno Ecological Restauration (EER) and PER (Del Amo *et al*., 2010, 2013; De Sousa, 2009). These are considered resilience mechanisms of forest ecosystems, which imply disturbance reduction below the thresholds of resilience and recovery of their structure and function through functionally useful species (Farías *et al*., 2013).

In the planning phase, each community and the researchers jointly designed the actions to tackle several problems, set clear achievable goals, and define roles. During the implementation phase, these actions were executed, monitored, and documented to observe their effects. This was followed by a reflective evaluation to discuss the outcomes and effectiveness of the interventions, leading to adjustments based on this feedback (De Oliveira, 2023; Folgueiras-Bertomeu & Sabariego-Puig, 2018).

In the context of ethnoecological restoration, this process also involves the intervention of indigenous knowledge and practices to restore ecosystems, planning and implementing traditional techniques with community oversight, and adjusting these practices based on joint evaluation. Similarly, in PER, the approach integrates sustainable economic activities, including agroforestry and developing and modifying strategies to balance ecological recovery with economic viability (Keahey, 2021). Overall, PER supports ethnoecological and productive restoration by ensuring that community knowledge and needs are integral to restoration efforts, making them more sustainable and mutually beneficial (Brydon-Miller *et al*., 2020).

Some of previous study cases were strengthened by participatory processes and dialog of knowledge between entities with very different visions, even when they share values and principles regarding sustainable livelihoods. Therefore, we worked with two groups of peasants (one per community) through a methodology implemented by FAO (Field Schools) (Waddington *et al*., 2014), which has been used since 2011 in the cocoa (*Theobroma cacao* L.) regions of Tabasco and Chiapas, Mexico. Figure 2 shows our schematic action proposal, which includes steps to follow the EER/PER approach with biocultural species to change strongly altered ecosystems originating from excessive land use.

Both frameworks helped distinguish the dynamics and diversification and established fragments with a corridor structure through agroforestry systems. The set of biological corridors and rural reserves also involved the management of "acahuales" (ecosystems that emerge when agricultural land is left fallow, allowing native vegetation to recover the area; this process increases biodiversity and improves the soil, supporting traditional agriculture and serving as a refuge for diverse species) or recently abandoned cornfields (Del Amo, 2001; Moreno-Casasola *et al*., 2011). In this sense, native species of biocultural value are the fundamental inputs of EER/PER (Del Amo, 2012, 2014).

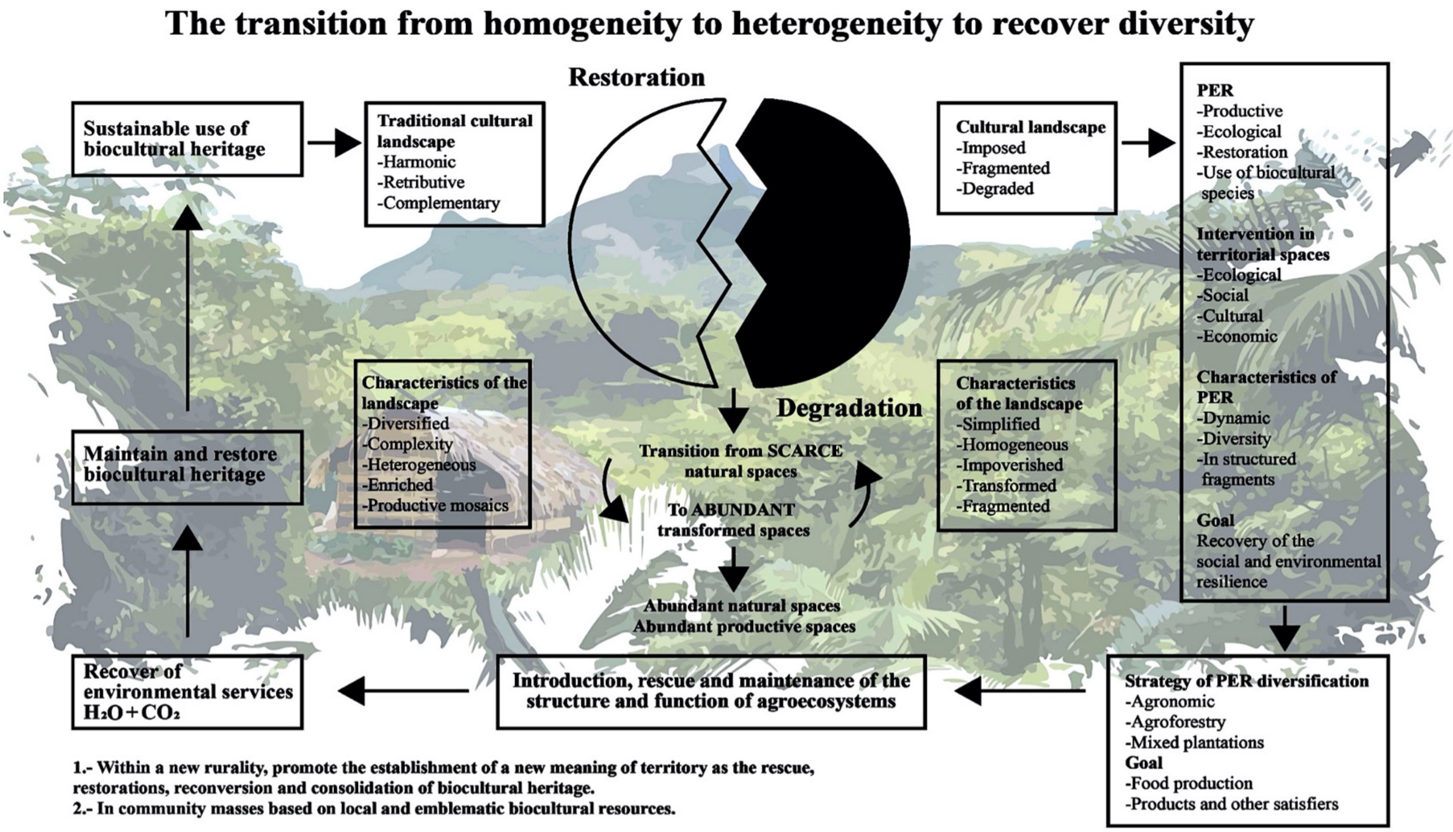

Figure 2. New paths of action in rural areas to preserve and enhance natural and cultural heritage through EER/PER approaches. It is indicated the transition from homogeneity to heterogeneity, recovering the agro and biodiversity.
Source: Author's own elaboration based on Lindholm & Ekblom (2019).

Recognition of landscape components

The general landscape components of this proposal were identified as follows: a) Agroforestry systems as production units of agricultural and forest conservation (ASPUAFC), b) Wildlife management units (WMU), c) Forest germplasm production units (FGPU), and d) Units for the payment for environmental services (UPES). This represents the initial task, focused on establishing agroforestry systems complemented by the aforementioned components. Notably, a key factor in success is ensuring stakeholder participation in planning, implementation, and feedback throughout the process.

The implementation of participatory action research strategies, policies, and action commitments must be seated at the beginning and subsequently executed to achieve the following goals: 1) to maintain and restore the structure and functionality of natural and cultural landscapes; 2) to maintain relationships between natural and cultural ecosystems and social-rural systems; 3) to develop an action plan, a proposal, and reach an agreement with land commitments in the long-term; and, finally, 4) to find efficient ways to gather scientific and empirical knowledge to suggest concrete actions.

Because of the preceding, the first step was to assess locals' skills, abilities, and perceptions of their environment that influence their future construction. The second step was to characterize different actors' roles and social groups in developing production chains to collectively improve their living conditions (Del Amo & Vergara-Tenorio, 2007). The third step involved assessing local knowledge of biocultural resources. All this information was recorded qualitatively in the corresponding databases, as a starting point for the recognition of the landscape components.

Development of strategic alliances among the proposal actors and their participatory roles

Strategic alliances were established with different sectors, one of which was the Soil Microbiology Group from the Benemérita Universidad Autónoma de Puebla, which created a vegetal biofertilizer called BiofertiBuap® that has been applied in a few experimental plots with cocoa cultivars (Hipólito-Romero *et al*., 2017). Another crucial step was the establishment of two experimental plots of 5000 m^2 each, where we utilized four different cocoa varieties in each plot, following the aforementioned FAO's field schools methodology to increase the productive management of the field.

Finally, associations were generated with two organizations of producers to have a physical space for working and to ensure the maintenance of the experimental plots, i.e., "Mujeres Artesanas de la Vainilla, S.C. de R.L. de C.V." (Vanilla Craftswomen) in the community of Nuevo Ojital, municipality of Papantla, Veracruz; and "Grupo Cerro Totomoztle, S.C. de R.L. de C.V." (Totomoztle Hill Group) in the community of Cerro Camarón, municipality of San Pedro Ixcatlán, Oaxaca.

Establishment of experimental cocoa agroforestry systems to promote fragmented landscapes recovering

As mentioned above, an experimental design of cocoa cultivar plots mixed with vanilla (Figure 3) was carried out to recover part of the fragmented ecosystems in both indigenous areas (Nuevo Ojital, municipality of Papantla, Veracruz; and Cerro Camarón, municipality of San Pedro Ixcatlán, Oaxaca, Mexico).

In the first instance, 1200 cocoa specimens (12-15 months old in plastic bags) were planted in two different experimental plots (600 plants per plot), each located in the rural surroundings of the study areas. The cocoa varietals were located every 3 m in a "staggered" distribution line where 20 horizontal plant lines were grouped equitably in five repetitions (four lines with 15 plants each per repetition). Each repetition line consisted of one of the four clonal cocoa varieties used in this study. Each plot was divided into two matrices (Zones A and B). In Zone A, a mixed plant culture was established using cocoa as the vanilla tutor. In Zone B, vanilla was intercropped with cocoa using different species as tutors.

In a complementary manner, three different fertilization treatments were applied in both zones (distributed in vertical columns): (1) biofertilization through a plant-beneficial bacterial consortium, i.e., standardized nitrogen-fixing strains (*Azospirillum brasilense* BUAP-151 and BUAP-154) and two insoluble phosphorus solubilizing strains (*Chromobacterium violaceum* BUAP 35 and *Acinetobacter calcoaceticus* BUAP 40) (All strains belong to the ceparium from the Soil Microbiology Laboratory of the Microbiological Sciences Research Center of the Science Institute of the Benemérita Universidad Autónoma de Puebla, Mexico [ICUAP].); (2) water (no fertilization); and (3) conventional chemical fertilization. Finally, 200 ml of each fertilization treatment was applied to each plant rhizosphere (twice per 16 months).

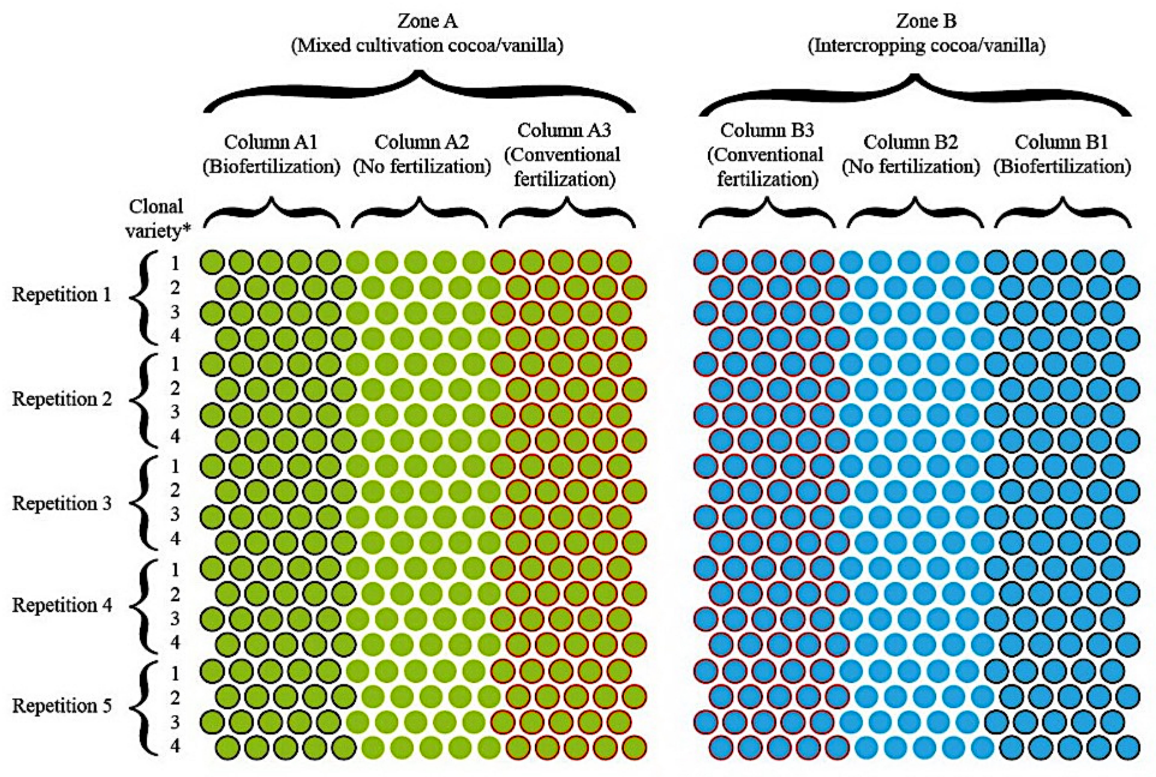

Figure 3. Experimental design of the cocoa plots established in the research communities. *1,2,3: cocoa varieties; *4: control (local cocoa variety); average plants per divided plot: 300.
Source: Author’s own elaboration.

Since cocoa varieties have been frequently used in some states of Mexico as an important economical resource due to their high fruit production, e.g., Tabasco and Chiapas, in order to establish a productive community in the experimental plots based on vanilla and cocoa, we used in a complementary way non-timber species, i.e., chamaedorea palm (*Chamaedorea elegans*), annatto (*Bixa orellana*), some nut and fruit trees, as well as other timber and non-timber species of biocultural value, including trees used in traditional or religious ceremonies like "palo volador" (*Zuelania ghuidonia*) and *Ceiba* sp.

Considering the cocoa's phenology and the plant age, and since the plots establishment and fertilization occurred between January 2022 and April 2023, the first fruit harvest is expected within the next three years, alongside the vanilla produced in the first year. Consequently, this initial stage of the project requires follow-up until at least 2026, allowing farmers to benefit from the first harvest. Figure 4 shows four fundamental actors of our initiative, which integrates the biological material used in the establishment of the experimental plots and human resources involved.

Figure 4. a) cocoa seedlings used in the establishment of the experimental plots; b) adult cocoa tree; c) vanilla cuttings used in the experimental agroforestry system; d) photograph of a couple of farmers near the study areas involved in the research initiative.
Source: Author's own elaboration.

Results and discussion

Recovering ethno and productive inputs for the ecological restoration

Tropical ecosystems are areas of harmony, resilience, and biodiversity (Estrada & Coates-Estrada, 1996; Karger *et al*., 2021; Myers, 1984). However, over time, they have been altered, looted, and decayed by human activities, losing features that completely change their nature and finally becoming barren and empty landscapes. Del Amo (2008) and Moreno-Casasola *et al*. (2011) state that cultural landscapes are essential indicators of Mexico's agricultural crisis because they expose the causes of their reduction. As mentioned above, the general principle of biological restoration is the recovery of the functional conditions of ecosystems (Chin *et al*., 2021).

As has been repeatedly mentioned, PAR is a methodological approach that integrates research, action, and community participation to generate practical knowledge and social change through the active participation and collaboration of participants, who are considered not only subjects of study but also co-researchers (Brydon-Miller *et al*., 2020; Fine *et al*., 2021; Folgueiras-Bertomeu & Sabariego-Puig, 2018). Therefore, in this research the process began with participatory diagnosis, where the problem or situation to be investigated was identified and defined collaboratively with the community. This involved organizing meetings with the community to understand their perceptions and priorities, collecting qualitative and quantitative data through surveys as well as interviews (data not shown) and participant observation, and jointly analyzing the gathered information to define the main problems and needs of the social collective (De Oliveira, 2023).

Following the diagnosis, the action planning phase involved the joint design of initiatives to address the identified problems. These included developing specific strategies, defining roles and responsibilities, and establishing clear and achievable objectives and goals. In this sense, during the action and observation phases of our research, planned actions were implemented, and their effects were observed. This step besides included executing interventions, continuously monitoring processes and results, and documenting experiences and outcomes in detail (Chin *et al*., 2021; Fine *et al*., 2021).

Subsequently, a participatory evaluation was conducted to analyze the results and processes during the reflection and evaluation phases. This implied reflective discussions about what showed favorable results, and what did not, evaluating the impact of actions based on the evidence collected, and adjusting and replanning based on learned experiences.

On the other hand, since ethnoecological restoration refers to the recovery of damaged ecosystems using the knowledge, practices, and values of the indigenous and local communities (Maryunani, 2019), this approach integrates worldview and traditional practices into ecological restoration. In PAR, this is commonly observed in the participatory diagnosis phase, in which traditional knowledge about the ecosystem and native species is gathered. In our action planning phase, restoration interventions were designed to respect and use traditional practices (Giunta, 2019).

The implementation of traditional restoration techniques under the supervision and participation of the community occurred during the action and observation phases. The effectiveness of traditional restoration practices was evaluated jointly in the reflection and evaluation phases. Finally, adjustments to restoration practices based on a combination of traditional and scientific knowledge were made in the replanning phase.

Given the aforementioned, we emphasize that PER seeks to recover ecosystems while generating sustainable economic benefits for local communities including agroforestry and forestry (De Oliveira, 2023). Thus, through PAR, this was evident in the participatory diagnosis phase, in which opportunities to integrate sustainable production into restoration were identified (Brydon-Miller *et al*., 2020). In this manner, the economic viability and ecological sustainability of the implemented practices were analyzed in the reflection and evaluation phases, and some strategies were slightly modified in the replanning phase in order to optimize ecological restoration and productivity.

As our proposal implies an extensive methodology to establish alliances and communication channels with indigenous communities, we suggest promoting teamwork with researchers, facilitators, co-learners, technicians, local populations, and restoration practitioners (Gayá & Reason, 2009). The participation of all actors allows sharing with the communities a set of common values and principles as part of the learning process that solves real problems of an interdisciplinary and transdisciplinary nature (Soler-Gallart, 2004).

Since the basis of this work is merely dialog and participation, our research group acted as a gear to reconcile the perspectives, needs, and expectations of all involved actors. Therefore, the farmers received grants, such as plants, cultivation training, and monitoring, to understand the new conditions in which a cocoa agroforestry system may be established. They also facilitated their lands and consequently sustained the plots. Thus, their benefit comes from product selling and the knowledge acquired from the training, once agroforestry systems are productive.

Our starting point (Figure 2) focuses on a two-sided coin. One face represents land degradation and the other represents land restoration. As mentioned earlier, setting up an agroforestry system entailed the cultivation of bushy species with nutritional and non-nutritional value, fruit trees, and herbaceous species used for food and medicinal purposes (Beer *et al*., 1998; Schroth & Ruf, 2014).

This practice also integrates two essential elements: biocultural species and territorial space. Biocultural species are those considered valuable by locals (Del Amo, 2012; Loh & Harmon, 2005). Territorial space involves the presence of four spaces of new territoriality: ecological, cultural, social, and economic. Thus, PER is considered a dynamic and diversified space with well-preserved vegetation fragments. Therefore, biodiverse and complex natural territories have increased with more diversified and complex productive mosaics of different compositions (Gayá & Reason, 2009; Groom *et al*., 2005).

However, as Hart (1985, 1990) pointed out, the transition from a disturbed ecosystem to an ecosystem in equilibrium is the starting point for processes that must be induced to recover some of the structural and functional characteristics that allow system management to imitate natural conditions. The worldview of American indigenous people described by Montemayor & Frischmann (2007) indicates that harmony and welfare can be rescued through collective agreements and concord through intercultural dialog. This way harmony transcends physical, chemical, biological, and ecological systems toward a nature-society relationship, and co-evolves between ecosystems and cultures.

The Totonacan region as an example of transition towards harmonious biocultural landscapes, an EER/PER perspective

As previously mentioned, in agroecological terms, the "acahual" is an agroforestry system enriched with species of biological and cultural value (Del Amo, 2001; Moreno-Casasola *et al*., 2011). It must have at least three necessary characteristics to recover degraded landscapes in the Mexican tropics: 1) to show similar structure and function to natural ecosystems; 2) to rescue the primary resources for human development, such as local food for a self-sufficient and commercial exchange to ensure social resilience; and 3) to control disturbances without chemical inputs (Estrada & Coates-Estrada, 1996; Hipólito-Romero *et al*., 2017).

Landscapes in the Totonac region of Veracruz are exemplified by two municipalities with different conditions, even though they share the same land-use plan. They are Zozocolco de Hidalgo, a town located on a mountain, and el Espinal, a mountainous coastal-plain transitional town (Del Amo *et al*., 2008a, 2008b).

At these sites, it has been observed that land use changed even in areas with steep slopes. Thus, there was a marked trend in the production of corn plantations. Zozocolco de Hidalgo has recovered areas with secondary vegetation that the ancient Totonacs had used to establish emblematic biocultural crops, including vanilla and cocoa (Hipólito-Romero *et al*., 2017). In contrast, el Espinal is located in the transitional zone between the coastal plain and mountainous areas.

The binomial "nature-culture" makes this proposal feasible by having a substantial positive ecological, social, and economic impact. In this sense, if we enrich the diversity of trees in the forest and cattle areas, the degraded landscapes could move toward a more harmonious and sustainable status.

Because fragmentation breaks the continuity of ecosystems and natural habitats, turning them into isolated patches may force them to lose their resilience (Groom *et al*., 2005). Therefore, this proposal does not seek to define a new role model in all cases, even in communities with similar conditions (poverty and marginality). The physical, chemical, and biological effects that occur due to land changes transform large areas of natural vegetation, resulting in the loss of a dynamic balance between the structure and function of the ecosystem (Steenberg *et al*., 2017).

The concept of landscape in this proposal links the natural and anthropological components. Here we clarify the junction mechanism since the dominant cultural landscape in the tropical areas of Mexico and other Latin American countries is highly fragmented due to the imposition of human progress and globalization (Paradowska *et al*., 2011).

The Totonacan region has been altered since the 1980s by livestock and land use changes to orange monocrops. However, in recent years, land use has changed to corn crops to produce cornhusks, which have great value and demand in the area (Del Amo *et al*., 2008a, 2008b; Yang *et al*., 2020). These two examples show the necessity of reorganizing and restoring the landscape by gradually changing the fragmented and overexploited agricultural matrix toward a more sustainable use through EER/PER processes.

It is important to mention that an agricultural matrix refers to the larger, often homogeneous agricultural landscape that surrounds and influences patches of natural habitats (Maryunani, 2019). Usually, this matrix consisted of crop fields, pastures, and other farming areas. It significantly affects biodiversity and ecological processes within natural habitat patches by acting as the context in which these patches exist. Thus, an agricultural matrix can determine the movement of species, flow of nutrients, and extent of human impact on these natural areas, influencing how isolated or connected these patches are within the broader landscape (Giunta, 2019).

Given this fact, setting agroforestry areas with enriched successional stages and diversifying cornfields enables the conservation and management of wildlife and germplasm units, with biological corridors to connect them (Del Amo, 2012, 2014).

Enabling an ecological restoration model through a multidisciplinary biocultural approach

The Mexican tropics are convergent regions with complex social, cultural, economic, and ecological conditions. Thanks to the close relationship between rural communities and their natural resources throughout pre-Columbian history, people have obtained different products from agroecosystems that impact worldwide gastronomy (Hipólito *et al*., 2013). Two representative examples are vanilla and cocoa, which are necessary for large-scale food production in the tropical regions (Banda *et al*., 2021; Pérez-Flores *et al*., 2020).

Part of this study was based on technical principles used to establish two different agroforestry systems, even when both show different conditions. At these sites, the productive structure was similar, at least with regard to the use of both species with considerable commercial value. On the other hand, considering that the starting point takes place from the same experimental design with technical and agroecological foundations, this proposal is not only limited to technical agronomic aspects but also to the dialog of knowledge (Ma *et al*., 2020) among actors who may possess different points of view and share the same interest, that is, to strengthen sustainable livelihoods of both groups of peasants.

In Nuevo Ojital, Veracruz, a participatory diagnosis was firstly conducted to understand the community's perspective on their biocultural heritage and environmental challenges. Based on this diagnosis, restoration strategies that combined ancestral and modern agroforestry techniques were developed, establishing experimental plots of cocoa and vanilla with active participation from the farmers.

In a similar way, the community of Nuevo Ojital perceived significant landscape degradation due to unsustainable agricultural practices, highlighting the importance of restoring ecological functionality and biocultural value to their lands (Giunta, 2019). They focused mainly on the cultivation of cocoa and vanilla due to their economic and cultural importance, promoting agroforestry systems and wildlife management units to conserve native species and to connect landscape fragments (Hipólito-Romero *et al*., 2017). This approach achieved effective integration of traditional and scientific knowledge and strengthened sustainable agricultural practices, though it faced limitations including the need for more time to observe complete results and dependence on external funding.

Given these considerations, our proposal is based on fundamental social principles, such as generating strategies that allow household members to achieve the means of having a dignified life. Consequently, fragmentation of their families will not be necessary in the future (owing to the abandonment of their cultural roots to look for better opportunities) (Hipólito-Romero *et al*., 2017). In the case of peasants' conditions, it is evident that it is necessary to improve new mechanisms to reactivate the Mexican countryside, which overcomes the welfare processes that have demonstrated a resounding failure in every governmental sexennial.

On the other hand, in Cerro Camarón, Oaxaca, local perceptions of landscape changes and cultural practices were captured through workshops and interviews, designing action plans that used native species and water conservation techniques (Fine, 2021). Cocoa species were planted, and biofertilization techniques were applied to enhance the sustainability of the experimental plots.

The community recognized the loss of biological diversity and cultural erosion, prioritizing specimens like cocoa, palm tree, and annatto for their biocultural value. Efforts were made to create biological corridors and forest germplasm production units to enhance the ecological and cultural connectivity of the landscape (Maryunani, 2019). This method strengthened local knowledge of sustainable practices and improved ecological infrastructure through agroforestry systems, though there was resistance to changing traditional practices and a need for more training for farmers.

In both locations, the EER/PER approach integrated local knowledge and perceptions into ecosystem restoration, promoting ecological and socially inclusive restoration that adapts interventions to local needs and facilitates continuous dialogue between science and traditional knowledge (Keahey, 2021).

Even under the least favored conditions, small indigenous and farmer communities have demonstrated that establishing strategic alliances may generate excellent value based on their knowledge (Del Amo & Vergara-Tenorio, 2007). Several studies (López-Juárez *et al*., 2019; Niether *et al*., 2019, 2020) suggest that the structure of diversified harvesting systems, such as cocoa planting, is a feasible strategy for producing vanilla, which resembles the structure and function of humid tropical forests (Hipólito-Romero *et al*., 2017; Plath *et al*., 2010).

Enabling the EER/PER model is a fundamental practice in rural communities, and due to this fact, an important question arises: How can a place in natural deterioration or fragmentation managed by a community be recovered and restored through a biocultural approach? Well then, we argue that natural ecosystems exhibit homeostasis, dynamic equilibrium, resistance mechanisms to disturbances and diversity, as Faucon *et al*. (2017) and Dhiman (2022) previously suggested. When the intensity of a disturbance ceases or decreases, natural ecosystems exhibit resistance, a mechanism that restructures and recovers harmonic flow cycles of matter and energy in the form of a dynamic equilibrium (Cumming & Peterson, 2017). In addition, direct recovery mechanisms are based on homeostatic phenomena with native and beneficial biocultural species in the EER or PER (Del Amo *et al*., 2010, 2013).

The preservation of collective memory through adopting the knowledge and way of living practices of local people and biocultural species implies a concept proposed by Nazarea (2006) (Memory Bank), which for many ethnic groups around the world means to rescue their "historical memory." Paradoxically, the restoration process proposed here aims to return an ecosystem to its original condition and merely recover vegetation, so that the system regulates itself. We emphasize that this proposal partially recovers agricultural practices and jointly recovers biodiversity, regaining food self-sufficiency, getting involved with the locals' cultural roots, and thereby guaranteeing the recovery of local communities' welfare.

On the other hand, co-creation originates responsibility in the participants for the environment in new forms of biocultural species assemblies, a product of social intelligence and collective wisdom that enriches nature (Del Amo, 2012; Kiatkowska & López-Wilchis, 2003). At the same time, this act of co-creation awakens appreciation for sensitivity toward the common good, and the affirmative action recognizes Mexico as a multi-ethnic and multicultural country.

As Maglianesi (2011) mentioned, ecological restoration is one of the fastest growing fields in applied ecology. It represents non-conventional opportunities and ways to conserve bio- and agro-diversity, in addition to the possibility of rescue and creation of new means of natural resource management. Theorists and practitioners of ecological restoration seek to recover the structure and function of ecosystems by accelerating the ecological processes (Jordan *et al*., 1987; Weidlich *et al*., 2021).

Thus, the implementation of this model has led to a well-known scientific debate. First, there is primary and disciplinary knowledge. Second, there is practical use of both; and in this sense, Mexico has been situated in ancestral empirical learning and local knowledge (Del Amo & Vergara-Tenorio, 2007; Solana, 1995). Finally, we agree with Bermúdez *et al*. (2005), who proposed that "the use of interculturality involves applying the holistic and integrity, balanced in the set of interrelationships between people and the environment".

The recovery of fragmented landscapes through the establishment of experimental cocoa agroforestry systems

Vanilla and cocoa are native to Central and South America, respectively, and are part of Mesoamerica's most significant biocultural resources, since this is a region where they were domesticated and had relevance as ritual foods and currencies in many pre-Hispanic cultures. Spaniards propagated their use worldwide and turned them into one of the most popular and consumed commodities (Hipólito-Romero *et al*., 2017). As mentioned in the Materials and methods section, our study proposes an alternative to address some of the problems in Latin American regions with evident ecological and biocultural erosion through the introduction of cocoa cultivars intercropped mainly with vanilla in traditional agroforestry systems (López-Juárez *et al.*, 2019).

As previously mentioned, these experiments were performed in synergy with the inoculation of nitrogen-fixing and insoluble phosphorus-solubilizing soil bacteria. Given the phenology of cocoa, as well as the age of the plants used in the experiment, and the fact that the establishment of the plots and the fertilization process took place between January 2022 and April 2023, it is expected that the first fruit harvest may take place within the next three years at the latest, which will be recollected by the farmers in the region (in addition to the vanilla produced in the first year). It is important to emphasize that the establishment of the experimental plots corresponds to the first stage of this project, which is why it will be necessary to follow up until at least 2026.

It should be mentioned that in order to study the effect of cocoa cultivar interactions with edaphic bacteria, the number of fruits, height, basal diameter, and number of leaves and branches will be recorded at a later date, and the population of microorganisms associated with the stem under the canopy of plants will be also characterized. Based on the above, it is expected that growth results should show good potential for the studied specimens, and that biofertilization may generate significant effects on some cocoa growth indicators. Thus, plant associations in agroforestry systems could be favorable for enhancing fruit development and resistance to pests and diseases as well as promoting vanilla development (Cocoletzi *et al*., 2022).

As shown in Figure 2, the shift from homogeneity to heterogeneity to regain biocultural variety depends on deploying new courses of action in rural areas using EER/PER methodologies. This allows for the protection and enhancement of natural and cultural resources, demonstrating that it is feasible to rehabilitate the agricultural sector and its biodiversity (Del Amo, 2012; Kiatkowska & López-Wilchis, 2003). The ecological restoration process entails intervening in the environment from an ecological, social, cultural, and economic standpoint, with the primary goal of restoring social and environmental resilience while considering attributes, including diversity and ecosystem restructuring (Dhiman, 2022; Faucon *et al*., 2017).

The current strategy is founded on theoretical-practical concepts from various agronomic and agroforestry disciplines, allowing for additional benefits like the recovery of environmental services (H_2O + CO_2 capture), maintenance and restoration of biocultural heritage, and sustainable use of resources (Steenberg *et al*., 2017).

With respect to the possibility of recovering other environmental services through this project, it is emphasized that the biocultural heritage restoration approach described here enhances climate regulation and carbon sequestration through reforestation and agroforestry with species like cocoa and vanilla, which absorb CO_2, helping mitigate the greenhouse effect (Folgueiras-Bertomeu & Sabariego-Puig, 2018; Giunta, 2019). Likewise, by restoring degraded landscapes and connecting habitat fragments via biological corridors, this project also promotes biodiversity conservation, including the protection of native and endemic species crucial for ecosystem functions (Giunta, 2019).

In addition, agroforestry and reforestation activities improve soil water infiltration and retention, aiding water cycle regulation, preventing erosion, and maintaining river flows, especially in drought-prone areas. The introduction of vegetation cover and soil conservation practices also reduces erosion and enhances soil structure and fertility. From this perspective, biofertilization with nitrogen-fixing and insoluble phosphorus-solubilizing bacteria enriches the soil, supporting sustainable agriculture (Del Amo *et al*., 2010; Hipólito-Romero *et al*., 2017).

Notably, since the project promotes diverse productive agroforestry systems, it ensures sustainable food production, providing economic alternatives that respect local biocultural heritage. Since these activities favors the restoration of diverse plant species, pollinators are commonly attracted, which is essential for plant reproduction and food production and supports organisms that contribute to nutrient recycling (Maryunani, 2019).

On the whole, by enhancing the ecological and social resilience of communities and their landscapes, this project may help areas withstand and recover from external disturbances, including extreme weather events or land-use changes, by integrating traditional knowledge into restoration practices that preserves indigenous and local knowledge, a valuable cultural service that contributes to community education and identity (De Oliveira, 2023).

Final thoughts and considerations

Our proposal explains how to achieve a feasible improvement in the welfare of poor and marginal people in rural areas, since it recovers the heterogeneity, complexity, and harmony of landscapes with ecological and natural heritage. Indeed, this could guarantee social reweaving and the appropriation of restoration as a new productivity currency in tropical areas with cultural heritage by recovering agrodiversity, cultural management practices, and specific technologies that preserve social heritage, thus giving value to collective wisdom and social intelligence.

We envisage the concept of landscape as a unit that integrates ecological peculiarities with the intervention of communities who have configured their environment based on their visions, needs, and perspectives throughout history. Consequently, our study does not intend to establish the principles for a "model" landscape but to highlight fundamental concepts that may still be used to restore landscapes under a biocultural approach.

ISSN online 2007-9621

It should be noted that this study aimed to address environmental fragmentation and overexploitation of agricultural matrices using PER tools to restore biocultural landscapes in two indigenous Mexican communities. Employing a multidisciplinary method, it established complementary agroforestry landscapes with biocultural values, fostering resilience and providing economic benefits.

The community members helped identify and resolve cultural and environmental challenges, ensuring effective restoration strategies. Action plans included planting native trees and water conservation continuously adjusted based on community feedback. On the other hand, integrating traditional knowledge with modern scientific techniques was key, focusing on recovering valuable biocultural species and promoting resilience. Also, experimental agroforestry systems with cocoa and vanilla were established, using biofertilization to enhance sustainability and productivity.

Strategic alliances with sectors like the Soil Microbiology Group from the Benemérita Universidad Autónoma de Puebla helped develop and apply biofertilizers. In this sense, partnerships with local producers ensured system maintenance and success, emphasizing collaboration. The project also focused on recovering environmental services including climate regulation and carbon sequestration through reforestation and agroforestry, promoting biodiversity. Creating biological corridors that enhanced ecological connectivity and supported native species were additional results.

Social and cultural impacts were addressed by integrating local knowledge and promoting sustainable practices, strengthening the communities' ecological infrastructure and cultural fabric. Likewise, the participatory approach ensured inclusivity and respect, fostering community ownership and empowerment. Overall, the research demonstrated the potential of combining traditional and scientific knowledge for biocultural restoration, emphasizing community involvement and continuous feedback, and providing practical models for sustainable development and resilience.

Notwithstanding the foregoing, we remain cognizant of the multifarious limitations of this project. The foremost among these challenges is the staggering magnitude of cultural and biological diversity that pervades the study areas, rendering the endeavor of generalizing results and applying universal theories, an intricate but formidable task. Furthermore, we consider that tapestry of socioeconomic and political inequalities that ensnares our nation exerts a profound influence on the modus operandi of research efforts and the subsequent application of legislation.

In addition, the paucity of access to requisite resources and cutting-edge agrotechnology poses an additional constraint that circumscribes the scope and depth of our research. Therefore, the exigencies of scientific pursuits are ensnared within the quagmire of technological insufficiencies. Moreover, the relentless juggernaut of urbanization, coupled with the inexorable erosion of cultural traditions within many indigenous communities, imperils the delicate equilibrium of biocultural preservation. Consequently, the confluence of modernity and tradition poses an ever-encroaching threat to the harmonious coexistence between humanity and nature.

Finally, the intricacies inherent in the nexus of cultural and biological interactions pose an intellectual labyrinth, wherein establishing unequivocal causal relationships becomes an elusive endeavor. These multifaceted limitations cast a glaring spotlight on the exigency to adopt interdisciplinary and culturally attuned approaches in the domain of bioculturality research within the Latin American context.

Conclusions

Emphasis is placed on PER as essential for biodiversity conservation and sustainable development, particularly in the rural and indigenous populations of Latin American countries. Through the recovery of degraded ecosystems and implementation of biocultural-based agricultural and forestry practices, it is possible to improve ecosystem services and improve the quality of life of local communities.

Overall, the dialogue of knowledge is crucial in integrating biocultural memory with the concepts of general systems theory and resilience. This dialogue has allowed for synergy between traditional knowledge and scientific approaches, facilitating a holistic understanding of biocultural restoration.

Besides that, traditional indigenous practices that maintain ecosystem stability through crop rotation and sustainable resource management were analyzed through the concepts of homeostasis and dynamic equilibrium. This analysis revealed how these practices contribute to the self-regulation and equilibrium of biocultural systems. In addition, local strategies to resist environmental disturbances were aligned with the concept of "resistance in resilience theory", highlighting how the diversity of practices and cultivated species increases the capacity of systems to absorb and adapt to changes and maintain their functionality.

Moreover, we believe that the biological and cultural diversity of the study communities is fundamental to their resilience. So, functional diversity and redundancy, as well as key concepts in systems theory, explained how a variety of practices and biological species made it possible to manage uncertainties and function effectively in the face of diverse disturbances.

By virtue of the above, the dialogue between biocultural memory and science has enriched the understanding of both domains, demonstrating that traditional practices are examples of ecological and systemic principles. This integrative approach, promoted by PAR, ensures that interventions for the restoration of biocultural heritage are respectful, inclusive, and based on a deeper understanding of the complexity and resilience of biocultural systems. This dialogue not only validates indigenous knowledge but also provides an adaptive framework to address environmental and cultural challenges in a changing world.

However, in spite of the outstanding conclusions we have reached, it is important to note that this project faces several limitations, including the time required to observe the full outcomes of restoration efforts, which may span several years, making immediate results difficult to quantify. Additionally, the project's success heavily relies on continuous external funding, without which long-term sustainability could be compromised. Resistance to changing traditional practices may also pose challenges, necessitating ongoing training and education for local farmers to foster acceptance and effective implementation of new sustainable practices. Furthermore, the complexity of integrating diverse ecological, social, and economic objectives requires robust interdisciplinary collaboration, which can be difficult to manage effectively across different stakeholder groups.

Acknowledgments

We thank the Totonac and Maya communities for sharing their wisdom. We thank Mujeres Artesanas de la Vainilla and Grupo Cerro Totomoztle for supporting this study. This work is the result of the hard work done in life by SAR and part of her work team, who always pleaded to study biocultural heritage in Mexico. Finally, we are indebted to the reviewers for their helpful and constructive comments and suggestions regarding this manuscript.

Conflict of interest

The authors declare that no conflicts of interest are derived from this research project.

References

Arts, B., Buizer, M., Horlings, L., Ingram, V., van Oosten, C., & Opdam, P. (2017). Landscape approaches: a state-of-the-art review. *Annual Review of Environment and Resources, 42*, 439-463. https://doi.org/10.1146/annurev-environ-102016-060932

Banda, H., Garza, R., & Vázquez, K. (2021). Supply chain and economic viability of *Vanilla planifolia* Andrew production: a case study. *Agroproductividad, 14*(1), 31-36. https://doi.org/10.32854/agrop.v14i1.1795

Beer, J., Muschler, R., Kass, D., & Somarriba, E. (1998). Shade management in coffee and cocoa plantations. *Agroforestry Systems, 38*, 139-164. https://doi.org/10.1023/A:1005956528316

Bermúdez, G. M., Mayorga, R. L, Jacanamijoy, T. B., Seygundibaand, Q. A., & Fajardo, E. T. (2005). El diálogo de saberes y la educación ambiental. Ideas, 7. Instituto de Estudios Ambientales Universidad de Colombia.

Boege, S. E. (2008). *El patrimonio biocultural de los pueblos indígenas de México: hacia la conservación in situ de la biodiversidad y agrodiversidad en los territorios indígenas*. Instituto Nacional de Antropología e Historia (INAH)-Comisión Nacional para el Desarrollo de los Pueblos Indígenas (CDI).

Brydon-Miller, M., Kral, M., & Ortiz, A. (2020). Participatory action research: international perspectives and practices. *International Review of Qualitative Research, 13*(2), 103-111. https://doi.org/10.1177/1940844720933225

Burke, L., Díaz-Reviriego, I., Lam, D. P. M., & Hanspach, J. (2023). Indigenous and local knowledge in biocultural approaches to sustainability: a review of the literature in Spanish. *Ecosystems and People, 19*(1), 2157490. https://doi.org/10.1080/26395916.2022.2157490

Chin, A., O' Dowd, A. P., Méndez, P., Velasco, K., Florsheim, L. J., Laurencio, L. R., & Leventhal, R. D. (2021). Toward natural approaches in restoration: Experiments of co-evolving physical and biological structures in a self-organizing step-pool channel. *River Research and Applications, 37*(10), 1-14. https://doi.org/10.1002/rra.3851

Cocoletzi, E., Hipólito-Romero, E., Ricaño-Rodríguez, J., & Ramos-Prado, J. M. (2022). Ecophysiological plasticity of *Theobroma cacao* L. clones in response to the structure and microclimate of agroforestry systems in Mexico. *Botanical Sciences, 100*(4), 960-976. https://doi.org/10.17129/botsci.2925

Cumming, G. S., & Peterson, G. D. (2017). Unifying research on social-ecological resilience and collapse. *Trends in Ecology & Evolution, 32*(9), 695-713. https://doi.org/10.1016/j.tree.2017.06.014

De Oliveira, B. (2023). Participatory action research as a research approach: advantages, limitations and criticisms. *Qualitative Research Journal, 23*(3), 287-297. https://doi.org/10.1108/QRJ-08-2022-0101

Del Amo, S. (2001). *Lecciones del programa de acción forestal tropical*. Plaza y Valdés.

Del Amo, S., & Vergara-Tenorio, M. C. (2007). Reflection on the social learning process for community work in rural areas of Mexico. *International Journal of Biological Sciences and Management, 3*(1), 31-45. https://doi.org/10.1080/17451590709618160

Del Amo, S. (2008). Paisaje y memoria totonaca: la relación entre ecología y el manejo de los recursos. In A. J. Mestre, A. M. G. Ángel & A. J. Gonzáles (eds.), *Nuevas rutas para el desarrollo en América Latina: experiencias locales y globales* (pp. 263-302). Universidad Iberoamericana y Agencia Española de Cooperación Internacional.

Del Amo, S., Vergara, T. C., Ramos, J. M., Jiménez, V. L., & Ellis, E. (2008a). *Plan de ordenamiento ecológico de participación comunitaria-Espinal*. Editorial de la Universidad Veracruzana.

Del Amo, S., Vergara, T. C., Ramos, J. M., Jiménez, V. L., & Ellis, E. (2008b). *Plan de ordenamiento ecológico de participación comunitaria-Zozocolco*. Editorial de la Universidad Veracruzana.

Del Amo, S., Ramos, J. M., & Vergara, T. C. (2010). Ethnoecological restoration of deforested and agricultural tropical lands for Mesoamerica. In E. N. Laboy-Nieves, M. F. A. Goosen & E. Evens (eds.), *Environmental and human health: risk management in development countries* (pp. 141-156). CRC Press Taylor and Francis Group.

Del Amo, S. (2012). *El repoblamiento del área rural, recuperando la sabiduría colectiva y la inteligencia social. Estrategias participativas de investigación-acción para la intervención local*. Plaza y Valdés.

Del Amo, S., Ramos, J. M., Hipólito, E., & Hernández, A. M. (2013). Manejo de los recursos bioculturales: una propuesta para mantener y enriquecer el patrimonio natural de los pueblos indígenas. In F. A. Conde, B. P. Ortiz, R. A. Delgado & F. R. Gómez (eds.), *Naturaleza-sociedad. Reflexiones desde la complejidad* (pp. 509-524). Universidad Autónoma de Tlaxcala.

Del Amo, S., Ramos, J. M., Hipólito, E., & Ricaño, J. (2014). La conservación comunitaria, la restauración, los recursos bioculturales y el diálogo de saberes. Un nuevo-viejo camino hacia la recuperación con dignidad del agro mexicano. *Proceedings from the COMBIOSERVE Conference Community Conservation in Latin America: Innovations in Research and Practice*.

De Sousa, B. (2009). A non-occidentalist west? Learned ignorance and ecology of knowledge. *Theory, Culture & Society, 26*(7-8), 103-125. https://doi.org/10.1177/0263276409348079

Dhiman, B. (2022). Ecosystem degradation and the need for restoration: through the lens of environment and human health. *Environmental Pollution and Climate Change, 6*(10), 1000304. https://ssrn.com/abstract=4280158

Estrada, A., & Coates-Estrada, R. (1996). Tropical rain forest fragmentation and wild populations of primates at Los Tuxtlas, Mexico. *International Journal of Primatology, 17*, 759-783. https://doi.org/10.1007/BF02735263

Farías, P., Lucena, C. M., Araújo, E. L., Chaves, A. G., & de Albuquerque, U. P. (2013). Conservation priorities of useful plants from different techniques of collection and analysis of ethnobotanical data. *Anais da Academia Brasileira de Ciências, 85*(1), 169-186. https://doi.org/10.1590/S0001-37652013005000013

Faucon, M. P., Houben, D., & Lambers, H. (2017). Plant functional traits: soil and ecosystem services. *Trends in Plant Science, 22*(5), 385-394. https://doi.org/10.1016/j.tplants.2017.01.005

Fine, M., Torre, M. E., Oswald, A. G., & Avory, S. (2021). Critical participatory action research: methods and praxis for intersectional knowledge production. *Journal of Counseling Psychology, 68*(3), 344-356. https://doi.org/10.1037/cou0000445

Folgueiras-Bertomeu, P., & Sabariego-Puig, M. (2018). Investigación-acción participativa. El diseño de un diagnóstico participativo. *Revista d'Innovació i Recerca en Educación, 11*(1), 16-25. http://doi.org/10.1344/reire2018.11.119047

Gayá, P., & Reason, P. (2009). Initiating action research: challenges and paradoxes of opening communicative space. *Action Research, 7*(3), 243-262. https://doi.org/10.1177/1476750309336715

Giunta, A. (2019). Looking back to move forward: The status of environmental rights under the UN Declaration on the Rights of Indigenous Peoples. *International Journal of Human Rights, 23*(1-2), 149-173. https://doi.org/10.1080/13642987.2019.1572874

Groom, M. J., Meffe, G., & Carroll, C. R. (2005). *Principles of conservation biology*. Sinauer Associates Inc.

Hart, R. (1985). *Conceptos básicos sobre agroecosistemas*. Centro Agronómico Tropical de Investigación y Enseñanza.

Hart, R. (1990). Componentes, subsistemas y propiedades del sistema finca como base para un método de clasificación. En G. Escobar & J. Berdegué (eds.), *Tipificación de sistemas de producción agrícola* (pp. 45-62). Centro Latinoamericano para el Desarrollo Rural: RIMISP.

Hipólito-Romero, E. (2011). *Modelo de intervención con enfoque ecosistémico para el desarrollo empresarial rural de pequeños productores: Estudio de caso en la región totonaca del Estado de Veracruz, México* [Tesis de Doctorado]. Universidad Veracruzana, CITRO.

Hipólito-Romero, E., Carcaño-Montiel, M. G., Ramos-Prado, J. M., Vázquez-Cabañas, E. A., López-Reyes, L., & Ricaño-Rodríguez, J. (2017). Efecto de inoculantes bacterianos edáficos mixtos en el desarrollo temprano de cultivares mejorados de cacao (*Theobroma cacao* L.) en un sistema agroforestal tradicional del norte de Oaxaca, México. *Revista Argentina de Microbiología, 49*(4), 356-365. https://doi.org/10.1016/j.ram.2017.04.003

Hipólito, E., del Amo, S., Ramos, J. M., & Hernández, A. M. (2013). El cultivo de la vainilla en los medios de vida de los hogares productores. In F. A. Conde, P. A. Ortiz, A. Delgado & G. Gómez (eds.), *Naturaleza-Sociedad. Reflexiones desde la complejidad* (pp. 195-218). Centro de Investigaciones Interdisciplinarias sobre Desarrollo Regional.

Hong, S. K. (2014). Philosophy and background of biocultural landscapes. In S. K. Hong, J. Bogaert & Q. Min (eds.), *Biocultural landscapes: diversity, functions and values* (pp. 1-7). Springer.

Instituto Nacional de Estadística y Geografía (INEGI). (2007). *Anuario estadístico de Veracruz de Ignacio de la Llave. Tomos I, II y III*. INEGI-Gobierno del Estado de Veracruz.

Instituto Nacional de Estadística y Geografía (INEGI). (2010). *Compendio de información geográfica municipal: San Pedro Ixcatlán, Oaxaca*. INEGI.

Jordan, W. R., Gilpin, M. E., & Aber, J. D. (1987). *Restoration ecology: a synthetic approach to ecological*. Cambridge University Press.

Karger, D. N., Kessler, M., Lehnert, M., & Jetz, W. (2021). Limited protection and ongoing loss of tropical cloud forest biodiversity and ecosystems worldwide. *Nature Ecology & Evolution, 5*, 854-862. https://doi.org/10.1038/s41559-021-01450-y

Keahey, J. (2021). Sustainable development and participatory action research: a systematic review. *Systemic Practice and Action Research, 34*, 291-306. https://doi.org/10.1007/s11213-020-09535-8

Kiatkowska, T., & López-Wilchis, R. (2003). Integridad: ¿Un proyecto o una ilusión?. In T. Kiatkowska & J. Issa (eds.), *Los caminos de la ética ambiental* (pp. 157-164). Plaza y Valdés.

Lindholm, K. J., & Ekblom, A. (2019). A framework for exploring and managing biocultural heritage. *Anthropocene, 25*, 100195. https://doi.org/10.1016/j.ancene.2019.100195

Loh, J., & Harmon, D. (2005). A global index of biocultural diversity. *Ecological Indicators, 5*(3), 231-241. https://doi.org/10.1016/j.ecolind.2005.02.005

López-Juárez, S. A., Hipólito-Romero, E., Cerdán-Cabrera, C. R., Ortiz-Ceballos, G. C., & Reyes-López, D. (2019). Asociación entre cultivos de cacao (*Theobroma cacao* L.) y Vainilla (*Vanilla planifolia* Jacks. ex Andrews) en un sistema agroforestal en Comalcalco, Tabasco. *Tropical and Subtropical Agroecosystems, 22*, 613-629. https://www.uv.mx/personal/ehipolito/files/2022/06/47.-Paper-Tropical-and-Subtropical-Ecosystem-Octubre-2019.pdf

Ma, Y., Nguyen, K. L., Xing, F. Z., & Cambria, E. (2020). A survey on empathetic dialogue systems. *Information Fusion, 64*, 50-70. https://doi.org/10.1016/j.inffus.2020.06.011

Maglianesi, M. A. (2011). Restauración ecológica: perspectiva histórica e implicaciones éticas de una disciplina en crecimiento. *Biocenosis. Revista Ambiental, 25*(1-2), 34-41. http://investiga.uned.ac.cr/revistas/index.php/biocenosis/article/view/1186

Maryunani, S. R. (2019). Community empowerment as a means in promoting local products: a case study in Bandung, Indonesia. *Journal of Promotion Management, 25*(3), 439-451. https://doi.org/10.1080/10496491.2019.1557821

Montemayor, C., & Frischmann, D. (2007). *Contemporary Mexican indigenous-language writers*. University of Texas Press.

Moreno-Casasola, P., Infante, D., & Madero-Vega, C. (2011). Germinación y supervivencia de dos especies de acahual de selva baja para restaurar dunas costeras. *Revista Mexicana de Ciencias Forestales, 2*(6), 19-36. https://doi.org/10.29298/rmcf.v2i6.572

Myers, S. C. (1984). Capital structure puzzle. *The Journal of Finance, 39*, 581-582. https://www.nber.org/papers/w1393

Nazarea, V. D. (2006). *Cultural memory and biodiversity*. The University of Arizona Press.

Niether, W., Jacobi, J., Blaser, J. W., Andres, C., & Armengot, L. (2020). Cocoa agroforestry systems versus monocultures: a multi-dimensional meta-analysis. *Environmental Research Letters, 15*(10), 104085. https://doi.org/10.1088/1748-9326/abb053

Niether, W., Schneidewind, U., Fuchs, M., Schneider, M., & Armengot L. (2019). Below- and aboveground production in cocoa monocultures and agroforestry systems. *Science of the Total Environment, 657*, 558-567. https://doi.org/10.1016/j.scitotenv.2018.12.050

Paradowska, K., del Amo, S., González, A., & Ramos, J. M. (2011). ¿En qué pensamos cuando hablamos del paisaje?. *Iberofórum, 6*, 174-183. https://ibero.mx/iberoforum/12/pdf/espanol/7_PARADOWSKA_IBEROFRORUM_NO12.pdf

Pérez-Flores, J., Córdova-Ávalos, V., Chávez-García, E., Hernández-Maldonado, E., Córdova-Lázaro, C. E., Córdova-Avalos, A., & Hinojosa-Cuéllar, J. A. (2020). Prehispanic and novohispanic drinks of cocoa and corn in la Chontalpa, Tabasco. *Agroproductividad, 13*(7), 3-8. https://doi.org/10.32854/agrop.vi.1605

Plath, M., Mody, K., Potvin, C., & Dorn, S. (2010). Establishment of native tropical timber trees in monoculture and mixed-species plantations: Small-scale effect of tree performance and insect herbivory. *Forest Ecology and Management, 261*(3), 741-750. https://doi.org/10.1016/j.foreco.2010.12.004

Ramos, J. M., & del Amo, S. (1992). Enrichment planting in a tropical secondary forest in Veracruz, Mexico. *Forest Ecology and Management, 54*(1-4), 289-304. https://doi.org/10.1016/0378-1127(92)90018-5

Schroth, G., & Ruf, F. (2014). Farmer strategies for tree crop diversification in the humid tropics: a review. *Agroforestry Systems, 34*, 139-154. https://doi.org/10.1007/s13593-013-0175-4

Society for Ecological Restoration (SER). (2004). *Grupo de trabajo sobre ciencia y políticas*. Principios de SER International sobre Restauración Ecológica. https://www.ser.org

Solana, J. L. (1995). La unidad y diversidad del hombre en la antropología compleja de Edgar Morín. *Gaceta de Antropología*, (11), 1-8. https://hdl.handle.net/10481/13607

Soler-Gallart, M. (2004). Reading to share: Accounting for others in dialogic literary gatherings. In M. C. Bertau (ed.), *Aspects of the dialogical self* (pp. 157-183). Lehmans.

Steenberg, J. W. N., Millward, A. A., Nowak, D. J., Robinson, P. J., & Ellis, A. (2017). Forecasting urban forest ecosystem structure, function, and vulnerability. *Environmental Management, 59*, 373-392. https://doi.org/10.1007/s00267-016-0782-3

Vandermeer, J., & Perfecto, I. (2006). The agricultural matrix and a future paradigm for conservation. *Conservation Biology, 21*(1), 274-277. https://doi.org/10.1111/j.1523-1739.2006.00582.x

Waddington, H., Snilstveit, B., Hombrados, J., Vojtkova, M., Phillips, D., Davies, P., & White, H. (2014). Farmer field schools for improving farming practices and farmer outcomes: a systematic review. *Systematic Reviews, 10*(1), i-335. https://doi.org/10.4073/CSR.2014.6

Wei, X., Song, W., Shao, Y., & Cai, X. (2023). Progress of ecological restoration research based on bibliometric analysis. *International Journal of Environmental Research and Public Health, 20*(1), 520. https://doi.org/10.3390/ijerph20010520

Weidlich, E. W. A., Nelson, C. R., Maron, J. L., Callaway, R. M., Delory, B. M., Vicky, M., & Temperton, V. M. (2021). Priority effects and ecological restoration. *Restoration Ecology, 29*(1), e13317. https://doi.org/10.1111/rec.13317

Yang, W., Feng, G., Read, J. J., Ouyang, Y., Han, J., & Li, P. (2020). Impact of cover crop on corn–soybean productivity and soil water dynamics under different seasonal rainfall patterns. *Agronomy Journal, 112*(2), 1201-1215. https://doi.org/10.1002/agj2.20110