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ORIGINAL

Biodiversity accounting and natural capital in the Mexican agro industrial sector

Contabilidad de la biodiversidad y capital natural en el sector agroindustrial Mexicano

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ABSTRACT
Objective: To analyze the relationship between biodiversity and natural capital accounting practices and the sustainability of the Mexican agribusiness sector, considering the identification of natural assets, the valuation of ecosystem services, the recording of environmental impacts and the use of ecological information in decision-making. Methodology: A quantitative, non-experimental, cross-sectional and descriptive-correlational research was carried out with a sample of 180 participants linked to agro-industrial activities in Chiapas, Veracruz, Michoacán and Yucatán. The information was collected through a 24-item questionnaire with a Likert-type scale, validated by specialists and with an overall reliability of 0.93 according to Cronbach's alpha. For the analysis, descriptive statistics, Spearman correlation and multiple linear regression were applied. Results: Natural capital accounting reached a medium level, while agro-industrial sustainability presented a high level. A positive, high and statistically significant relationship was identified between both variables. The incorporation of environmental information in decision-making was the dimension with the greatest explanatory capacity, followed by the valuation of ecosystem services. Limitations were also evident in the monetary valuation and accounting record of impacts on biodiversity. Conclusions: Biodiversity and natural capital accounting contributes to the strengthening of the environmental and productive sustainability of the Mexican agro-industrial sector. Its application allows us to recognize dependencies, risks and ecosystem benefits; however, it requires standardized procedures, technical training, and greater integration of environmental information into enterprise accounting systems.

Keywords: biodiversity; natural capital; environmental accounting; agribusiness; sustainability.

RESUMEN
Objetivo: Analizar la relación entre las prácticas de contabilidad de la biodiversidad y capital natural y la sostenibilidad del sector agroindustrial mexicano, considerando la identificación de activos naturales, la valoración de servicios ecosistémicos, el registro de impactos ambientales y el uso de información ecológica en la toma de decisiones. Metodología: Se desarrolló una investigación cuantitativa, no experimental, transversal y descriptivo-correlacional, con una muestra de 180 participantes vinculados con actividades agroindustriales de Chiapas, Veracruz, Michoacán y Yucatán. La información se recopiló mediante un cuestionario de 24 ítems con escala tipo Likert, validado por especialistas y con una confiabilidad global de 0,93 según el alfa de Cronbach. Para el análisis se aplicaron estadísticos descriptivos, correlación de Spearman y regresión lineal múltiple. Resultados: La contabilidad del capital natural alcanzó un nivel medio, mientras que la sostenibilidad agroindustrial presentó un nivel alto. Se identificó una relación positiva, alta y estadísticamente significativa entre ambas variables. La incorporación de información ambiental en la toma de decisiones fue la dimensión con mayor capacidad explicativa, seguida de la valoración de los servicios ecosistémicos. También se evidenciaron limitaciones en la valoración monetaria y el registro contable de los impactos sobre la biodiversidad. Conclusiones: La contabilidad de la biodiversidad y capital natural contribuye al fortalecimiento de la sostenibilidad ambiental y productiva del sector agroindustrial mexicano. Su aplicación permite reconocer dependencias, riesgos y beneficios ecosistémicos; sin embargo, requiere procedimientos estandarizados, capacitación técnica y una mayor integración de la información ambiental en los sistemas contables empresariales.

Palabras clave: Palabras claves: biodiversidad; capital natural; contabilidad ambiental; agroindustria; sostenibilidad.

INTRODUCTION

Biodiversity and ecosystems support a significant part of agroindustrial activity by providing water, soil fertility, thermal regulation, pollination, biological control, and necessary raw materials. However, these benefits are often excluded from traditional accounting, which only considers financial assets, costs, and revenues. As indicated by Obst et al. (1), the inclusion of ecosystem assets and the services they provide in accounting systems better represents the interrelationship between the economy, the environment, and social well-being.

Natural capital accounting aims to identify, measure, and communicate the stocks and changes associated with natural resources used in economic activity. Ecosystems can be considered assets that generate benefits over a specified period; therefore, their degradation, conservation, or restoration can be expressed in physical and monetary indicators. Valuation of ecosystem service space also describes how to identify strategic areas and incorporate analysis of the impacts derived from land use changes (2,3).

Keith et al. (4) affirm that ecosystem accounts make explicit the trade-offs between production, conservation, and resource use. From this perspective, agroindustrial performance should not be evaluated exclusively by production levels or profitability, but should also be assessed in contexts where forest cover, species diversity, soil quality, and the capacity of ecosystems to maintain their functions are taken into account.

Incorporating biodiversity into accounting is a challenge due to the difficulty of measuring species, habitats, and functions. King et al. (5) point out that environmental accounting systems require indicators capable of linking accounting-economic information with the extent, condition, and capacity of ecosystems. This interrelationship is key in agriculture, an economic activity that depends on the use of natural resources and, at the same time, can significantly affect them at the territorial scale.

Ecosystem accounts can contribute to the design and evaluation of agricultural policies by enabling comparison of production practices based on their environmental effects. Grondard et al. (6) highlight that this type of information facilitates the identification of systems that preserve ecological functions and of models that cause progressive losses of natural capital. The application of ecosystem accounts can strengthen agroindustrial planning and improve resource allocation for conservation, restoration, and sustainable production.

In the business realm, biodiversity accounting must record both the dependency of organizations on ecosystems and the impacts caused by their operations. Houdet et al. (7) proposed adapting double-entry accounting to recognize positive and negative changes in renewable natural capital. Thus, the loss of habitats or ecosystem services could be recorded as a decrease in natural assets, while restoration and conservation actions would represent recovery.

Despite these benefits, the adoption of these systems faces challenges related to data availability, measurement costs, lack of standardized procedures, and limited understanding of the generated information. Acceptance of natural capital accounting increases when its results are clear, relevant, and applicable to production and management decisions (8,9). Therefore, its design must be adapted to the characteristics of agricultural businesses and linked to planning, risk assessment, and resource allocation.

The valuation of natural capital also allows expanding the analysis of economic performance. Campos et al. (10) demonstrated that the benefits of productive systems are not limited to marketed goods, because ecosystems provide environmental services that can be incorporated into sustainability indicators. This approach helps distinguish between profitability based on the balanced use of resources and that obtained through their progressive degradation.

Mexico constitutes a relevant scenario for applying this approach due to its biological diversity and the presence of agroindustrial systems associated with coffee, avocado, agroforestry, and home gardens. Arcos Severo and Ruiz Rosado (11) identified various ecosystem services in home gardens in central Veracruz, demonstrating that these agroecosystems generate environmental, economic, and social benefits that are susceptible to valuation.

Mexican coffee systems are among the main examples of interaction between biodiversity and production. Hernández-Martínez et al. (12) identified differences between agroecosystems in Veracruz according to their productive intensity, vegetation, and management. In turn, plant structure and biological diversity can be related to the profitability and sustainability of coffee farms (13,14).

Shade vegetation constitutes an important component of natural capital in these systems. Soto-Pinto et al. (15) observed that tree density and composition influence coffee production in Chiapas.

In addition to contributing to microclimatic regulation and species conservation, agroforestry systems can store carbon in biomass and soil, generating an environmental service that is normally not included in financial records (16).

Pollination is also a fundamental ecosystem service for the Mexican agro-industry. Lara-Pulido et al. (17) valued it in the avocado production of Michoacán and showed that pollinators generate measurable benefits for the productive system. This value, however, is often excluded from accounting management, which makes it difficult to identify the economic risks related to habitat loss and the decline of pollinator species.

While there is knowledge about biodiversity, ecosystem services, and practices related to productive systems in Mexico, their link with accounting records and business decision-making remains scarce. Environmental information is generally used to describe impacts or to establish conservation measures, but it is rarely linked to financial, administrative, and productive indicators. This leads to companies lacking adequate knowledge of the value of their natural assets or a clear relationship between the costs derived from their deterioration.

Therefore, the objective of this research is to analyze the relationship between biodiversity and natural capital accounting practices and the sustainability of the Mexican agro-industrial sector. The hypothesis is that the identification, valuation, and recording of natural assets and ecosystem services are positively and significantly related to the environmental and productive sustainability of agro-industrial companies.

METHODOLOGY

The research was developed using a quantitative approach, with a non-experimental and cross-sectional design, because the variables were analyzed in their natural context without intervening or manipulating the activities of the participating organizations. The scope was descriptive and correlational-explanatory, since initially the level of application of biodiversity and natural capital accounting practices was identified and, subsequently, their relationship with the environmental and productive sustainability of the Mexican agro-industrial sector was examined.

The population consisted of professionals and responsible individuals linked to companies, associations, and agroindustrial productive units in Chiapas, Veracruz, Michoacán, and Yucatán. Activities related to the production of coffee, avocado, agroforestry systems, family gardens, and other crops characteristic of these regions were considered. Participants held administrative, accounting, environmental, technical, or productive roles and had experience in natural resource management or decision-making within the sector.

The sample consisted of 180 participants, selected through non-probabilistic convenience sampling and inclusion criteria. Adults with at least a year of experience in agro-industrial activities and knowledge of the organization's production, environmental, or administrative processes were considered. Incomplete questionnaires and those with inconsistent responses were excluded.

The independent variable was the accounting of biodiversity and natural capital, evaluated through four dimensions: identification of natural assets, valuation of ecosystem services, recording of environmental impacts, and incorporation of ecological information in decision-making. The dependent variable was agro-industrial sustainability, comprising the dimensions of biodiversity conservation, responsible management of natural resources, productive sustainability, and generation of economic and ecosystem benefits.

For data collection, a structured questionnaire consisting of 24 items was used. Twelve questions corresponded to biodiversity and natural capital accounting, and the remaining twelve assessed agro-industrial sustainability. Responses were organized using a five-point Likert scale: strongly disagree, disagree, neither agree nor disagree, agree, and strongly agree.

The content of the instrument was submitted for evaluation by three specialists in environmental accounting, sustainability, and agro-industrial management, who reviewed the clarity, relevance, and coherence of the items. Subsequently, a pilot test was conducted with 25 participants who were not part of the final sample. Reliability was determined using Cronbach's alpha coefficient, with values of 0.70 or higher considered acceptable.

The questionnaire was administered digitally and in person, depending on the availability of the participants. Before responding, the objective of the study was explained and informed consent was requested. Participation was voluntary, anonymous, and confidential. The collected data were used exclusively for academic purposes and care was taken to avoid recording information that could identify the individuals or organizations involved.

The information was cleaned, coded, and processed using a statistical program. In the descriptive analysis, frequencies, percentages, means, and standard deviations were calculated. The results of each dimension were classified into low, medium, and high levels, according to the ranges obtained from the scale used.

To determine the distribution of the data, a normality test was applied. Based on the results, the Pearson or Spearman correlation coefficient was used to examine the relationship between biodiversity accounting and agro-industrial sustainability. Furthermore, a multiple linear regression model was developed to identify which dimensions of natural capital accounting had the greatest explanatory power for sustainability. The significance level was set at $p < 0.05$.

RESULTS

The sample consisted of 180 participants linked to agro-industrial activities in Chiapas, Veracruz, Michoacán, and Yucatán. The highest participation corresponded to Chiapas, with 28.9%, followed by Veracruz with 26.7%. Regarding productive activity, the cultivation and processing of coffee and avocado predominated. The majority of respondents performed functions in production, administration, accounting, or environmental management.

Table 1. Characteristics of the participants of the Mexican agro-industrial sector

Characteristic	Category	Frequency	Percentage
State	Chiapas	52	28,9
	Veracruz	48	26,7
	Michoacán	44	24,4
	Yucatán	36	20,0
Agro-industrial activity	Coffee	58	32,2
	Avocado	42	23,3
	Agroforestry systems	34	18,9
	Milpa and home gardens	28	15,6
	Other activities	18	10,0
Function performed	Production	54	30,0
	Management and accounting	50	27,8
	Technical or environmental management	48	26,7
	Direction or property	28	15,5

Note. The distribution summarizes the main characteristics of the 180 evaluated participants. Own elaboration.

The internal consistency of the questionnaire was satisfactory. The biodiversity and natural capital accounting scale obtained a Cronbach's alpha of 0.91, while the agro-industrial sustainability scale reached a value of 0.90. For the complete instrument, the coefficient was 0.93, indicating adequate reliability.

Descriptive results showed that biodiversity and natural capital accounting reached an overall mean of 3.47, corresponding to a medium level. The highest-rated dimension was identification of natural assets, with a mean of 3.82. In contrast, the accounting record of environmental impacts presented the lowest score, with a mean of 3.05.

Agro-industrial sustainability obtained an overall mean of 3.74, corresponding to a high level. Productive sustainability presented the highest value, while the generation of economic and ecosystem benefits recorded the lowest score within this variable.

The results indicate that organizations recognize the presence and relevance of resources such as soil, water, vegetation, pollinators, and tree cover. However, there are greater difficulties in assigning them a monetary value and accounting for their loss, recovery, or transformation. A favorable valuation of the incorporation of environmental information in productive decisions was also observed, although this practice is not yet fully formalized.

The normality test showed significance values lower than 0.05, so the Spearman correlation coefficient was used. A positive, high, and statistically significant relationship was identified between biodiversity and natural capital accounting and agro-industrial sustainability, with a coefficient of 0.72 and a significance level lower than 0.001.

Table 2. Levels of natural capital accounting and agro-industrial sustainability

Variable and dimension	Mean	Standard deviation	Level
Biodiversity and natural capital accounting	3,47	0,61	Medium
Identification of natural assets	3,82	0,67	High
Assessment of ecosystem services	3,21	0,74	Medium
Record of environmental impacts	3,05	0,78	Medium
Environmental information in decisions	3,79	0,69	High
Agroindustrial Sustainability	3,74	0,58	High
Biodiversity conservation	3,68	0,65	High
Responsible management of resources	3,79	0,62	High
Productive sustainability	3,83	0,60	High
Economic and ecosystem benefits	3,66	0,68	High

Note. The levels were interpreted according to the means obtained on the Likert scale. Own elaboration.

The dimension with the highest relationship with sustainability was the incorporation of environmental information in decision-making, with a coefficient of 0.69. Positive relationships were also found with the valuation of ecosystem services, the identification of natural assets, and the recording of environmental impacts.

The multiple linear regression model was statistically significant, with an F value of 63.14 and a significance below 0.001. The adjusted coefficient of determination was 0.58, indicating that the dimensions of biodiversity and natural capital accounting explained approximately 58% of the variation in agro-industrial sustainability.

The incorporation of environmental information in decision-making was the most important predictor, followed by the valuation of ecosystem services. Although the recording of environmental impacts presented a lower explanatory capacity, its effect was also positive and significant. These results allowed us to accept the research hypothesis, because a greater application of natural capital accounting practices was related to better levels of environmental and productive sustainability.

Table 3. Relationship and effect of natural capital accounting on agro-industrial sustainability

Predictor dimension	Spearman	Standardized beta	p value
Identification of natural assets	0,58	0,21	0,004
Valuation of Ecosystem Services	0,61	0,26	< 0,001
Record of environmental impacts	0,54	0,17	0,018
Environmental information in decision-making	0,69	0,34	< 0,001
Global natural capital accounting	0,72	—	< 0,001

Note. The regression explains the joint effect of the evaluated accounting dimensions. Own elaboration.

DISCUSSION

According to the results, biodiversity and natural capital accounting is positively related to agro-industrial sustainability. Organizations that identify their natural assets tend to value ecosystem services and use environmental information for decision-making, which translates into confirmation of resource conservation and production sustainability. The coefficient attests that biodiversity management cannot be dissociated from economic management, since agro-industrial activity depends on the quality of the ecosystems that sustain it.

The identification of natural assets obtained very high values, giving the impression that the participating production units value soil, water, vegetation cover, and species associated with production systems as assets. This does not necessarily translate into formal valuation and registration procedures.

For example, Peeters et al. (18) showed that traditional coffee systems in southeastern Mexico can produce coffee, timber, and firewood, allowing the conclusion that a production unit can provide several goods and services. Natural capital accounting could serve to record these contributions and not only evaluate performance based on the main crop.

The environmental impact record received the lowest score among the accounting dimensions. This result suggests that companies recognize the biodiversity present in their territories but still have difficulty measuring the losses caused by the simplification of production systems. Greenberg et al. (19) identified differences in bird populations between rustic plantations and managed shade coffee plantations, demonstrating that production decisions modify the capacity of agroecosystems to conserve species. The absence of indicators for these changes prevents their deterioration from being reflected in administrative and accounting information.

The assessment of ecosystem services was significantly related to agroindustrial sustainability, although it had a medium level of application. This situation can be attributed to the difficulty of assigning physical or monetary values to functions such as soil conservation, water regulation, or genetic diversity. In family and peasant systems, these benefits have economic and social importance that is often excluded from commercial calculations. The agrobiodiversity of home gardens contributes to self-consumption, product exchange, and food security of rural communities (20).

Salazar-Barrientos et al. (21) found that the use of milpa agrobiodiversity is conditioned by socioeconomic factors, resource availability, and producer characteristics. This coincides with the need to design accounting systems adapted to the differences among large companies, associations, and family units. A uniform model could exclude relevant environmental and social benefits, so indicators must consider the production scale, crop type, and territorial conditions.

The incorporation of environmental information into decision-making was the main predictor of sustainability. This finding demonstrates that the usefulness of natural capital accounting depends not only on collecting data but also on using it to plan land use, select production practices, and assess risks. Orozco-Ramírez et al. (22) documented agricultural use transformations in central-western Mexico associated with processes of productive specialization. These changes can increase immediate profitability but also reduce crop diversity and increase territorial vulnerability when their cumulative effects are not considered.

The expansion of agro-industrial activities represents one of the main challenges for the conservation of natural capital. Pérez-Solache et al. (23) showed that the change in the use of temperate forests related to avocado production affects soil properties, plant traits, and insect-vegetation interactions. These effects support the need to record not only the income generated by productive expansion, but also the declines in ecosystem quality and potential restoration costs.

The results also show that biodiversity conservation can be compatible with economic viability if appropriate management practices exist. Mas and Dietsch (24) demonstrated that shade coffee certification can be beneficial for the conservation of birds and butterflies that depend on this type of coffee, and the benefits of such certification depend on the management criteria adopted. Similarly, the relationship between biodiversity, yield, and certification shows that diversified systems provide production systems in which economic incentives can be included for producers (25). Such evidence contradicts the assumption that conservation necessarily implies a reduction in agro-industrial profitability.

However, the estimated model explains a large proportion of agro-industrial sustainability, while also revealing that other economic, social, technological, and regulatory factors influence organizational performance. Natural capital accounting is a necessary yet challenging tool that must be complemented by training, public incentives, certifications, market access, and environmental monitoring systems.

CONCLUSIONS

The research findings revealed a positive, strong, and statistically significant relationship between biodiversity accounting and natural capital and the sustainability of the Mexican agro-industrial sector. This provides evidence that organizations that recognize their natural assets tend to value ecosystem services and incorporate environmental information into decision-making.

The identification of natural assets and the incorporation of environmental information into decision-making are the most developed practices, but the greatest limitation is observed in the monetary valuation of ecosystem services and in the accounting recognition of environmental effects.

This indicates that the valuation of soil, water, vegetation, and pollinators has not yet been translated into formal valuation and recording procedures.

The results also indicate that biodiversity conservation can be compatible with productivity and profitability. Agroforestry systems, shade-grown coffee, the agrobiodiversity of the milpa, and the protection of pollination services are alternatives that allow maintaining economic benefits with minimal irreversible degradation of the natural resource base on which production depends.

We suggest that Mexican agro-industrial companies incorporate physical and monetary indicators of biodiversity, ecosystem services, and land use changes into their accounting systems. They should strengthen the training of administrative and accounting personnel, establish monitoring mechanisms, and move towards establishing public incentives for the conservation and restoration of ecosystems.

The limitations of this study are the use of non-probabilistic sampling, the cross-sectional design, and reliance on perception-based information. Therefore, future research should include biophysical measurements, financial records, cartographic data, and longitudinal studies that assess changes in natural capital in different Mexican agro-industrial chains.

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