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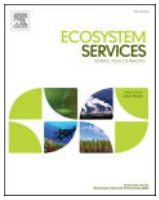

Review Paper

Payments for ecosystem services in Mexico: Two decades of progress and challenges between research and practice

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ABSTRACT

As some of the world's largest, longest lasting and most researched initiatives that reward individual and communal landowners for conserving forests and associated ecosystem services, Mexico's Payments for Ecosystem Services (PES) programmes provide a significant opportunity to examine questions of how, where, and by whom scholarship has been produced and the potential gaps revealed when comparing research insights with implementation patterns. To address these questions, we assembled the most up-to-date and comprehensive database of PES peer-reviewed publications and programme data in a single country. Our study includes a systematic analysis of relevant scientific literature in English and Spanish through 2022 (N = 140) and an assessment of the spatial and temporal distribution, timing, focus, and scope of all federally funded PES programmes at national, subnational, and local levels between 2003 and 2022. We find that variations in the spatial coverage of programme implementation have been associated with proportional levels of research interest over time and that studies represent multiple themes, spatiotemporal scales, and disciplinary and methodological approaches. With some variation, there is congruence among research findings that programmes have produced mostly positive ecological effects and mixed social effects. However, research has been disproportionately concentrated in specific geographic regions and Mexican scholarship has had considerably less global visibility and impact than European and U.S.-based research. By focusing our analysis on PES research and practice within a country-specific context and including literature produced in the local language, our analysis provides greater nuance than previous PES reviews regarding how knowledge is produced and by whom. We identify permanence of programme effects in Mexico as a key emerging issue for future research and, at a global scale, for the need to

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conduct such nuanced and inclusive assessments of other specific PES programmes to help identify and address key drivers of knowledge gaps in incentive-based environmental policies.

1. Introduction

Payments for Ecosystem Services (PES) have become popular incentive-based instruments for natural resource management over the last two decades (Wunder et al., 2018). They provide economic incentives for landowners that are conditional on either the direct provision of ecosystem services (ES) (e.g. carbon, water, biodiversity), an indirect proxy of ES (e.g. forest cover), or a specific resource management activity (e.g. forest fire prevention, water retention measures). Innovative nation-wide schemes in countries such as Costa Rica, Mexico, China, and Ecuador in the late 1990s and early 2000s were later complemented by hundreds of other initiatives. A global review documented more than 550 such schemes worldwide disbursing USD$36–42 billions annually (Salzman et al., 2018).

The meteoric rise of PES reflects high expectations placed by policymakers on economic incentives as a policy alternative to conserve biodiversity, avoid deforestation, and achieve other natural resource management goals whilst providing socio-economic co-benefits among rural households and communities who manage vital ecosystems (Bulte et al., 2008; Kaiser et al., 2021). In turn, rising PES implementation has led to ever increasing interest and research among scholars from diverse epistemic communities across the social and natural sciences, with a 26-fold increase in annual publications between 2005 and 2019 documented by Kolinjivadi et al. (2023). Thus far, PES reviews include systematic revisions of scholarly literature and *meta*-analyses of research or programme implementation that address a range of themes, including: social or ecological effectiveness and associated drivers (Adhikari & Agrawal, 2013; Blundo-Canto et al., 2018; Börner et al., 2017; Brouwer et al., 2011; Calvet-Mir et al., 2015); design and implementation factors (Engel, 2016; Sattler & Matzdorf, 2013; Wunder et al., 2018); enabling conditions (Huber-Stearns et al., 2017; Jindal et al., 2008); and implementation patterns (Ezzine-de-Blas et al., 2016; Salzman et al., 2018).

These and other previous reviews share an emphasis on geographic breadth and the drawing of comparisons across programmes and contexts, such as how outcomes and processes vary according to: i) the type of ecosystem service targeted by the programmes –e.g. watershed services (Ferraro, 2009; Huang et al., 2009; Martin-Ortega et al., 2013; Southgate & Wunder, 2009) or carbon sequestration (Jindal et al., 2008); ii) the geographic region of implementation –e.g. Global South vs Global North (Schomers & Matzdorf, 2013), across the Global South (Milne & Niesten, 2009), in Africa (Ferraro, 2009; Jindal et al., 2008), in Asia (Huang et al., 2009) or in Latin America (Grima et al., 2016; Martin-Ortega et al., 2013; Perevochtchikova et al., 2021); or iii) the type of ecogeographic region targeted –e.g. the tropics (Calvet-Mir et al., 2015).

A more recent theme addressed by PES reviews relates to how knowledge is produced in a PES context. A global review of anglophone publications by Kolinjivadi et al. (2023) highlights that PES research is mainly authored by researchers from institutions in the Global North but focuses on empirical investigation in the Global South. This study also demonstrates that much PES research around the world is decontextualized from the political histories of the territories that shape socio-ecological relations. Another review by Kaiser et al. (2021) shows that the authors' disciplinary backgrounds –i.e. environmental economics, ecological economics, political ecology– influence the degree of praise or critique towards PES in published work. Understanding such knowledge production patterns in PES matters because studies in other fields of environmental science have revealed severe biases in how, where, and by whom scientific knowledge is being produced. For example, a review by Corbera et al. (2021) on research addressing ecosystem services and poverty alleviation identified the following biases: *gender*, with male researchers dominating publication numbers and influence; *geography of affiliation*, with Global North academics being overrepresented; and *disciplinary background*, with single disciplines such as ecology, biology, or economics dominating over other social sciences or multidisciplinary studies.

Mexico's experience with PES is an ideal context to examine patterns of knowledge production and how they compare with PES programme implementation processes. Mexico's federal government was one of the early pioneers of PES deployment, beginning in 2003, with a range of local to national-level programmes (Muñoz-Piña et al., 2008), which have attracted a large volume of scholarly research (Kolinjivadi et al., 2023).

The Mexican federal government has implemented four distinct PES programmes under 12 components since 2003. The first and longest lasting is the hydrological component of the national programme, *Pago por Servicios Ambientales Hidrológicos* (PSA-H) (Muñoz-Piña et al., 2008), which was followed by several other national, subnational, and local PES initiatives across the country. These include diverse iterations of payments for biodiversity and/or carbon sequestration programmes (PSA-B and PSA-CABSA), the Local Matching Funds programme (MLPSA-FC), the *Fondo Patrimonial de la Biodiversidad* (FPB), and so-called Early Action PES programmes (*Programas Especiales de Acción Temprana*) that target specific sites or regions within a REDD-readiness framework. Since 2020, PSA-H and PSA-B have been incorporated into a general 'environmental services' component. Mexico's federal PES programmes have continued uninterruptedly for 20 years, albeit under different names and categories, making them one of the largest and longer lasting PES initiatives worldwide (Shapiro-Garza, 2020).

Although there is significant variation in the scope and focus of each programme, with design and implementation having evolved over time in each, key shared and constant aspects across programmes include: i) design and implementation by a single, federal agency, the National Forestry Commission of Mexico (CONAFOR in Spanish acronym); ii) an emphasis on conservation of natural forest cover as the main condition for participation (though early iterations of the PSA-B component prioritised other cover types and the presence of key species); iii) short-term, renewable, contracts (e.g. 5-years) with annual payments per hectare enrolled (e.g. ~$50 USD in 2023); and iiii) pro-social targeting and prioritisation of collective enrolment by agrarian (*ejidos*) and indigenous communities (Izquierdo-Tort et al., 2021).

In this article, we assemble the most comprehensive academic publication and programme implementation database of PES for a single country, which includes an extensive sample of relevant scientific articles focused on PES programmes in Mexico written in English and Spanish up to year 2022 (N = 140), as well as the locations, timing, focus, and scope of all federally funded PES programmes implemented at the national, subnational, and local levels between 2003–2022. We address three specific research questions:

1) Where, when, and how do PES implementation and research (mis) align?
2) What have been the main research priorities, reported results and impact of this scholarship and how do these vary based on the spatial scale of the research, language of publications and the country of institutional affiliations of the scholars?
3) What do these results reveal about the patterns of embedded biases and the directions of influence between research and policy practice?

Unlike previous reviews of the scholarly literature on PES which include only anglophone publications, we account here for peer-reviewed research on Mexico's PES published in Spanish. We suggest that there are at least three benefits of including such publications in

local languages when conducting PES reviews. First, it is a way to recognise and amplify the body of knowledge that is being produced in local languages –often by in-country scholars and by other institutions like Non-Governmental Organisations (NGOs) who implement programmes locally– but that is generally omitted from global discourses and debates (North et al., 2020). Second, it can help improve the quality and validity of results derived from PES reviews, for instance, by reducing sampling bias and providing complementary data points and contextual insights on specific PES processes and outcomes (Konno et al., 2020). Finally, including scholarship in local languages and comparing it with anglophone publications can shed light on how researchers' positionality, such as publication language and geography of affiliation, influences knowledge production priorities and outcomes (Konno et al., 2020). We thus examine where and by whom has research on Mexico's PES programmes been conducted and published and how these factors have in turn affected the types of questions scholars have asked, their ability to influence our understanding of both the dynamics and outcomes of these particular programs and of PES as an approach, and the assumptions and biases that might be introduced if certain scholars and scholarship is less visible and valued.

Our focus on both the content of academic publications and programme implementation patterns also enables us to examine how PES research and practice relate to one another on key dimensions such as temporal, programmatic, and geographic coverage. Such comparison can help uncover gaps and biases in knowledge production by identifying specific time periods, regions, or programmes that have received disproportionate scholarly attention relative to implementation. It can also help discern patterns and directions of influence between research and policy practice. For instance, previous studies suggest that publication delays in the conservation literature or other barriers imposed by the research process, such as time required for acquiring funding, data collection, analysis, and peer review, can significantly reduce the ability for research to inform decision-making (Christie et al., 2021). Cvitanovic et al. (2015) identify additional barriers to knowledge exchange between environmental scientists and decision-makers, including: *cognitive and cultural differences*, such as different mindsets and priorities, and personal perceptions and worldviews affecting how information is interpreted; *institutional barriers,* such as lack of support or incentives within academia for conducting engagement activities*;* and *conventional approaches to knowledge exchange,* in which scientists and decision-makers work independently and knowledge transfer processes are linear and unidirectional.

We believe that the more holistic accounting of Mexico's PES scholarship and programme implementation provided by this review allows us to explore the interplay between knowledge production and policy implementation, for PES and incentive-based conservation approaches more broadly, with greater nuance and rigour than other less geographically specific or comprehensive reviews.

2. Materials and methods

2.1. Programme implementation

We compiled data of federal PES programme implementation between 2003 and 2022 from CONAFOR (Table 1, Fig. 1). All programme data from 2003 to 2018 was provided to the authors by the Mexican Ecosystem Services Office in 2019, while data from 2019 onwards is publicly accessible at the National System for Forest Information (snif.cnf.gob.mx). Data for all 12 PES schemes was standardised, resulting in a geodatabase containing, for each contract established, the following information: name of the PES programme and component, year, location (state, municipality), type of beneficiary (communal or private property, name of matching funds partner where applicable), number of hectares, total payment amounts over five years (where available), and polygon data for the plot or plots enrolled. This allowed us to calculate the rate of PES programme implementation across type of scheme, type of beneficiary, geographic location, and their timeline.

2.2. Literature review

We carried out a systematic review of scientific literature on the federal PES programmes of Mexico. To do so, we assembled the 'PESMEX20′ database (Alatorre et al., 2024), which contains relevant scientific publications on Mexico's PES up to the end of the year 2022. Our approach to article selection followed PRISMA established norms (Moher et al., 2009). We employed advanced searches for publications in several internationally recognised databases as suggested by previous PES reviews (Calvet-Mir et al., 2015; Kolinjivadi et al., 2023; Perevochtchikova et al., 2021; Schomers & Matzdorf, 2013) and other related literature reviews. Specifically, we conducted searches in three internationally recognised databases: i) Scopus (international database of peer-reviewed academic publications worldwide); ii) Scielo (international database of peer-reviewed academic publications, mainly from Latin America, Ibero-America, and South Africa); and iii) Redalyc (international database of peer-reviewed academic publications from Latin America, the Caribbean, Spain, and Portugal).

Additionally, given our specific interest in PES literature based in Mexico, we also conducted online searches of articles published in nationally recognised scientific journals based in Mexico. Our analysis focused on peer-reviewed journals with indexation by Mexico's Science and Technology Journal Classification System (CRMCYT in Spanish acronym) as of 2023. From a list of 109 CRMCYT indexed journals from seven thematic areas, we narrowed our search to 14 journals based on title and thematic relevance. Of these 14 journals, 11 were already included in Scopus, Scielo, or Redalyc. We therefore conducted additional searches in the 3 remaining Mexican journals: *Estudios Sociológicos de El Colegio de México; Política y Gobierno;* and *Papeles de Población.*

The systematic review process first consisted of online searches of publications with keywords related to PES programmes in Mexico in English, Spanish, and Portuguese. The search elements were sought specifically in the title, abstract and keywords for Scopus and Scielo, and in the publications' full text for Redalyc and the three individual Mexican journals.[1] The syntax used included a wide array of combinations of the following terms:

> Mexico/Mexican AND payment/programme/scheme + ecosystem/ environmental/ hydrological/biodiversity/carbon service (Appendix A).

In total, 1357 records were obtained and downloaded in a single Excel spreadsheet containing records until 2022. Duplicate records (N = 152) were identified and excluded, with the final publication database including a total of 1205 publications (Fig. 2).

Our analysis focused exclusively on peer-reviewed journal articles and book chapters and omitted other grey literature, such as theses, reports, and books. Whilst we recognise that grey literature can provide valuable insights, we made this decision to ensure consistency, methodological rigour, and replication as the selected peer-reviewed publications are easily accessible in web searches and undergo standardised evaluation processes that enhance the reliability and comparability of findings.

2.2.1. Inclusion and exclusion criteria

The following step consisted of identifying the set of records related to PES programmes in Mexico from the publication database, and thus relevant for analysis (Fig. 2). We coded each record according to two dimensions:

[1] The search engines did not include an option to search only in the title, abstract and keywords.

Table 1
Categorisation of Mexico's federally funded PES programmes.

Programme	Number of publications*	Component	Main focus	Timeline	Number of contracts	Hectares enrolled
National PES	94	Hydrological (PSA-H)	Maintaining forest cover for aquifer recharge in vulnerable watersheds	2003—2019	6 351	4 319 561
		Biodiversity (PSA-B)	Maintaining forest and agroforest cover for the conservation of wild flora and fauna	2004—2019	3 203	2 267 747
		Agroforestry	Early inclusion of forest and agroforest regeneration	2004—2009	200	102 256
		Carbon capture	for carbon capture that was replaced by REDD	2004—2005	7	11 146
		Regeneration	initiatives	2008	3	7 165
		Environmental Services	Conservation of forested areas through good management practices and diversified, sustainable productive projects	2020—2022	1 493	1 131 074
		Tren Maya	Landowners in the path of the Train Maya infrastructure project	2022	15	22 294
Early Action REDD+	11	Programa Especial Selva Lacandona	Ecosystem service provision in Selva Lacandona Chiapas	2010—2022	190	116 258
		Programa Especial Peninsula de Yucatan	Ecosystem service provision in the Yucatan peninsula	2013—2014	38	7 749
		Programa Especial Cuencas Costeras de Jalisco	Ecosystem service provision in the Coastal areas of Jalisco	2011—2014	148	87 763
Fondo Patrimonial de Biodiversidad (FPB)	0		Priority biodiversity areas within the Jalisco region that lacked other sources of funding	2011—2022	100	83 309
Local Matching Funds (MLPSA-FC)	36		Proposed and partially funded by interested parties, priority given to key watersheds, biological corridors and conservation areas	2008—2022	1 476 **	788 652
TOTAL	140				13 217	8 944 975

Source: authors with data from CONAFOR. Notes: * Categories are not mutually exclusive; ** Based on data provided by CONAFOR's Ecosystem Services office and published online. We are aware that additional contracts exist in alternative databases provided by collaborators, and as confirmed through fieldwork.

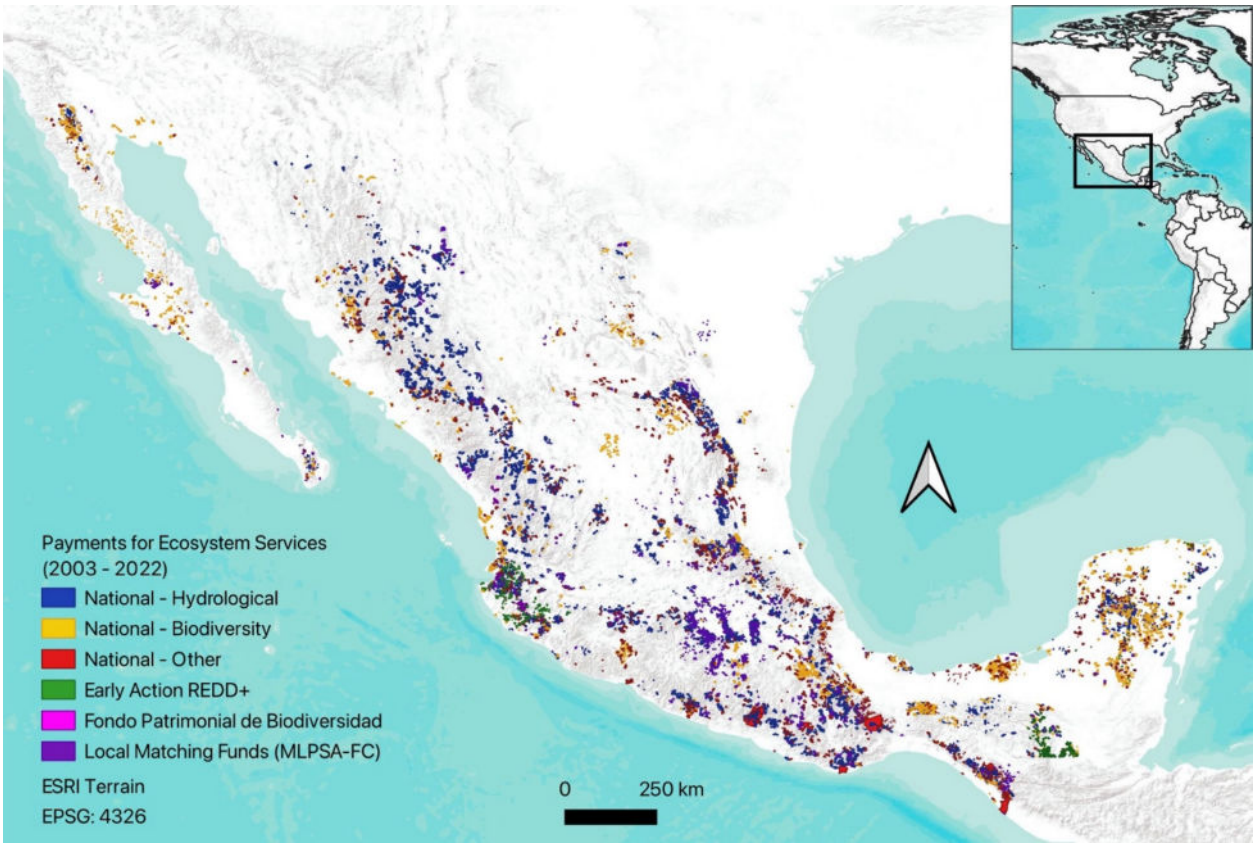

Fig. 1. Cumulative implementation of the 12 distinct federal PES programmes in Mexico, 2003–2022. Notes: 'National – Other' includes PES for agroforestry, regeneration, carbon capture, Tren Maya, and unspecified 'environmental services' (see Table 1).
Source: authors with data from CONAFOR

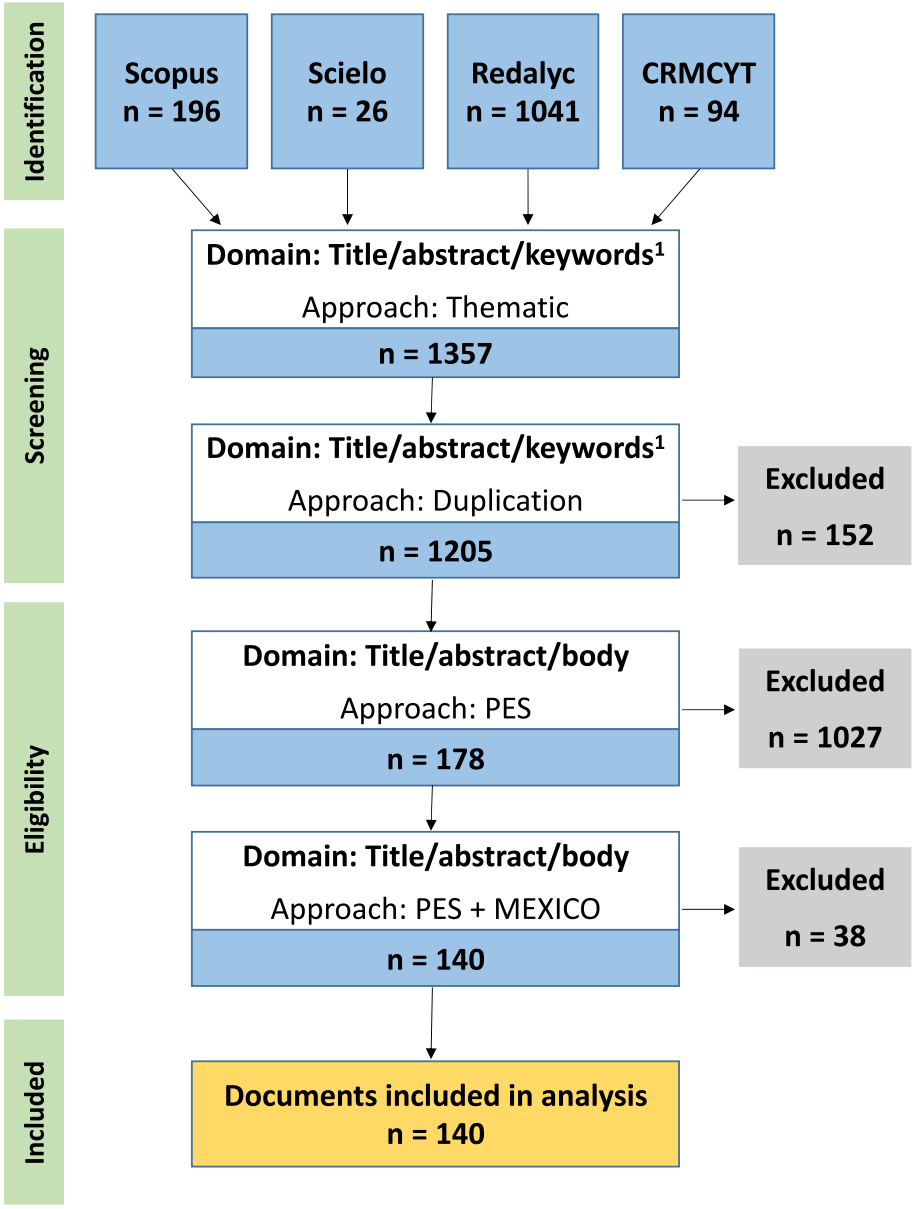

Fig. 2. Methodology and search criteria based on PRISMA guidelines. The inclusion criteria are: PES = related to existing PES programmes and/or provides insights related to their application, MEXICO = based entirely or partially in Mexico.
Source: own elaboration based on Moher et al. (2009)

- PES focus: publication relates to actual or hypothetical PES programmes and/or providing insights related to their application. Actual PES programmes include the federal PES programmes (Table 1) and other public and private programmes addressed by the studies.
- Mexico focus: publication provides insights and/or data collected in Mexico. This includes comparative studies based in Mexico and other geographic regions.

For each dimension, the coding process consisted of two main steps: i) searching for keywords in the title related to PES or Mexico; ii) reading of the abstract to confirm or refute PES or Mexico focus. Whenever the publication's classification was unclear after steps i) and ii), the body of the publication was further scanned. This codification was developed by the first author and was independently reviewed by another co-author. Discrepancies in classification were identified, discussed, and resolved collectively. Once all records were coded, only those publications that combined a focus on PES and Mexico were selected for our analysis.

In total, 140 publications met both PES and Mexico requirements, and thus formed the empirical basis for the 'PESMEX20′ database and our analysis (Alatorre et al., 2024). These 140 publications included 137 peer-reviewed journal articles and three book chapters.

2.2.2. Content analysis and coding procedure

The 'PESMEX20′ database explores a series of variables that cover four main components: i) basic features; ii) thematic coverage; iii) methodological coverage; and iv) reported effects. Each entry was coded twice independently in separate spreadsheets by two co-authors who have experience with PES programmes and research in Mexico. Subsequently, the spreadsheets were merged, and each result was double checked for consistency and, in cases where discrepancies were found, the coders jointly deliberated to reach a result. We initially selected a sample of 14 papers to test intercoder reliability (ICR), achieving a result of 69.7 %. At the end of the coding process, the ICR fell to 59.5 %; however, all discrepancies were discussed among the two independent coders until consensus was achieved.

The *basic features component* identifies the lead authors and country of institutional affiliation (i.e. the country where the first institution named is based and not their nationality), publication outlet, publication year, and number of citations (citation number retrieved from Google Scholar on 8 November 2023).

The *thematic coverage component* identifies the set of themes addressed by the publication. Whilst various frameworks have been developed to analyse and evaluate different topics of PES programmes on-the-ground, none of these has comprehensively captured the multiple topics covered by PES research in a specific site or region. Therefore, here we propose an assessment framework that situates PES research within four main phases of PES design and implementation: i) design process and evolution; ii) participation; iii) effectiveness; and iv) policy recommendations (Fig. 3). Each of these phases involves, in turn, a series of theme-specific categories. The framework was developed based on our existing knowledge acquired from long-term research of PES programmes and is composed of a series of well-established themes in PES literature (see references in Fig. 3).

The first theme, situated in the assessment and planning phase, relates to *programme design process and evolution*, which includes analyses focused on PES programmes' conceptual underpinnings (Muradian et al., 2010; Shapiro-Garza et al., 2020; Wunder, 2015), and the combination of factors that influence the design and evolution of programmes (Shapiro-Garza et al., 2020). Themes two and three are associated with the implementation and evaluation phase. The second theme, *participation*, includes studies that examine participants' main features and the set of decision factors that drive participation at different levels (Kosoy et al., 2008; Pagiola et al., 2005). The third theme is programme *effectiveness*, assessed by different types of impacts (e.g. environmental, economic, social) (Perevochtchikova et al., 2021) and their associated interactions, which are driven by a combination of contextual and design factors (Alix-Garcia et al., 2012, 2015; Börner et al., 2017). The final theme relates to studies focused on policy *recommendations*, such as how to refine enrolment criteria or ecological targeting, or how to maximise social outcomes (Engel, 2016; Muradian et al., 2010; Sims et al., 2014; Wunder et al., 2018). We believe these themes are mutually exclusive and collectively exhaustive, although we note that individual publications can cover more than one theme. Indeed, publications in the 'PESMEX20′ database addressed 2.15 themes on average.

The *methodological coverage component* characterises the programme (s) studied (type, geographic location) and the study's design (if and where primary data was collected, the type of methods employed and the temporal scale of analysis). Our classification of type of publication is as follows: 'conceptual work' if the work involves the development of analytical, conceptual or theoretical approaches but no application to empirical data; 'literature reviews' if the work draws exclusively on secondary data; 'original work' if it entailed primary data from one or more case studies; and 'hypothetical/experimental PES' if it aims at developing hypothetical or experimental PES scenarios but did not analyse any specific PES programme. We also captured the degree of critique towards PES based on the overall tone and language of the study's abstract and conclusions based on the following categories: 'not at all critical' for those limited to describing programme outcomes and processes, both positive and negative, without reflecting on what this means for the suitability or desirability of this type of programme; 'somewhat critical' for those that describe programme outcomes and processes but provide some caveats or words of caution about PES design or implementation; and 'openly critical' for those that outright question the desirability and/or feasibility of PES as a policy approach.

From the list of 140 publications focused on PES in Mexico, we added a further inclusion criterion to identify a total of 56 publications that focused on ecological or social effects, which form the basis of the *reported effects component*. This subset includes publications that provide empirical evidence related to PES environmental and/or social impacts or outcomes and excluded reviews as well as conceptual, experimental and hypothetical studies. Specifically, we examined what scholars conclude about the social and ecological effects of Mexican PES programmes in terms of key indicators, whether the study assesses outcomes versus impact (through counterfactual analysis), and the authors' conclusions on the direction (positive, negative or neutral) and magnitude of effects. Classification as positive or negative was based on our interpretation of the authors' overall assessment of environmental and social outcomes (separately). If reported outcomes were predominantly positive, we classified the effects as positive, and vice versa for negative outcomes. Where findings did not allow an assessment of outcome direction, or in instances where there was a balance of positive and negative outcomes, we designated these as neutral.

3. Results

3.1. Research and programme implementation (mis)alignments

3.1.1. Temporal coverage

In total, at least 7.4 million hectares of distinct land surfaces were enrolled between 2003–2022 in the various federal PES programmes (Fig. 4). The cumulative area enrolled is at least 8.9 million hectares, but 17 % of this area corresponds to overlapping polygons caused by

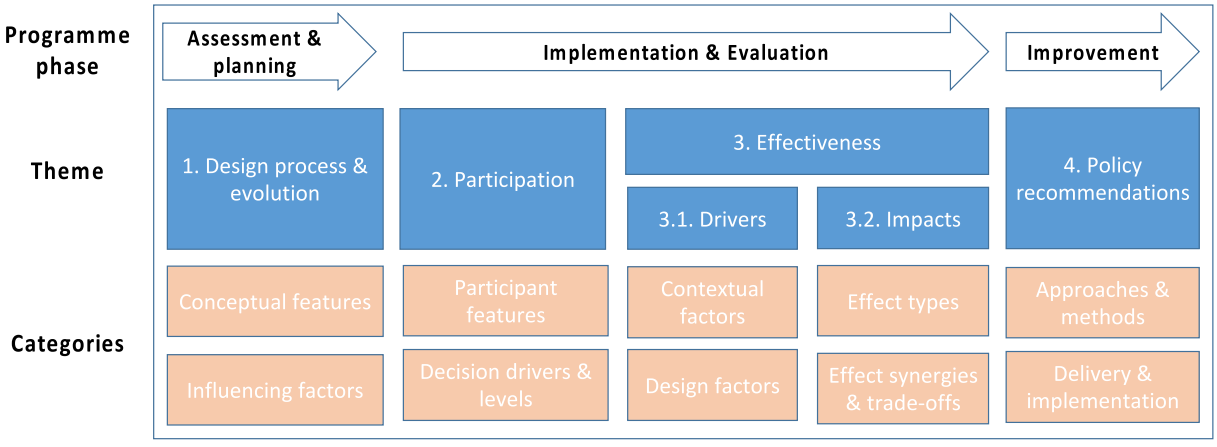

Fig. 3. Review framework for PES scholarly literature in Mexico. Themes 1–4 and associated categories are well-established research topics in the PES literature: programme design process and evolution (Muradian et al., 2010; Shapiro-Garza et al., 2020; Wunder, 2015), participation (Kosoy et al., 2008; Pagiola et al., 2005), effectiveness (Perevochtchikova et al., 2021) and drivers of effectiveness (Alix-Garcia et al., 2012, 2015; Börner et al., 2017), and policy recommendations (Engel, 2016; Muradian et al., 2010; Sims et al., 2014; Wunder et al., 2018).

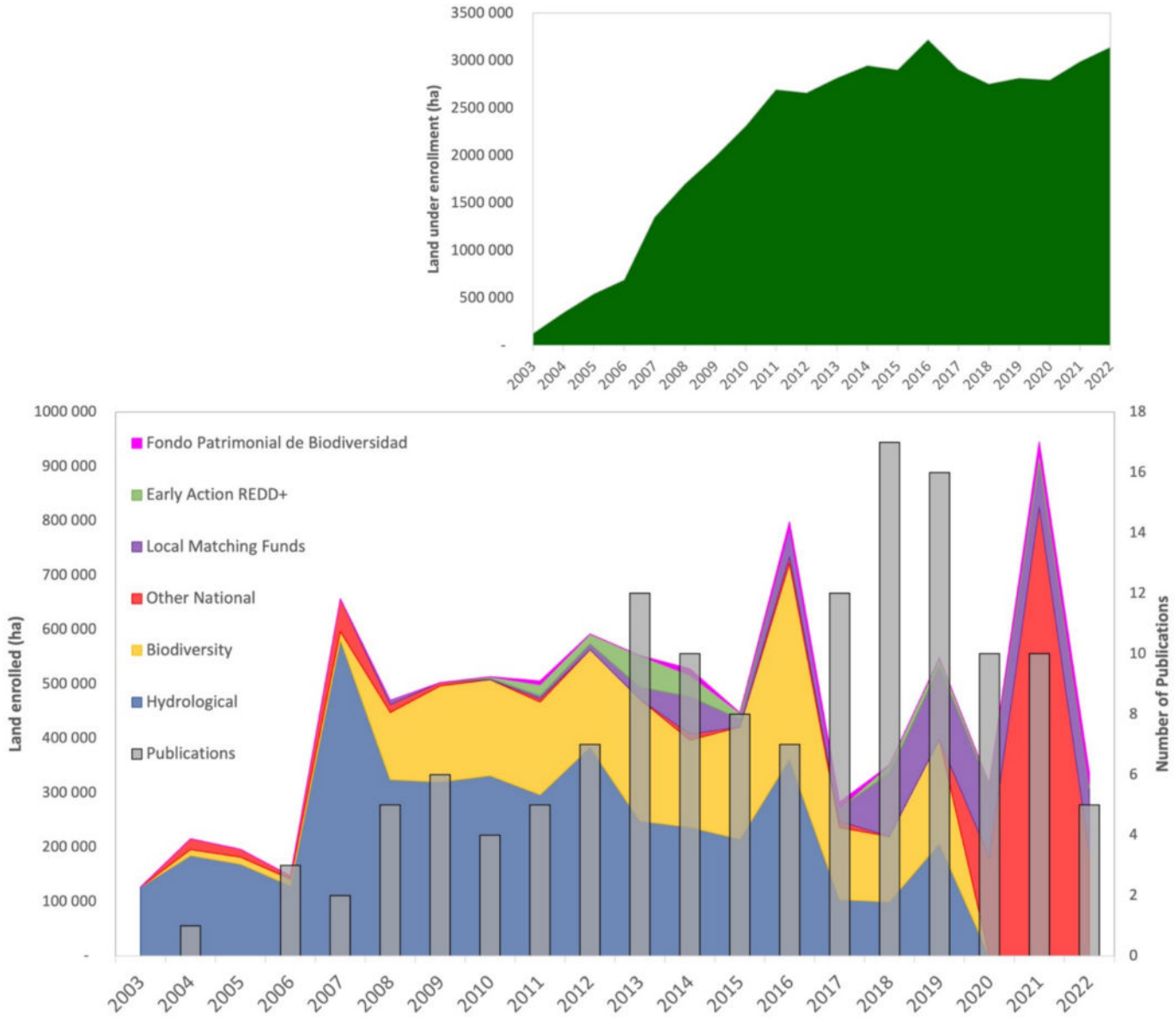

Fig. 4. PES land enrolment and publications in Mexico over time. Cumulative hectares under PES enrollment over the past two decades (top); number of hectares enrolled for each PES component and number of publications per year (bottom). Notes: 'Other National' includes PES for agroforestry, regeneration, carbon capture, Tren Maya, and unspecified 'environmental services' (see Table 1).
Source: Own elaboration based on data from CONAFOR

contract renewals or transitions between programmes. The number of hectares actively under PES contracts (i.e. the total number of hectares enrolled in a given year, which can include lands enrolled from previous 5-year contracts) has plateaued after an initial period of rapid growth. Active hectares increased from ~120 thousands in 2003 to ~2.7 million hectares by 2012, but showed only a modest rise to ~3.1 million hectares by 2022.

Annual land enrolment (i.e. the number of additional lands enrolled in a given year) increased significantly from ~200 k hectares per year from 2003 to 2005 to more than ~500 k hectares from 2006 to 2016 but then declined to ~400 k hectares from 2017 to 2020. There was a significant increase in annual enrolment in 2021 at a level of ~900 k hectares, followed by a sharp decline in 2022 at ~300 k hectares. Local Matching Funds became more prominent after 2018, while Early Action REDD + programmes largely ceased to be active around the same time. Since 2020, no distinction is made between PES subtypes within the national schemes, instead being labelled simply as *Servicios Ambientales*; these are included within the 'Other national' schemes category. These erratic implementation trends stem from the fact that funds allocated for the environmental sector, and therefore to CONAFOR and its various programmes, are annually allocated as part of the larger national budget (Izquierdo-Tort et al., 2021).

The number of annual publications on Mexico's PES had an upward trend since the first publication in 2004 and until 2018 but sharply declined thereafter (Fig. 4). More than 75 % of the articles in our database were published between 2013–2022 as opposed to less than 25 % in the previous ten years. The period 2017–2019 was the most productive, with an average of 14.3 publications on Mexico's PES programs per year. By 2022, however, the number of annual publications (six) was the lowest since 2012. The ups and downs of implementation predate those of research by a few years (Fig. 4). In the Discussion we provide some tentative explanations for the relationship between PES research and practice.

3.1.2. Programmatic coverage

By far, the largest PES programme in terms of land and number of contracts is the national PES programme, and within it the hydrological (PSA-H) component (Fig. 5). In terms of research, most studies have focused on federal schemes, including the national PES, Local Matching Funds, and Early Action REDD+ (Fig. 5). The national PES programme has also been by far the most researched, representing nearly all studies that address existing schemes. Within the national scheme, the PSA-H component has been the most studied, with 52 publications. Notably, 27 publications focus on hypothetical or experimental PES scenarios not associated with a specific programme, mostly to do with how to improve policy design or implementation. Another 16 publications target other PES schemes that are not managed by CONAFOR, including private initiatives for voluntary carbon markets and other programmes implemented by local governments, NGOs, and/or private companies, with no inputs from the federal government. We do not have implementation data for these non-CONAFOR PES programmes.

Local Matching Funds (MLPSA-FC) are the second most studied initiatives with 25 % of the analysed publications. The most highly mentioned local schemes are FIDEICOAGUA (Fideicomiso para la Promoción y Preservación de la Zona Montañosa de Coatepec) (n = 9), PROSAPIX (Programa de Compensación por Servicios Ambientales en la Cuenca del Río Pixquiac) (n = 7), and Fondo Monarca (n = 4). This is in stark contrast to the implementation data, where only Fondo Monarca features among the top MLPSA-FC contributors (Fig. 6). The most widely implemented MLPSA-FC is the Protectora de Bosques del Estado de México (PROBOSQUE), a state government initiative. However, PROBOSQUE it was not mentioned by any of the publications reviewed. On the other hand, FIDECOAGUA and PROSAPIX have only 11 and 10 contracts, respectively, covering a cumulative total of 3,800 ha. Overall, the mismatch between research productivity and implementation breadth on Local Matching Funds is quite significant.

3.1.3. Geographic coverage

Our results reveal important mismatches between research and implementation in terms of geographic coverage (Fig. 7). Federally funded PES programmes have been unevenly implemented across all 32 Mexican states, reflecting both the geographic distribution of forests across the country and specific programmes' eligibility criteria (Ezzine-de-Blas et al., 2016). The states with the highest number of total contracts are Chiapas, Jalisco, Oaxaca, and Veracruz, while Oaxaca had by far the most hectares enrolled (895 509 ha, or 10 % of the state's total area), with Durango (595 399 ha), Chiapas (581 025 ha), and Jalisco (512 398 ha) trailing far behind. With regards to land tenure, 72 % of all federal PES contracts took place in collective land regimes, including ejidos and indigenous communities, representing 90 % of enrolled hectares.

Research has similarly concentrated in the southeast, mainly in the states of Veracruz, Chiapas, and Oaxaca (Fig. 7). Ciudad de México, however, is featured in a disproportionately high number of publications with regards to its relatively low number of contracts. Very few studies have taken place in Central or Northern Mexico, and we found no state-specific PES studies in eleven of these states: Guanajuato, Chihuahua, Zacatecas, Nuevo León, Coahuila, Nayarit, Hidalgo, Sonora, Sinaloa, Aguascalientes, and Tlaxcala. In total, these eleven states with no state-specific PES research contain 24 % of all PES contracts. We note, however, that some national-level analyses have been informed by data collected from these states, resulting in scientific publications (Alix-Garcia et al., 2012a, Alix-Garcia et al., 2015, 2018) and reports (Alix-Garcia et al., 2012b).

Our database further allowed us to zoom in on the specific sites of empirical data collection. While a variety of units of study were employed by the authors (i.e. city, community, watershed, protected area, municipality), we standardised to the municipality scale to explore trends within individual states. We found that within the three most studied states, data collection is further concentrated within one or two municipalities in each (Fig. 7): 22 publications address Coatepec and neighbouring municipalities in Veracruz (these include the studies targeting the FIDECOAGUA and PROSAPIX schemes mentioned above), while nine publications study the Chinantla region in Oaxaca (San Felipe Usila municipality) and a further 10 publications study two municipalities neighbouring the Montes Azules Biosphere Reserve in Chiapas (nine in Marqués de Comillas and one in Benemérito de las Américas). Other highly studied municipalities include those surrounding the Monarch Butterfly Biosphere Reserve, mainly Ocampo (n = 8), and those belonging to the Suelo de Conservación protected region in Mexico City, mainly Tlalpan (n = 7) and La Magdalena Contreras (n = 6). This result highlights the highly regionalised nature of PES research in Mexico.

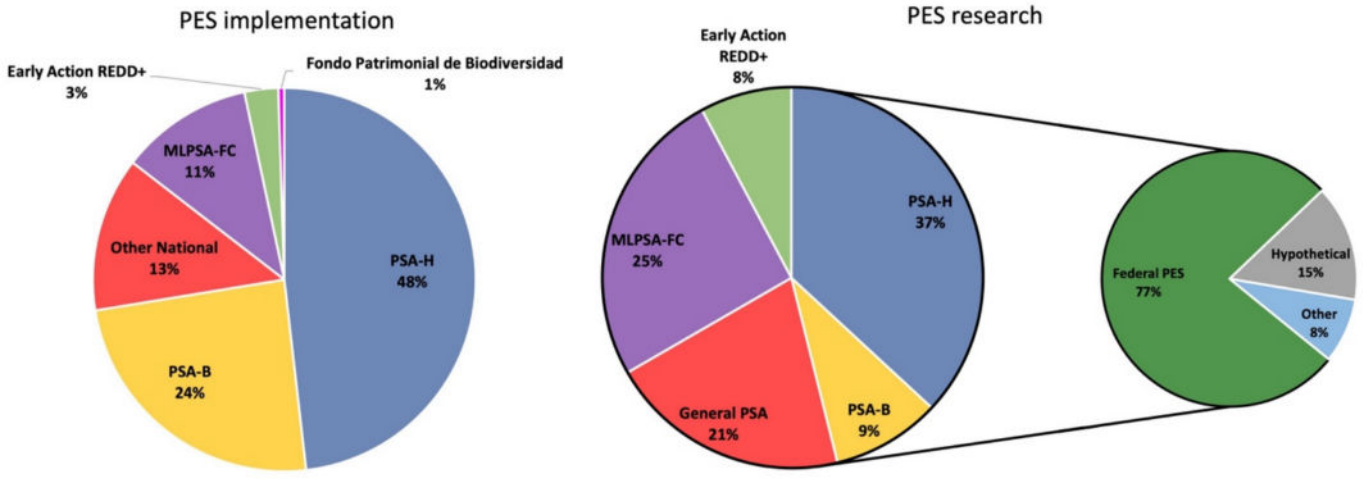

Fig. 5. Comparison of PES implementation and research in Mexico by programme type: percentage of the total number of contracts (left) and publications (right). For PES implementation, 'Other national' includes PES for agroforestry, regeneration, carbon capture, Tren Maya, and unspecified 'environmental services' (see Table 1). For PES research, 'Other' schemes include PROFACE (Programa de Fondos de Apoyo para la Conservación y Restauración de los Ecosistemas a través de la Participación Social) (n = 3), voluntary carbon markets (n = 3), and PRCSA (Programa de Retribución por la Conservación de Servicios Ambientales) (n = 2), while 'General PSA' contains studies that do not specify a programme component.
Source: Own elaboration based on data from CONAFOR

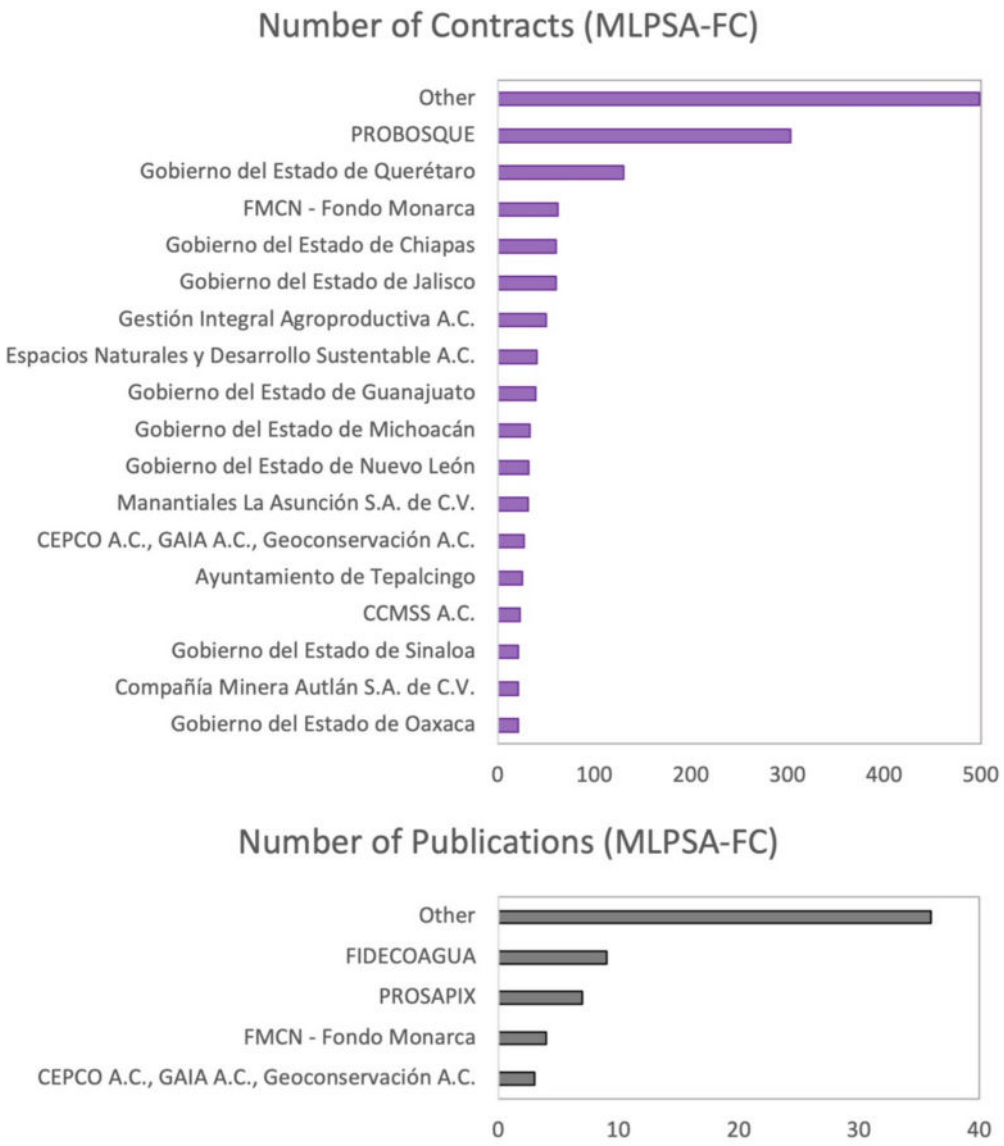

Fig. 6. Comparison of the most prolific Local Matching Funds PES (MLPSA-FC) in terms of number of contracts (cumulative between 2008 and 2022) and publications. The top graph shows all schemes with more than 20 contracts, and the bottom shows all schemes mentioned by more than one publication ('Other' contains the remaining contracts and publications, including those that do not specify the name of the scheme).
Source: Own elaboration based on data from CONAFOR

3.2. Research priorities and relation with researchers' country of institutional affiliation

3.2.1. Contributions by geography of institutional affiliation

PES publications were produced by lead authors based in institutions from eleven different countries in North America, Europe and South America. By far, lead authors based in Mexico have contributed the most in terms of volume, with 55 % (n = 77) of all publications, followed by the U.S. (25.7 %, n = 36), Spain (5.7 %, n = 8), UK (4.3 %, n = 6), Canada (2.9 %, n = 4), and France (2.1 %, n = 3).[2]

In terms of affiliation, the top ten contributors include six public education or research institutions from Mexico: Universidad Nacional Autónoma de México (UNAM) (n = 21), El Colegio de México (COLMEX) (n = 9), Instituto de Ecología A.C. (INECOL) (n = 7), Colegio de Postgraduados (COLPOS) (n = 5), Universidad Autónoma del Estado de México (UAEM) (n = 4), and Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP) (n = 3). Within UNAM, specific institutes, faculties or centres with high productivity include: Instituto de Investigaciones Económicas, Instituto de Investigaciones Sociales, Instituto de Geografía, Instituto de Investigaciones en Ecosistemas y Sustentabilidad, Centro de Investigaciones en Geografía Ambiental, Facultad de Ciencias, and Facultad de Economía. Highly contributing foreign institutions include the Institut de Ciència i Tecnologia Ambientals at Universitat Autònoma de Barcelona (ICTA-UAB) based in Spain (n = 5), and Duke University (n = 4), Colorado State University (n = 3), and University of Wisconsin-Madison (n = 3) based in the U.S.

3.2.2. Publication venues and influence

English was the preferred choice of language among researchers studying Mexico's PES, as 70 % (n = 99) of all 140 publications were written in English. However, 51 % of publications by a lead author in a Mexican institution were written in Spanish, while 97 % of publications by lead authors in foreign institutions were in English. In terms of target

[2] Countries contributing less than 2% include The Netherlands, Luxembourg, Colombia, Chile, and Austria.

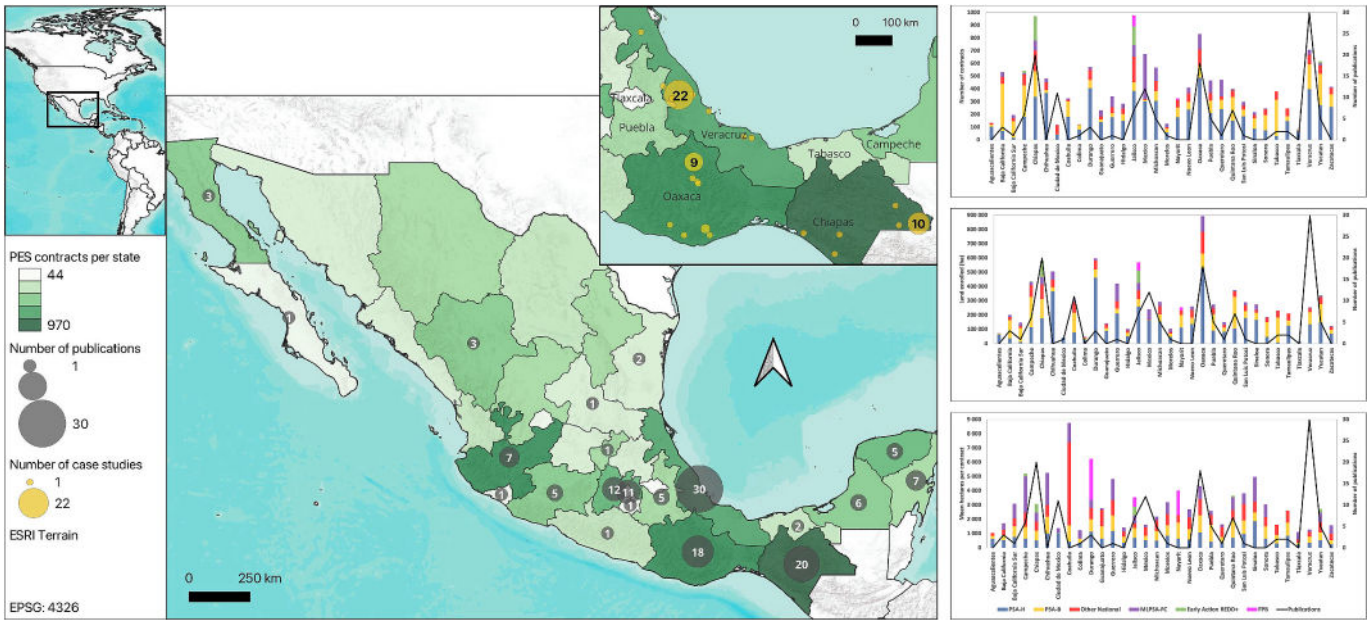

Fig. 7. Left: Heatmap showing the total number of federal PES contracts (2003–2022) and number of publications per state. Note that 29 publications contain national-scale analyses. Within the most studied states (Veracruz, Oaxaca and Chiapas), we zoom into the case study locations where empirical data was collected. **Right: graphs showing the number and type of PES contracts (top), total hectares enrolled (centre) and the mean hectares per contract (bottom), with each showing the number of publications for each state, evidencing cases of mismatch between research and implementation.** 'Other National' includes PES for agroforestry, regeneration, carbon capture, Tren Maya, and unspecified 'environmental services' (see Table 1).
Source: Own elaboration based on data from CONAFOR

journals, eight of the ten most popular outlets were in English and only two in Spanish. These include: Ecosystem Services (n = 10), Ecological Economics (n = 8), Sociedad y Ambiente (n = 7), Madera y Bosques (n = 6), Environmental Conservation (n = 5), Global Environmental Change (n = 4), Land Use Policy (n = 4), Society and Natural Resources (n = 3), Conservation Biology (n = 3), PLoS One (n = 3), and Journal of Environmental Management (n = 3).

In terms of citations, publication in English or by lead authors in foreign institutions were significantly more highly cited than those in Spanish or by lead authors based on a Mexican institution: publications in Spanish had 17.7 citations on average whilst those in English had 78.8 (Welch two sample *t*-test = -4.27, p-value = 0.000042); in turn, publications by a lead author in Mexico had 33.6 citations on average and foreign ones had 94.3 citations (Welch two sample *t*-test = -2.97, p-value = 0.0036). The ten most highly cited publications were all written in English and all first authors of these, except for the top cited article by Muñoz-Piña et al. (2008), were by a lead author based in a foreign institution (Fig. 8). Seven of these top ten publications include national level analyses, whilst the remaining three focus on case studies in Southeast states (Corbera et al., 2007, 2009; Kosoy et al., 2008). Most of these highly cited publications were published early in the life of Mexico's PES programmes, as six of the ten were published in 2010 or earlier and the most recent in 2017.

Given that in some disciplines like economics lead authorship is selected alphabetically and thus is not always a good measure of attribution of responsibility, we also classified publications as having any author from a Mexican institution. Our results reveal a similar pattern as when classifying by country of lead authorship: publications with at least one author from a Mexican institution had 39.1 citations on average and those with no authors from Mexican institutions had 117.4

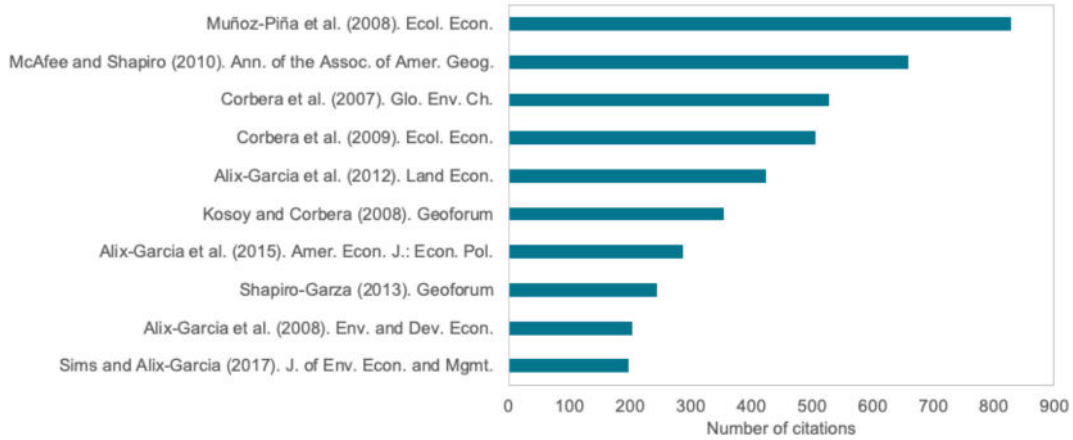

Fig. 8. Publications with highest number of citations. The list of publications is as follows (Alix-Garcia et al., 2008, 2012, 2015; Corbera et al., 2007, 2009; Kosoy et al., 2008; McAfee & Shapiro, 2010; Muñoz-Piña et al., 2008; Shapiro-Garza, 2013; Sims & Alix-Garcia, 2017). Note: number of citations based on Google Scholar as of 8 November 2023.

citations (Welch two sample *t*-test = -2.804, p-value = 0.0073). Among publications with a lead author from a foreign institution (n = 63), those with authors from a Mexican institution had 56.8 citations on average, whilst those with no authors from Mexican institutions had 117.4 citations (Welch two sample *t*-test = -2.097, p-value = 0.0409).

3.2.3. Thematic and methodological coverage

The publications reviewed cover different themes and rely on multiple methods (Fig. 9). Overall, we found no statistically significant differences between publications with lead authors based in a Mexican institution versus those based in foreign institutions in terms of thematic coverage nor in most methodological categories, including type of publication, main discipline, scale of analysis, and data collection and analysis approaches. We did find, however, differences in terms of temporal focus and degree of critique, as we discuss below.

The most studied theme so far has been programme effectiveness (61 % of publications), which includes analyses of PES environmental or social impacts or outcomes and associated drivers. The other primary themes are policy recommendations or improvements, participation, and design process and evolution. In terms of publication type, about three quarters (74 %) of all publications provided original analyses of an existing PES programme, whilst 19 % of publications discussed a hypothetical or experimental programme, often through spatial analysis or choice experiments. The remaining typologies included review papers and conceptual works that did not directly examine empirical or hypothetical data. In terms of disciplinary focus, environmental social sciences (which includes various combinations of economics, geography, development studies, and policy analysis) contained 44 % of publications, followed by neoclassical economics with 34 %. Natural sciences (which includes biology and ecology) and anthropology and sociology each covered around 10 %. More than three quarters (76 %) of publications relied on primary data collection but data analysis was balanced in terms of quantitative and qualitative approaches. Almost 30 % of publications used a mixed approach combining quantitative and qualitative analysis.

In terms of spatiotemporal focus, the publications reveal a tendency for local-level scale of analysis and a balance between static analysis (i.e. covering a snapshot at a given moment in time) versus longitudinal analysis (i.e. analysis or data covering several time periods). Local-level studies include analyses of single or groups of cities, communities, municipalities, protected areas, and watersheds. Publications from lead authors based in a Mexican institution had a significantly lower rate of longitudinal analysis in relation to lead authors based abroad (Chi-square = -4.89, p-value = 0.0269). Lead authors from Mexican institutions also had a higher rate of local-level as opposed to national-level analysis, but this difference is not statistically significant (Chi-square = 3.35, p-value = 0.1869).

Geographically, publications from lead authors in Mexican and foreign institutions are similarly focused on Chiapas, Veracruz, and Oaxaca. However, many publications from authors in Mexico also focus on Mexico City and the state of Mexico, which are much less studied by lead authors in foreign institutions. Notably, a few institutions –some of which the authors here are based on– concentrate publications focused on specific regions, including: INECOL in Veracruz, COLMEX in Mexico City, and UNAM in Chiapas. Overall, publications from lead authors in Mexican institutions tend to adopt a more static approach compared to those from foreign authors, an issue we further examine in the Discussion.

Finally, we found that most lead authors from both Mexico and abroad adopted a 'somewhat critical' stance towards PES, but the percentage of authors that were classified as 'not at all critical' based on their findings and conclusions (see Content Analysis section for a description of degree of critique classification) was much higher for lead authors from Mexico, whereas 'openly critical' rates were much higher for lead authors abroad. These differences are significant (Chi-square = 9.67, p-value = 0.0079). In the Discussion, we link these results to the politics of knowledge production in Mexico and provide some tentative explanations.

3.2.4. Reported ecological and social effects

We identified 56 publications that focus on programme outcomes or impacts (Fig. 10). This publication subset reveals a preference for studying social over ecological dimensions, as well as addressing outcomes (measurable indicators of the effects of the programme) over impact (assessing additionality through counterfactuals). Outcome-focused studies are much more diverse in terms of indicators than impact-focused studies: for ecological studies, impact evaluation is mainly based on forest cover or avoided deforestation, whilst other outcomes analysed include perceptions on forest conservation and natural resource management, water quality and biodiversity; for social studies, impact analysis is based on household income, assets, or social capital, whilst other outcomes include benefit-sharing, capacity building, communal governance, and pro-conservation attitudes. Although the volume of total publications that focus on programme effects is similar for lead authors based in Mexico versus in foreign institutions (48 % and 52 %, respectively), those based in Mexico had a lower propensity for using impact evaluation (Chi-square = 1.3095, p-value = 0.2525), though these differences are not statistically significant.

Reported PES effects were generally positive across publications, and particularly for ecological effects. Almost 80 % of studies that measure ecological impacts or outcomes report positive effects, although 12 % –all from Mexican institutions– also reported negative effects. Positive ecological outcomes were mostly related to compliance with programme activities and rules, avoided deforestation, and improved natural resource management. Reported negative effects and associated drivers include: i) poor spatial selection, with enrolled lands having low deforestation risk or low value for ecosystem service provision such as water capture; ii) lack of compliance in enrolled polygons, for example due to ongoing land-cover change or illegal logging; iii) leakage, by reducing deforestation pressure in enrolled parcels but displacing it to other areas; iv) lack of permanence associated with an expressed desire to deforest after the programme ends.

Reported social effects were also mostly positive (55 % of publications reported positive effects), but the rate of negative findings was higher at 25 %. A higher percentage of studies from lead authors in Mexico reported negative social outcomes than studies from foreign institutions (30 % versus 22 %) but the difference is not significant (Chi-square = 0.33, p-value = 0.8459). Positive social effects across publications include increased income and consumption, poverty reduction, enhanced conservation attitudes among participants, improved collaboration and organisation within the community, investments in public services such as electrification and roads, job creation, and capacity building. Negative social effects include insufficient payment levels, elite capture in terms of resources, decision-making and information, and inadequate benefit-sharing among and inclusion of non-landed individuals or families.

Similarly, linking reported effects with the scale of analysis –i.e. national, subnational, local–, we found that publications that had a larger spatial scale of analysis reported more positive outcomes than those at lower spatial scales. For ecological effects, the rate of positive outcomes was 100 % for national-level studies and 53 % for local studies. For social effects, the rate of positive outcomes was 100 % for national studies and dropped to 77 % for local studies.

4. Discussion

We have analysed trends in the temporal and spatial relationship between PES programme implementation and related research in Mexico over a 20-year period, as well as how research priorities and outcomes relate to the researchers' country of affiliation and scale of analysis. Below we discuss these findings with respect to the relationship between policy research and practice; potential knowledge gaps and

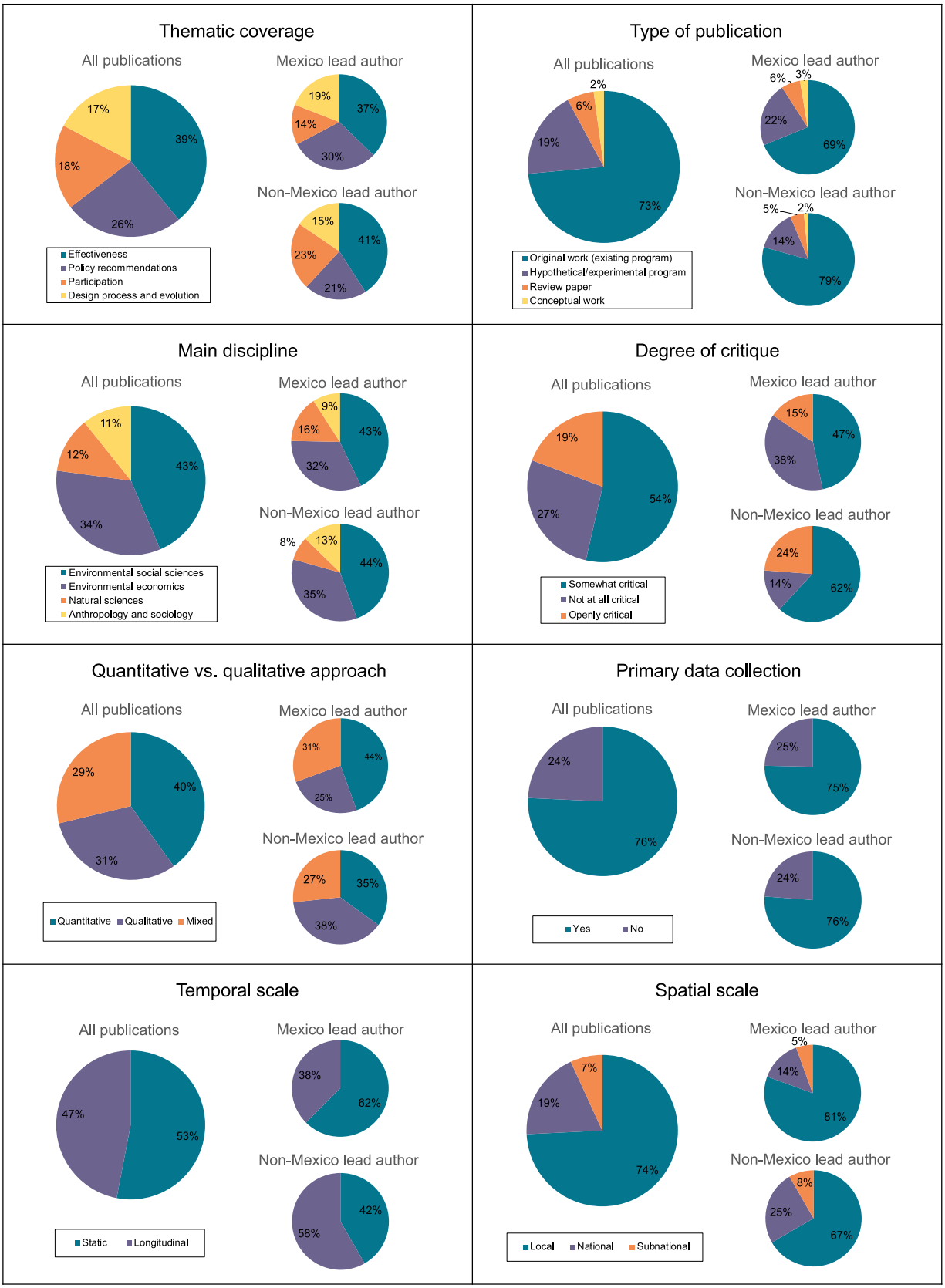

Fig. 9. Thematic, methodological, and spatiotemporal coverage of PES research in Mexico. Note: Spatial scale includes the lower scale of analysis in the publication. For example, a publication that includes a national and subnational analysis is classified as subnational. Local is defined as any scale smaller than state-level, whereas subnational is defined as any scale equal or higher than an individual state but not national level.

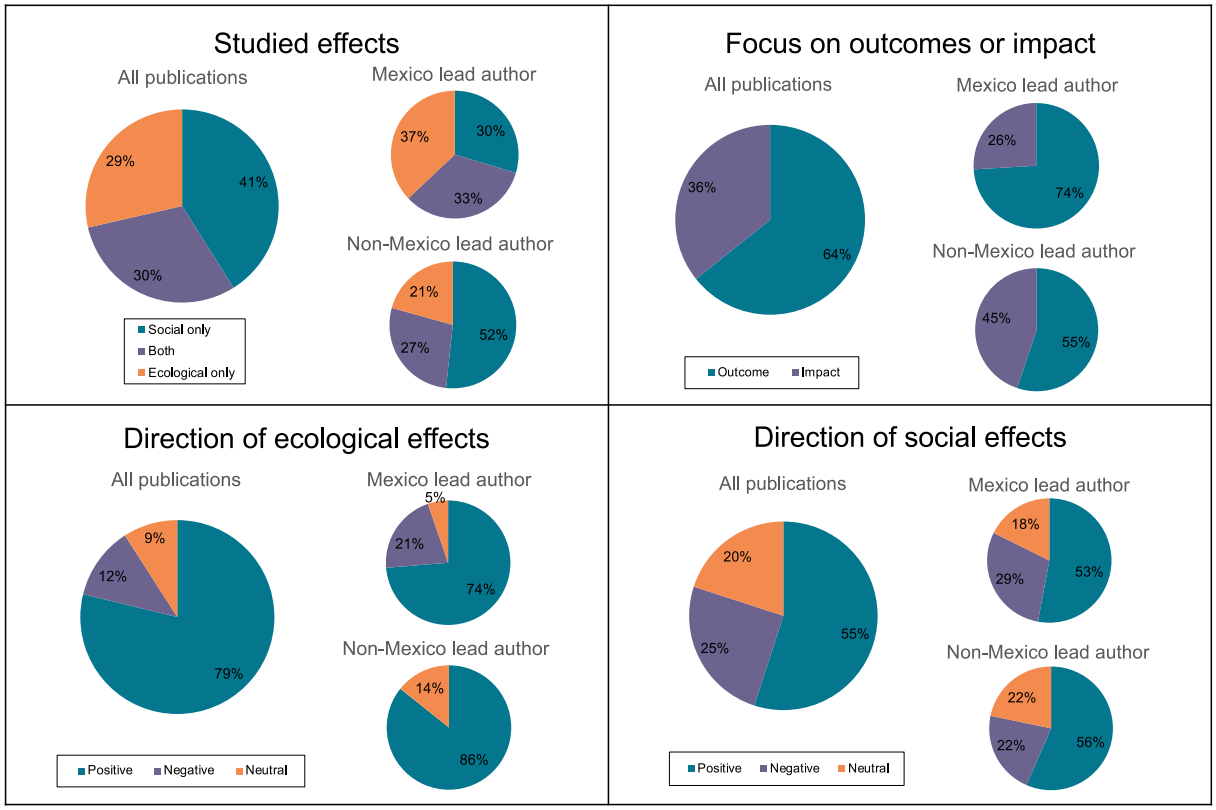

Fig. 10. Reported ecological and social effects.

biases introduced by uneven geographic coverage; and the limited influence and recognition of Mexican PES scholarship.

4.1. *Interplay between policy research and practice*

As shown here and elsewhere (Calvet-Mir et al., 2015; Kolinjivadi et al., 2023; Perevochtchikova et al., 2021), PES programmes in Mexico have received swift and extensive scholarly attention since their establishment in the early 2000s. However, by comparing key trends in both PES publications and programme implementation in Mexico, we can shed light on the relationship between research and practice.

The inverse U-shaped pattern observed in the number of published articles per year suggests a positive relation between the ups and downs of the volume of research produced annually with respect to the level of PES programme implementation, albeit with a 2 to 3-year delay (see Fig. 4). The rising number of annual PES publications up to 2018 coincided with a period of expanded programme implementation until 2016, as well as in a context of growing interest in PES globally as a field of academic enquiry and conservation practice (Kolinjivadi et al., 2023). Both factors can help explain why Mexico's PES received so much attention by scholars in both Mexican and foreign institutions during this period.

However, we have also observed a sharp downward trend in the volume of annual PES research produced in Mexico since 2019, which is puzzling given that scholarly interest in PES has remained strong globally (Kolinjivadi et al., 2023). Significant reductions in research funding from Mexico's National Centre for Science and Technology (CONACYT in Spanish acronym) in recent years[3] may explain such decreased productivity, at least among scholars based in Mexican institutions. It is also possible that Mexico's PES became less interesting for researchers over time as implementation levels dropped, as the literature reached a saturation point, or as programmes exploded in other contexts outside Mexico. Yet, such diminished interest in Mexico's PES programmes stands in contrast with other regions where programmes have faced defunding or discontinuation –including cases in Ecuador, China, Uganda, Brazil, and Colombia– but have nonetheless continued to attract significant scientific interest in examining the effect on programme outcomes and processes in post-PES scenarios (Carrilho et al., 2022; Etchart et al., 2020; Hayes et al., 2022; Vorlaufer et al., 2023). To date, only one publication has addressed the issue of permanence in Mexico's PES programmes (Le Velly et al., 2017).

With regards to research influencing implementation, our evidence is limited. There are generally no formal or binding mechanisms or structures for Mexican decision-makers to incorporate findings provided by academic research into policy. However, there have been a range of formal and informal interactions (e.g. through projects workshops, meetings and conversations) between Mexico's PES policymakers and researchers (Alix-Garcia et al., 2012a, 2012b, Alix-Garcia et al., 2015, 2018; Izquierdo-Tort et al., 2021; Muñoz-Piña et al., 2008; Shapiro-Garza, 2013). Future research should explore the extent to which research processes have directly influenced policy formation, the set of factors (e.g. cultural, political, institutional) that hamper or enhance PES researchers' ability to inform decision-making (Christie et al., 2021; Cvitanovic et al., 2015), as well as how research influence over time is affected by the level of collaborativeness of different public institutions.

4.2. *Potential knowledge gaps and biases introduced by uneven geographic coverage*

We have shown that the geographic coverage of PES research in Mexico does not correspond with the geographic distribution of programme implementation. This resonates with previous studies that have also recorded geographic disparities in knowledge production for specific issues, including biodiversity monitoring, resource co-

[3] https://animalpolitico.com/verificacion-de-hechos/te-explico/conacyt-presupuesto-2022-reduccion-2018.

management, ecosystem services, and PES in other countries (Collen et al., 2008; Corbera et al., 2024; d'Armengol et al., 2018; Kolinjivadi et al., 2023). Our analysis reveals that such geographic disparities also occur in Mexico, with research location often not matching implementation efforts.

We attribute the research emphasis on a handful of states in Central and Southeast Mexico –including Ciudad de México, Veracruz, Chiapas, and Oaxaca– and specific regions or municipalities within these states to a combination of factors that increased the feasibility and desirability of conducting research in those areas. Based on an understanding of the socio-ecological context of Mexico, and as scholars who have conducted and published many PES studies based on long-term engagement experience with local NGOs and communities in such regions, we posit that driving factors for these trends include researchers' relationships with academic or other institutions and networks that facilitate access to the study area, key ecological and socioeconomic attributes of academic interest (e.g. PES implementation amongst indigenous communities, in highly biodiverse tropical forest contexts, or in sites with higher deforestation rates and other key land use dynamics), as well as logistical and safety conditions in the least studied regions.

There were no specific studies providing insights or data directly from 11 states in central and northern Mexico, though we acknowledge that aggregate information from field research conducted in these regions has informed some national-level analyses (Alix-Garcia et al., 2012a, 2012b, Alix-Garcia et al., 2015, 2018). We speculate that such research gap can be attributed to issues of safety for conducting fieldwork in these states, which often suffer from violence and civil unrest driven by drug and human trafficking cartels, including instances of violence against researchers.[4] Not unrelatedly, this absence of PES studies could reflect a relatively lower emphasis on and capacity for studying environmental issues within academic communities in this region with respect to those located towards the centre and southeast of the country. Regardless of the drivers, the lack of PES studies in central and northern regions represents a major gap in our knowledge of PES in Mexico since these regions combined represent almost a quarter of all PES contracts that have been implemented across the country, which additionally have specific biophysical (e.g. arid and semi-arid ecosystems) and socioeconomic and cultural attributes (e.g. presence of pastoralist societies, the impact of the presence of organised crime) that could be relevant for understanding PES processes and outcomes.

Overall, our evidence highlights the need to recognise the potential knowledge limitations and biases of scholarly research when it comes to documenting PES experiences. Despite a large and growing body of research containing over one hundred scientific publications, our current academic knowledge of Mexico's PES remains severely limited to the specific geographic contexts where research has been conducted, as well as to the specific themes and time periods covered. Further studies in so far omitted geographic regions could uncover novel insights about PES dynamics, outcomes and impacts in these regions.

4.3. *Inadequate influence and recognition of research produced by scholars based in Mexican institutions*

We found similar publication rates between lead authors based in Mexican institutions and those based in foreign ones, as well as no statistically significant differences in thematic coverage nor in most methodological categories between both groups, with key exceptions. We showed that in-country scholarship was less likely to take a critical stance on PES and tended to have a narrower geographic and temporal focus. We hypothesise that the lower level of critique and narrower geographic coverage are likely because scholars based in Mexican institutions –including several authors of this article– have benefited from a longer engagement with local communities and have worked more closely with implementing actors in a specific region, such as local NGOs, which together can explain the geographic concentration of studies in some states and some regions therein –as in a few municipalities in Veracruz, Oaxaca, and Chiapas– and offer a more positive and nuanced understanding of PES outcomes. Further research could explore the extent to which lower levels of critique towards PES by lead authors based in Mexican institutions are explained by the academic context in which these scholars are embedded, with potentially distinct epistemic networks than those of European and U.S. scholars. Key questions to address include: How do academic institutions and funding sources in Mexico and elsewhere influence research priorities and perspectives regarding PES? How do characteristics of the epistemic networks of authors based in Mexican institutions compare to those of their European and U.S. counterparts? What differences are there in the availability and access to data, resources, and literature on PES between scholars based in Mexican institution and those based in Europe and the U.S.?

Though intriguing, we believe the finding that publications by scholars based in Mexican institutions tend to adopt a more static approach compared to those from foreign authors is not inconsistent with longer term local engagement but could even be a consequence of it. In-country scholars' emphasis on more regional and static analyses could also result from funding limitations, as scholars based in Northern institutions have access to larger funding sources, which enables larger and more longer-term data collection efforts. Taking the example of Marqués de Comillas in Chiapas –where several authors of this article have ample research and practitioner experience–, there has been a strong interest in documenting key PES outcomes and processes as quickly as possible to inform local actions and provide policy recommendations. Long-term engagement has thus produced several publications which *collectively* provide a more comprehensive and longer-term understanding of PES dynamics even if each publication *individually* has had a narrow temporal scope. Such types of scholarly engagement in Mexico's PES contrast with patterns of 'helicopter science' –i.e. scholars, often from wealthy nations, developing research without considering local priorities or involving local participants– documented by Kolinjivadi et al. (2023) in their global review of PES literature.

We found that more than half of all 140 publications on Mexico's PES programmes were written by a lead author based in a Mexican institution, which is in stark contrast with the most comprehensive global review of PES literature to date in which the authors found that Global North scholars produce most of the research related to PES implementation in Global South contexts (Kolinjivadi et al., 2023). One likely reason for this difference is that our analysis included 41 publications in Spanish, of which 39 came from lead authors based in Mexico, while the above-mentioned review focused only on publications written in English. On this point, the publication rate of scholars from Mexico increased from 38 %, when considering only those in English, to 55 % when also considering those in Spanish. This confirms the value of including non-English publications as a critical input that can recognise and amplify the body of knowledge that is being produced in local languages (North et al., 2020), and improve the quality and validity of results by providing complementary data and potentially reducing sampling bias when data is scarce (Konno et al., 2020). It also confirms how knowledge production priorities and outcomes are influenced by researchers' positionality and attributes such as publication language and geography of affiliation (Konno et al., 2020).

However, we also demonstrated that publications by scholars based in Mexican institutions have had a significantly lower degree of global visibility and impact (based on citation rates) than those led by scholars based in European and U.S. institutions. The same applies for publications with at least one author from a Mexican institution versus those without. This inadequate recognition of in-country scholarship for informing our broader, global understanding of PES, is at least problematic, not to mention the power asymmetries, coloniality of

[4] https://news.mongabay.com/2023/08/killing-of-u-s-biologist-adds-to-rising-violence-against-scientists-in-mexico/.

knowledge, and research ecology that this reveals in terms of whose scholarship is valued and acknowledged (Bhambra, 2014; Choquez-Millan et al., 2024). Such a mismatch in scholarly recognition also raises a series of important questions regarding the ultimate objectives of these publications, and of scholarship more broadly, that warrant further scrutiny: What kind of epistemic circulation do publications feed into, with what purposes, and to what effects? How is PES research entangled in particular networks or ecologies of research? Who is deemed legitimate to contribute to PES knowledge and at what and whose cost? How are voices (beyond academia) included in PES studies? We invite the readers to use the 'PESMEX20′ database (Alatorre et al., 2024) to address some of these questions.

The high level of engagement of scholars based in Mexican institutions with PES research can also be attributed to the existence of a well-established academic sector across the country, as supported by the fact that 6 out of the 10 institutions with the largest number of publications were based in Mexico, with UNAM –Latin America's largest university– at the top. Whereas this condition may not apply in other countries, Mexico has also been a global leader in PES design and implementation which has resulted in both in-country and foreign attention. We also acknowledge that our analysis omits publications other than peer-reviewed articles or book chapters –which can include books, theses, and reports– that do not appear in web-based databases. Further research could examine if including these data could tip the scale in terms of how knowledge produced by scholars based in Mexico is accounted for. It would also be interesting to include a more in-depth analysis of the discourses employed by implementing organisations in Mexico, comparing them to some of our findings.

5. Conclusion

Regardless of whether one sees Mexico's PES plate as half full or half empty after 20 years of experience, it is clear that this policy instrument has shaped the trajectories of local socio-ecologies. As one of the largest, longest standing and most researched PES programmes in the world, there is now considerable evidence about its impacts and outcomes for both forest conservation and socio-ecological systems of Mexico. With some variation, there is congruence among the findings of research from disparate disciplinary and methodological approaches that the programmes have had mostly positive ecological effects and mixed social effects.

Our comprehensive review of PES implementation and research in Mexico, grounded on a detailed database of all 12 subtypes of federal PES programmes and 140 peer-reviewed publications written in English and Spanish, has revealed significant advancements in terms of research and practice, but also key gaps and biases in knowledge production. We have documented the trajectories of different programmes and their components, which jointly represent more than 13,000 awarded contracts covering a staggering 7.4 million hectares from 2003 to 2022, almost 4 % of the national territory, mainly within communal lands (90 %), with 3.1 million hectares being under PES contracts in 2022. Whilst the number of peer-reviewed publications per year was commensurate with shifts in the scale of PES programme implementation over time, the considerable lag time between research and dissemination represents a significant barrier to the ability of research to directly inform policy. There was also a strong concentration of studies in specific regions of southeast Mexico, whilst many states in the central and northern regions of the country remain largely unstudied. The substantial differences in both the socio-political and ecological contexts of these regions mean that our understanding of the dynamics, impacts and outcomes of federally funded Mexican PES programmes is incomplete. Lastly, we found scholars in Mexican institutions led 55 % of the publications reviewed but have been much less cited than those published by scholars in Europe or the U.S. Given the degree to which the longstanding Mexican programmes have served as a reference and model worldwide, the imbalance in geographic focus and the lack of recognition of research informed by scholars based in Mexican institutions implies a significant deficit in our knowledge of PES as a policy approach.

We are certainly not alone in recognising the need to account for the scientific relevance and policy impacts of PES after more than twenty years of widespread implementation across the globe. However, our novel approach –a review of research within the context of a particular country that accounts for the relationship of research to programme trends and includes publications by scholars based in Mexican institutions in the local language– reveal heretofore poorly documented biases and gaps in our knowledge of PES. For Mexico, these findings suggest a need for additional research to assess the drivers of these biases and resulting knowledge gaps and the implications of these for the design and implementation of PES and related incentive-based policies. With the recent precipitous decline in PES programme implementation in Mexico, additional research is also needed to know if documented effects will continue in the absence of incentives. At a global scale, there is obviously a further need for such deep, nuanced and inclusive assessments of the state and gaps in knowledge of particular PES programmes. Additionally, innovative science-policy engagement mechanisms need to be put in place to facilitate the dialogue between scientists, practitioners and policymakers to account and correct for the drivers of our gaps in knowledge of PES and, by extension, of incentive-based environmental policies more broadly.

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CRediT authorship contribution statement

Santiago Izquierdo-Tort: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Andrea Alatorre:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Elizabeth Shapiro-Garza:** Writing – review & editing, Writing – original draft, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Esteve Corbera:** Writing – review & editing, Writing – original draft, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Jimena Deschamps-Lomelí:** Writing – review & editing, Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Véronique Sophie Ávila-Foucat:** Writing – review & editing, Resources, Funding acquisition, Conceptualization. **Julia Carabias:** Writing – review & editing, Validation, Conceptualization. **Jérôme Dupras:** Writing – review & editing, Funding acquisition, Conceptualization. **Vijay Kolinjivadi:** Writing – review & editing, Software, Methodology, Conceptualization. **Juan Manuel Nuñez:** Writing – review & editing, Resources, Conceptualization. **Maria Perevochtchikova:** Writing – review & editing, Methodology, Conceptualization. **Katharine Sims:** Writing – review & editing, Methodology, Conceptualization. **Gert Van Hecken:** Writing – review & editing, Software, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial

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Appendix A. Web search syntax

Scopus: TITLE-ABS-KEY (méxic* OR mexic*) AND TITLE-ABS-KEY ("payment for ecosystem service" OR "payment for environment* service" OR "Payment for hydrologic*" OR "payment for carbon" OR "payment for biodiversity" OR "ecosystem service program*" OR "environmental service program*" OR "PES program*" OR "PES scheme" OR "payment scheme" OR "payment program*" OR "carbon program*" OR "hydrologic* program*" OR "biodiversity program*" OR "pago por servicio ambiental*" OR "pago por servicio ecosist*" OR "pago por servicio hidrol*" OR "pago por carb*" OR "pago por biodiversidad" OR "programa de servicios ambiental*" OR "programa de servicios ecosist*" OR "programa PSA" OR "esquema PSA" OR "esquema de pago" OR "programa de pago" OR "programa de carbon*" OR "programa hidrolog*" OR "programa de biodiversidad").

Scielo, Redalyc, and individual Mexican journals: (méxico OR mexico OR mexican OR mexicano OR mexicanos OR mexicana OR mexicanas) AND ("payment for ecosystem service" OR "payments for ecosystem service" OR "payment for environmental service" OR "payments for environmental service" OR "Payment for hydrologic" OR "Payments for hydrologic" OR "Payment for hydrological" OR "Payments for hydrological" OR "payment for carbon" OR "payments for carbon" OR "payment for biodiversity" OR "payments for biodiversity" OR "ecosystem service program" OR "environmental service program" OR "PES program" OR "PES programme" OR "PES scheme" OR "payment scheme" OR "payment program" OR "payment programme" OR "carbon program" OR "carbon programme" OR "hydrologic service program" OR "hydrologic service programme" OR "hydrological service program" OR "hydrological service programme" OR "biodiversity program" OR "biodiversity programme" OR "pago por servicio ambiental" OR "pago por servicios ambientales" OR "pagos por servicio ambiental" OR "pagos por servicios ambientales" OR "pago por servicio ecosistémico" OR "pagos por servicio ecosistémico" OR "pago por servicios ecosistémicos" OR "pagos por servicios ecosistémicos" OR "pago por servicio hidrológico" OR "pago por servicios hidrológicos" OR "pagos por servicio hidrológico" OR "pagos por servicios hidrológicos" OR "pago por carbón" OR "pagos por carbón" OR "pago por carbono" OR "pagos por carbono "OR "pago por biodiversidad" OR "pagos por biodiversidad" OR "pago de servicio ambiental" OR "pago de servicios ambientales" OR "pagos de servicio ambiental" OR "pagos de servicios ambientales" OR "pago de servicio ecosistémico" OR "pagos de servicio ecosistémico" OR "pago de servicios ecosistémicos" OR "pagos de servicios ecosistémicos" OR "pago de servicio hidrológico" OR "pago de servicios hidrológicos" OR "pagos de servicio hidrológico" OR "pagos de servicios hidrológicos" OR "pago de carbón" OR "pagos de carbón" OR "pago de carbono" OR "pagos de carbono" OR "pago de biodiversidad" OR "pagos de biodiversidad" OR "programa de servicio ambiental" OR "programa de servicios ambientales" OR "programas de servicios ambientales" OR "programa de servicio ecosistémico" OR "programa de servicios ecosistémicos" OR "programas de servicios ecosistémicos" OR "programa PSA" OR "programas PSA" OR "esquema PSA" OR "esquemas PSA" OR "esquema de pago" OR "esquemas de pago" OR "programa de pago" OR "programas de pago" OR "programa de carbón" OR "programa de carbono" OR "programas de carbón" OR "programas de carbono" OR "programa hidrológico" OR "programas hidrológicos" OR "programa de biodiversidad" OR "programas de biodiversidad").

Data availability

The data is available in the public 'PESBIOMEX20' database (Alatorre et al. 2024): https://zenodo.org/records/11549024

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