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Short Communication

Investing in nature-based solutions: Cost profiles of collective-action watershed investment programs

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ABSTRACT

Worldwide, an increasing number of watershed management programs invest in nature-based solutions (NbS) to water security challenges. Yet, NbS for water security currently are deployed at well below their hypothesized cost-effective global potential, with uncertainty about costs identified as one key constraint on increased investment. Data on administrative and transaction costs of watershed investment programs are especially limited, but the few available studies indicate that these costs can be substantial. We conducted a cost survey of

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Transaction costs
Full cost accounting

municipal-scale collective-action watershed investment programs, which pool resources from water users and other stakeholders to finance NbS. We obtained data from 18 programs in Latin America and the Caribbean (16), Asia (1) and Africa (1) with intervention areas from 133 ha to over 100,000 ha. During the first ten years, programs with ≥ 10 years of data had average annual costs of 0.25–3.02 million (median: 0.75 million) purchasing power-adjusted 2018 international dollars, and average annual per-hectare costs varied more than 50-fold among these programs. Administrative and transaction costs on average accounted for 46 % (range: 10–84 %) of total cumulative costs across programs during the first ten years. This share sharply declined over the initial five years but stabilized at around 40 percent of annual costs. The wide range in per-hectare costs, and the size and range of administrative and transaction cost shares reflect diverse local contexts, intervention portfolios, and program design and implementation characteristics. While large, the observed share of administrative and transaction costs is not surprising given the social, political, institutional, and technical complexity of implementing collective-action programs that involve land use changes and is similar to that of some large public environmental programs. Our findings are consistent with the few available estimates for comparable programs, underscoring the need for watershed investment programs to budget for substantial administrative and transaction cost throughout their life cycle.

1. Introduction

Much of the world's population is facing high and increasing levels of threat to freshwater security (Vörösmarty et al., 2010; Flörke et al., 2018). Nature-based solutions (NbS) – the protection, improved management, or restoration of natural or modified ecosystems that address societal challenges, simultaneously providing human well-being and biodiversity benefits (Cohen-Shacham et al., 2016) –increasingly are recognized for their potential to cost-effectively improve water security (Vörösmarty et al., 2018, 2021; Palmer et al., 2015; Ruangpan et al., 2020). Natural assets such as forests, wetlands and well-managed agroecosystems represent key components of any water security asset portfolio and should be managed systematically by water utilities using the principles and tools of asset management (Albert et al., 2020; Water Research Foundation, 2020), in collaboration with local communities and other key stakeholders.

Around the world, a growing number of programs seek to address water security concerns via voluntary mechanisms where government or water users invest in NbS in watersheds. As of 2015, 387 such programs existed worldwide, totaling some USD 24.7 billion in transaction value (Salzman et al., 2018). Approximately one quarter of these Payments for Watershed Services (PWS) programs take the form of local (municipal-scale) collective-action programs (Bennett and Ruef, 2016). These collective-action programs are newly-created entities that bring together public, private and civil society stakeholders and feature three principal organizational characteristics: 1) a financial mechanism that mobilizes and pools resources from multiple sources, including beneficiaries of improved delivery of target hydrologic services (often, reduced sediment or nutrient concentrations or improved timing of flows) and other stakeholders (NGOs, government bodies); 2) a governance mechanism for joint planning and decision-making; and 3) a watershed management mechanism for the implementation of conservation, restoration and improved management activities expected to improve target ecosystem services flows (Bremer et al., 2016; Goldman-Benner et al., 2012; Salzman et al., 2018). Typically, these programs establish land management agreements with upstream land managers that often include monetary or in-kind incentives (e.g., Bremer et al., 2016). Municipal-scale collective-action PWS programs thus differ from bilateral PWS schemes in which a single user (a private entity or government agency) compensates one or more parties for activities thought to deliver target hydrologic flows (Salzman et al., 2018), such as in the well-known Vittel example (Bingham, 2021). Finally, municipal-scale collective-action PWS programs differ from national-level PES programs such as Costa Rica's Payments for Environmental Services (PSA) Program (Pagiola, 2008) in that the former's scope is limited to one or a few watersheds rather than large portions, or the entirety, of a country. Collective action PWS programs increased fivefold in number between 2005 and 2015 (from 16 to 95; Salzman et al., 2018; Bennett and Ruef, 2016) and now span all inhabited continents.

However, the potential for NbS to improve water security is thought to be much larger (e.g., Tellman et al., 2018; Vörösmarty et al., 2021), with some analyses suggesting that watershed conservation potentially may be cost-effective in addressing key water security challenges in at least 690 cities serving more than 433 million people globally (Abell et al., 2017). Given that NbS deployed for hydrologic objectives generally provide additional benefits such as climate mitigation, livelihood support, biodiversity conservation, and resilience (Abell et al., 2019; Chausson et al., 2020; Giordano et al., 2020; Keesstra et al., 2018; Watkin et al., 2019) while engineered alternatives often negatively impact natural systems and the services they provide (Palmer et al., 2015), the chasm between the current and potential scale of NbS investment urgently requires bridging. Scaling watershed investments toward anywhere near their global potential faces several challenges, including the predictability of benefits and costs (Vogl et al., 2017a; Seddon et al., 2020; Cooper, 2020).

The state of practice has advanced in addressing informational challenges to assessing the benefits, costs, and cost-effectiveness of NbS (Seddon et al., 2020; Wild, 2020), including the development of frameworks for cost analysis through life-cycle costing and opportunity cost analysis of NbS (Ruangpan et al., 2020); development of practical metrics needed for costs and benefits (Vogl et al., 2017a); and a growing number of economic case studies (De Risi et al., 2018; Kroeger et al., 2018; Stafford et al., 2019; Turpie et al., 2017; Vogl et al., 2017b). Yet, information on the full costs of PWS programs implementing NbS remains extremely limited, as is true for conservation interventions more broadly (White et al., 2022). The lack of reliable cost information from comparable programs makes it difficult for prospective programs to predict budget needs, plan and fundraise. It also presents a challenge for attempts to rigorously evaluate the return on investment of existing and prospective programs. Crucially, such credible assessments of the performance and cost-effectiveness of PWS programs in providing desired hydrologic services as well as their competitiveness with conventional, engineering solutions are critical to mobilizing the needed increases in watershed conservation investments (Bennett and Carroll, 2014; Seddon et al., 2020; Ruangpan et al., 2020; Vogl et al., 2017a). This is especially true for private sector investments, which may be key to closing the funding gap for water infrastructure globally (Sadoff et al., 2015; Shiao et al., 2020).

Few economic analyses of PWS programs account for full program cost. Most completely or partially omit the transaction costs associated with planning, convening and engaging partners and communities and the costs associated with general program administration, which some recent studies show together can account for up to one half of total program costs (Jayachandran et al., 2017; Kroeger et al., 2018). Moreover, the few review studies that do report at least partial transaction and administrative costs (Wunder et al., 2008; Alston et al., 2013; Montoya-Zumaeta et al., 2021) are dominated by national-level, government-financed programs and include few municipal- or basin-scale, collective-action type programs.

The lack of comprehensive data on administrative and especially transaction costs is partly due to the difficulty of collecting this information for programs that involve multiple parties, as many collective action-type PWS programs do (Finney, 2015; Bremer et al., 2016). It may also be attributable to a presumption that such costs are primarily incurred by demonstration or pilot projects or during program start-up, supporting evidence for which is limited (Finney, 2015). Importantly, full costs may vary considerably among PWS programs even adjusted for program size, due to differences in institutional contexts, opportunity costs of land, numbers and types of program objectives and design characteristics, as well as in the mixes of interventions implemented (Börner et al., 2017; Wunder, 2013), effectively making each program unique (Bremer et al., 2016).

To begin filling these data gaps on the full costs of collective action watershed investment programs, their composition, and their evolution over time, we surveyed PWS programs to collect information on costs by major activity category, institutional context, and program characteristics expected to affect costs.

2. Methods

Our study targeted municipal-scale collective action PWS programs (Bennett and Ruef, 2016). We developed the initial list of candidate programs by screening programs affiliated with The Nature Conservancy (TNC) and the database underlying Forest Trends' *State of Watershed Investment* report series (e.g., Bennett and Ruef, 2016) using the following inclusion criteria: (1) local-scale collective-action programs (as opposed to bilateral or national-scale PES schemes), and (2) at least nearing the completion of long-term program design to ensure programs had cost data for all activities related to program planning and management, and realistic intervention cost estimates. A total of 63 programs met these criteria and were contacted between 2018 and 2019. Data collection was conducted during two periods. During February to July 2018, the survey was promoted and distributed via TNC's and Forest Trends' external and internal networks (in English only), and key PWS program staff or representatives of the screened-in programs were contacted. Because of the low response rate to this initial outreach, between August and December 2019 a follow-up was conducted that focused on a smaller set of longer-lived Latin American PWS programs expected to have empirical cost data for 10 years or more. For this second outreach phase, the survey was translated into Spanish and Portuguese, and respondents were offered live assistance by phone or site visits to assist in survey completion and data compilation.

We compiled information on program costs and context and implementation characteristics using a structured, two-part survey that included a questionnaire (Appendix C) and a pre-formatted Excel spreadsheet. In addition to program descriptive information, the questionnaire probed for whether programs (a) actively established any of the necessary and facilitating conditions for PES implementation identified in the literature (see Tables A.1 and A.2); (b) employed spatial targeting, payment differentiation, or conditionality, features frequently employed to improve PES program efficiency (Börner et al., 2017; Ezzine-de-Blas et al., 2016; Montoya-Zumaeta et al., 2021; Wunder et al., 2020); and (c) conducted effectiveness or socio-economic impact analyses. The absence of PES enabling or facilitating context factors, the use of efficiency-enhancing program design and implementation features, and monitoring and impact analyses all result in additional costs

Grouping	Major activity category	Examples of activities included
Administration & transaction costs	Stakeholder outreach	• Stakeholder identification and outreach (incl. surveys, interviews, visits) • Coordination with program partners • Partner enrollment and management
	Legal services	• Institutional, legal, and policy analyses/studies • Contracts preparation and management • Legal processes required for program establishment • Enforcement of contracts in case of non-compliance
	Technical analyses	• Biophysical analyses and modeling • Socio-Economic analyses • Business case analysis (return on investment; cost-effectiveness) *(Includes field visits, focus group meetings, surveys, expert consultations)*
	Program management	• Program strategy design, fundraising, administration • Training and capacity building workshops that program staff participate • Landowner enrollment (selection, engagement, contract negotiations etc.)
	Communications	• Marketing, outreach materials, web materials; internal and external reporting • Event organization
	Monitoring	• Hydrologic, biodiversity, or socioeconomic monitoring • Landowner compliance monitoring • Data management • Contract design, implementation, and maintenance of monitoring system • Impact evaluation
Intervention costs	Interventions implemented by program	• NbS intervention costs borne by program for directly implementing NbS or for assisting landowners in implementation • Design and planning, equipment, materials, maintenance, technical assistance to landowners • Contracts to implement conservation activities
	Payments (cash or in-kind) to landowners	• Payments (cash or in-kind) to landowners and/or communities for implementing agreed-upon interventions • Cost of purchasing and delivering in-kind support to landowners/communities
Other	Other	Anything not falling under categories above

Fig. 1. Cost categories used in data collection. For each category, potential expenses include (1) any salaries and related employer-paid benefits (e.g., health insurance; pension contributions) for relevant staff, based on percent time spent on the activities; (2) contracts with third parties; (3) materials, supplies, or equipment purchases, if relevant; (4) transportation and travel (for the relevant activities under the category); and (5) any other costs incurred during the activities. Color coding is the same as in other figures.

for programs and thus may help explain differences in observed program costs. We developed a simple scoring system to convert questionnaire responses into a quantitative comparison of programs' efforts to establish PES enabling or facilitating conditions, use efficiency-enhancing design features, and assess effectiveness and impacts (see Appendix D). The preformatted Excel spreadsheet provided a list of nine cost categories that together comprise the full range of costs programs may incur, along with the major activities within each cost category (Fig. 1). Respondents were asked to enter annual costs in local currency, by cost category, indicating whether costs reflect only costs borne by the respondent's institution or also those borne by program partners. These discrete cost categories can be grouped into two overarching cost types: administrative and transaction costs, and intervention costs (Fig. 1). Our cost typology follows the common classification of PES program costs into the broad categories of implementation costs, opportunity costs, and transaction costs (Pagiola and Bosquet, 2009). However, because participation in the PWS programs in our sample is voluntary and programs compensate participating landowners, our intervention costs include both implementation costs (for programs and landowners) and opportunity costs. Implementation costs arise from activities directly associated with the changes in land management a program seeks to effect. Opportunity costs measure the forgone net benefit landowners would have received from the alternative use the land would have been put to absent the program. Finally, transaction costs result from any activities not directly associated with the implementation of changes in land management practices (Jindal and Kerr, 2013), and comprise search and information costs, negotiation and decision costs, monitoring and enforcement costs, and insurance costs (Stavins, 1995; Dudek and Wiener, 1996). Transaction costs are the result of a range of program activities such as feasibility and legal analyses, identification and engagement of program partners and other stakeholders, landowner identification, engagement, and enrollment, compliance monitoring and enforcement, and communication (Fig. 1; see also Valatin et al., 2022). Respondents were asked to report annual costs for 20 years since initiation of any program-related activities, such as initial discussions with stakeholders or pre-feasibility assessments. The 20-year time horizon spans the time from those first activities to program maturity. We chose this 20-yr time frame to capture any changes during this period in the composition of overall costs by major program activity. For programs with histories shorter than 20 years, respondents were asked to estimate future annual costs in each cost category based on a program's current implementation plan and associated annual budgets. Where existing detailed program plans did not extend to the end of the 20-year period, we asked respondents to estimate future annual costs beyond their current planning horizon based on expected levels of each activity category (Fig. 1) and recent unit costs of the respective activities.

Costs were converted to 2018 international dollars using 2018 purchasing power parity (PPP$) conversion factors (https://data.worldbank.org/indicator/PA.NUS.PPP, accessed June 2020) and annual domestic inflation rates (https://www.imf.org/external/datamapper/PCPIPCH@WEO, accessed June 2020). Data compilation and management were performed in Excel (Excel for Microsoft 365 MSO, version 2020), and analyses were performed using R (R Core Team, 2022, version 4.2.2) and RStudio (RStudio Team, 2022, version 2022.07.2+576).

3. Results

We obtained full cost data from 18 PWS programs (response rate: 28.6 %): 4 in Brazil, 4 in Ecuador, 2 in Colombia, 2 in the Dominican Republic, and 1 each in Costa Rica, Guatemala, Mexico, Peru, China and South Africa (Fig. 2; Table 1). Because only two programs had close to 20 years of actual cost data (FONAG and PSAH; Table 1), unless otherwise stated, our analysis below focuses on the ten programs that reported at least ten years of actual (i.e., not projected) cost data. At the time of our survey, three of these (Pipiripau, FORAGUA and Aquafondo) had only eight or nine years, respectively, of historic data. However, they had funded budgets and implementation plans for the next two years, so we included them in our 10-year sample. Additional results for the full set of programs, in some cases including projected costs, can be found in Appendix B. Importantly, our key findings from the analysis of programs with ten years of actual data (n = 10) are consistent with those of the full sample (n = 18), 20-year data that include projected costs.

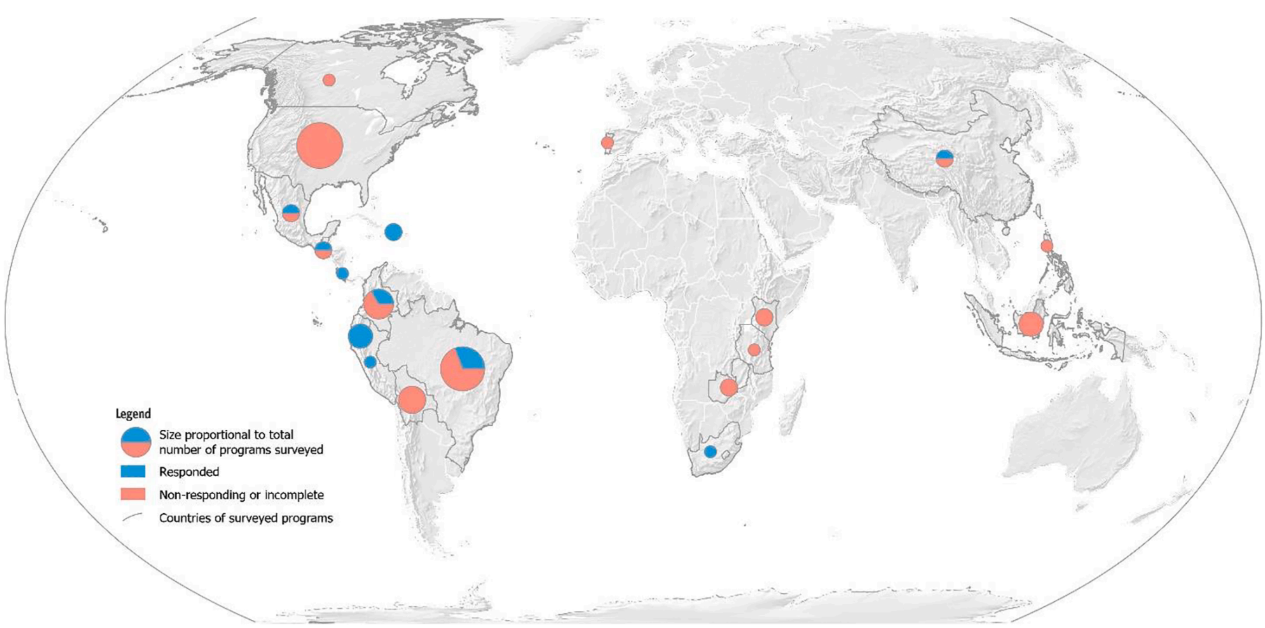

Fig. 2. Map showing countries (outlined in grey) in which 63 contacted programs are located. Pie charts are sized proportionally to the total number of programs. Blue: percentage of programs that responded and whose data are included in analyses. Red: percentage of non-responding programs or programs only sharing partial cost data. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
PWS programs included in analyses along with their status at the time of the survey. Actual data shown in **bold** are included in our core analysis of programs with 10 years of data. See Table B.1 for more detail on interventions and Table B.2 for additional programmatic characteristics.

Program name	Country	Data start year[1]	Data period (yrs)		Average annual costs, first five years (thousand 2018 PPP $•yr^{-1})
			Actual	Projected	
Produtor de Água do Pipiripau	Brazil	2011	**8**	9	867.7
Fundo de Água de São Paulo (Jaguariuna)	Brazil	2013	6	14	443.2
Produtor de Água e Floresta (PAF-Guandu)	Brazil	2008	**10**	1	1024.8
Produtor de Água do Rio Camboriú	Brazil	2010	**10**	10	191.8
Fondo para la protección del Agua (FONAG)	Ecuador	2000	**19**	1	157.6
Fondo del Agua para la Conservación de la Cuenca del Río Paute (FONAPA)	Ecuador	2010	**10**	0	355.5
Fondo de Páramos Tungurahua y Lucha contra la Pobreza	Ecuador	2008	**11**	1	530.1
Fondo Regional del Agua y Fondo Ambiental (FORAGUA)	Ecuador	2009	**9**	1	140.1
Corporación Cuenca Verde	Colombia	2013	6	14	3113.4
Fundación Fondo Agua por la Vida y la Sostenibilidad (FAVS)	Colombia	2009	**10**	10	2323.2
Fondo Agua Santo Domingo	Dominican Republic	2015	5	0	204.4
Fondo Agua Yaque del Norte	Dominican Republic	2015	5	1	236.2
Programa de Servicio Ambiental Hidrico (PSAH)	Costa Rica	2000	**18**	2	100.1
Fundación para la Conservación del Agua de la Región Metropolitana de Guatemala (FUNCAGUA)	Guatemala	2011	7	13	84.1
Fondo Ambiental Metropolitano de Monterrey (FAMM)	Mexico	2014	4	5	1317.7
Aquafondo	Peru	2011	**9**	11	263.3
Longwu Water Fund	China	2015	4	6	143.0
Greater Cape Town Water Fund	South Africa	2017	3	17	1147.6

[1] First year for which cost data were entered. May not reflect the year programs were initiated due to data documentation limitations.

3.1. PWS program costs

Overall costs varied considerably among programs. Average annual costs during the first five years varied 37-fold for the full sample ($n = 18$; Table 1), and during the first ten years varied 12-fold among programs with 10 years of actual cost data (Table 2). During the first ten years, eight out of the ten programs with at least ten years of actual cost data had average annual costs of less than 1 million (M) PPP$, one of between PPP$ 1 M and 2 M, and one of over PPP$ 2 M (Fig. 3).

3.2. Cost composition

Our analysis reveals that, on average across the surveyed programs, administrative and transaction costs (segments in shades of blue) combined accounted for nearly-one half (46 %; median: 46 %; range among programs: 10–84 %; Fig. 4 panels A, B) of total cumulative costs during the first ten years ($n = 10$), and over one half (54 %; median: 50 %; range among programs: 7–99 % of total cumulative costs during the first five years ($n = 18$; Fig. B.1). The combined administrative and transaction cost share and the size of individual administrative and transaction cost components varied substantially among programs (Fig. 4, panels A and C) but were large in nearly all cases.

On average across programs, during the first ten years, direct interventions (i.e., those implemented by the programs themselves as opposed to by land users) represented the single-largest cost component (48 %), followed by program management costs (28 %; Fig. 4, panel B). On average across programs, transaction costs (for stakeholder outreach, legal services, technical analyses, communications, and monitoring) accounted for nearly 18 percent of total cumulative costs during the first ten years.

3.3. Changes in size and composition of program costs over time

The time profile and composition of annual costs also varied widely among programs (Fig. 5 panel C). In two of the ten programs with at least ten years of actual cost data, annual costs continued to increase by year ten, driven by increases in both administrative and transaction costs and intervention costs (PSAH, FONAPA). In programs whose annual costs during the first ten years showed a clear peak followed by a more or less pronounced decline (FAVS, Pipiripau, Guandu, Camboriú), this peak was driven by a peak in intervention costs. For these programs, intervention costs generally accounted for a larger share of total costs during the first ten years than for programs whose annual costs kept increasing (PSAH, FONAPA) or showed no clear trend by year ten (Aquafondo, FORAGUA, FONAG, Tungurahua).

3.4. Importance of administrative and transaction costs over time

The composition of annual costs shows that, on average, administrative and transaction costs together dominated total costs during the early years (Fig. 5 panel A). This is not surprising since most programs do not implement interventions on a large scale during the program design and early operational phases. As the scale of interventions increased, the combined share of administrative and transaction costs

Table 2
Average annual costs of surveyed programs with 10 years of actual data (thousand 2018 PPP$·yr^{-1}).

	First 10 years (n = 10)
Range	247.0–3015.6
Mean ± 1 SD	963.0 ± 820.1
Median	745.1

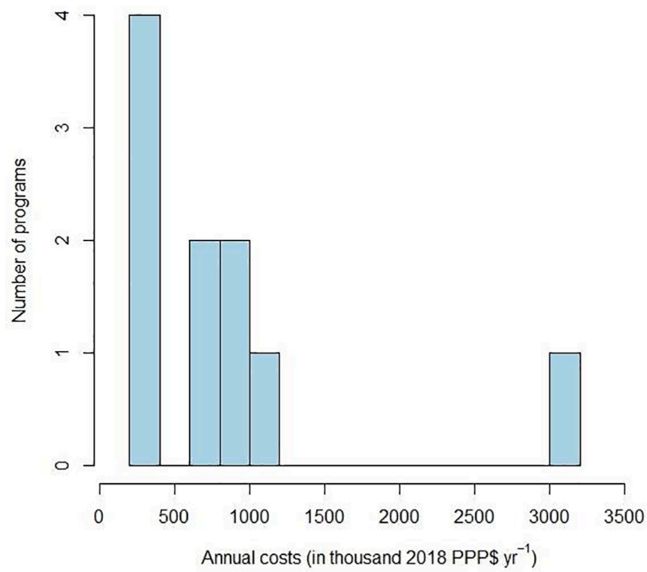

Fig. 3. Frequency distribution of average annual program costs during first ten years (n = 10).

declined over the initial five years but then levelled off, stabilizing at approximately 40 percent of annual costs for the median program by year ten (Fig. 5 panel B). Moreover, for the nine programs providing 20 years of cost data (including projected costs; see Table 1), the average share of administrative and transaction costs across programs remained fairly stable beyond year five, averaging more than one-third of annual costs in years six to 20 (Fig. B.2 showing median, Fig. B.3 showing mean). The same is true for the two programs with nearly 20 years of historic cost data (FONAG, PSAH), whose combined administrative and transaction cost shares fluctuated relatively little in years 11 to 20, averaging 47 percent (Fig. B.4).

3.5. Diversity in cost-relevant contexts and implementation features

Our survey revealed large differences among programs in context characteristics and implementation features that affect program costs. Fig. 6 illustrates these differences in programs' efforts to create the enabling environment for their operation (panel A), and in their design and implementation (panels B-D), for the ten programs with at least ten years of actual cost data. Each spoke in the diagrams represents a necessary or facilitating condition for PES that at least some programs needed to establish (panel A), or a design or implementation feature (panels B-D; see Table B.2 or Appendix D for list of conditions and features and legend). Location at the base of a spoke indicates that a program did not need to establish the respective necessary or facilitating condition (panel A); did not deploy the respective efficiency-enhancing program design or implementation feature (panel B); did not conduct the respective monitoring or impact analysis (panel C); or did not have the respective other implementation characteristic (panel D) represented by that spoke. Note that the scaling varies across spokes (see Appendix D) and that the cost of creating the necessary or facilitating conditions for program operation, or of implementing specific program features, may differ among condition or features and sites. Thus, scores cannot be added across spokes to derive a total score that could be expected to correlate with a ranking of total costs across programs. Rather, Fig. 6 provides a highly aggregated visual comparison of the variability among programs in cost-relevant context and implementation features. More detail on each program's context and features can be found in Fig. D.1.

4. Discussion

Our sample of 18 collective-action watershed investment programs yields several important insights. Arguably most important among these is the large share of administrative and transaction costs (Fig. 4 panels A and B), and the fact that this share on average stabilizes at around 40 percent of annual total costs for mature programs (Fig. 5 Panel B, Figs. B.1 and B.2). This finding is in line with the few available estimates of the share of administrative and transaction costs of collective-action PWS programs, which range from 10 to 85 % of total program costs (Table 3).

Arguably, this finding should not be surprising: professionally-run PWS programs that seek to affect land use change, involve multiple partners, aim for high additionality of impacts through well-designed and targeted interventions and at least moderate conditionality of payments with their attendant scientific analyses and monitoring and enforcement requirements, and continually engage their various stakeholder groups to ensure program sustainability over time, should not be expected to have low administrative and transaction costs (Kroeger et al., 2018). Importantly, high transaction costs, or a high transaction cost share, are not an indication of poor program design. Rather, they can be the consequence of necessary investments in the creation of the enabling environment for PES application (Table A.1), or in efficiency-enhancing program design characteristics such as additionality, conditionality, or payment differentiation that have the potential to reduce overall program costs or increase program outcomes (Ezzine-de-Blas et al., 2016; Wunder et al., 2020). In some cases, activities that result in transaction costs can also result in direct social benefits. For example, many PES programs actively work to clarify or formalize tenure rights (e.g., Montoya-Zumaeta et al., 2021; Adhikari and Agrawal, 2013; Sunderlin et al., 2018). Even if a program does not actively work on improving tenure security, transaction cost-involving activities such as compliance monitoring and contract enforcement themselves can result in local community actions to clarify tenure that improve perceived tenure security (e.g., Jones et al., 2020). Because improvements in tenure security often generate tangible human well-being benefits for affected land managers (Tseng et al., 2021), tenure security interventions and compliance monitoring are examples of typical PWS program actions that result in both transaction costs and potential direct social benefits.

Interestingly, the estimated average share of administrative and transaction costs for the programs examined here is similar to the 38 percent these costs account for in the public sector costs of programs administered by the United States Natural Resources Conservation Service (McCann and Easter, 2000).

While combined administrative and transaction costs in the sampled programs generally accounted for a sizeable share of total costs, this share did vary considerably among programs, ranging from ten to 84 percent of each program's initial 10-year costs (Fig. 4 panel A), similar to the 10–85 percent range reported for other programs in the literature (Table 3). One likely explanatory factor is differences in intervention portfolios among programs. For example, at the time of our survey, major direct program interventions by the Longwu Water Fund in China, had been limited to transferring lands into the program and ceasing fertilizer and herbicide application, resulting in a low share of direct intervention costs and concomitant large share of management costs. Similarly, in the case of Aquafondo, Peru, the high share of administrative and transaction costs stems from the program's large investments in educational campaigns and programs, national and local policy advocacy, and close coordination with local, regional and national water governance institutions as well as Lima's water company. In contrast, the Greater Cape Town Water Fund, South Africa, features labor-intensive alien invasive plant removal across a targeted area of 54,300 ha across several watersheds, resulting in a high direct intervention cost share.

However, the observed wide range of activity cost shares among

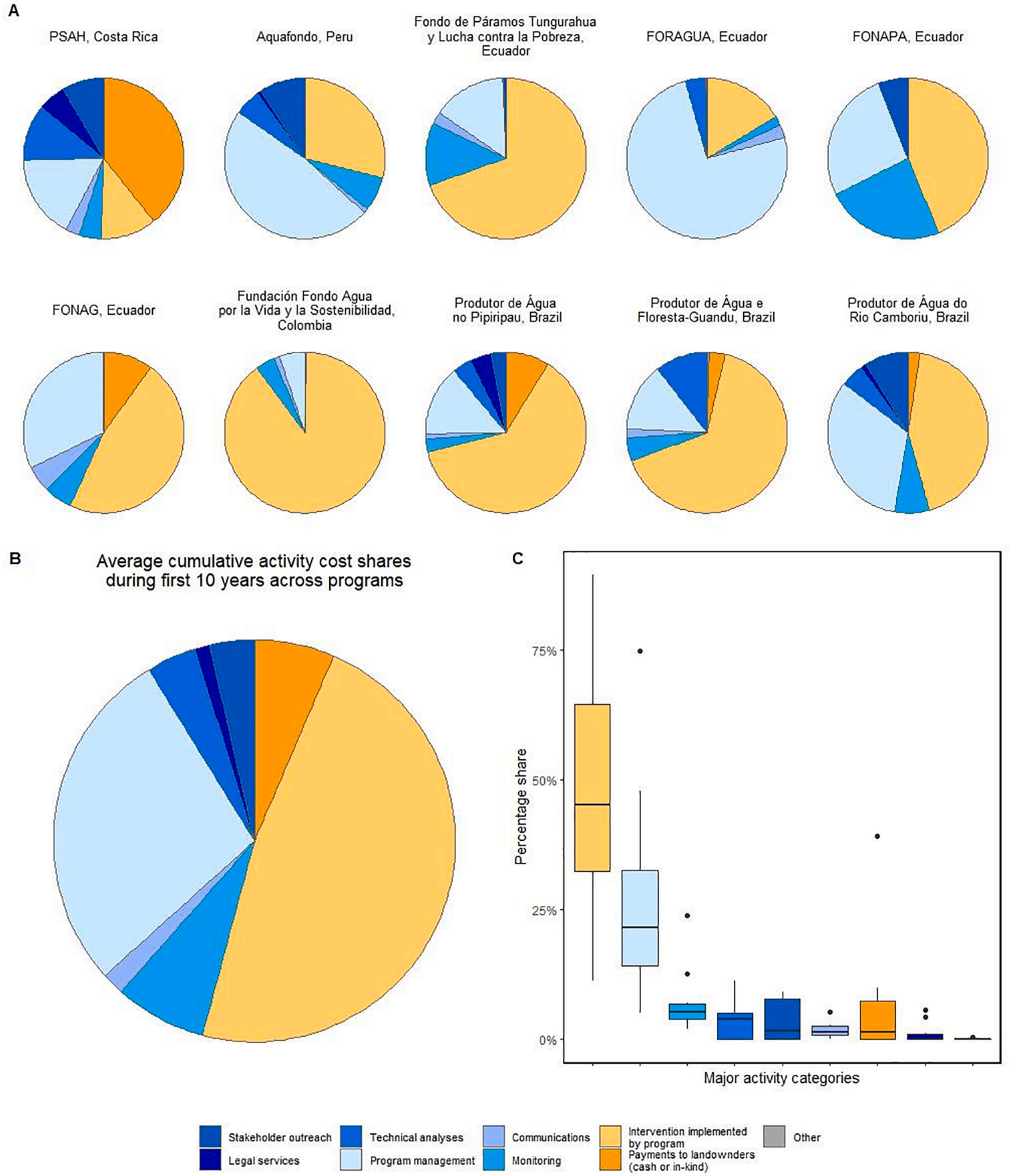

Fig. 4. Cumulative activity cost shares during first ten years for programs with at least ten years of actual cost data (n = 10). (A) Cumulative cost shares by major activity category. (B) Cumulative cost shares during first ten years, averaged across the ten programs. (C) Box plot showing the median, 25th and 75th percentiles, the interquartile range (whiskers), and outliers (dots) for the percentage cost shares by major activity category.

programs also underscores the importance of local context and of program design and implementation features as drivers of both program cost and performance (Börner et al., 2017; Montoya-Zumaeta et al., 2021; Pagiola et al., 2019). For their implementation to become feasible, PWS programs require a number of enabling conditions (Table A.1). For example, PWS programs regularly must first expend considerable effort on creating an environment conducive to their operation, such as clarification of tenure (e.g., see the Moyobamba PWS program in Montoya-Zumaeta et al., 2021) or establishment of relationships and sufficient trust among stakeholders (Wunder, 2013). In addition to these necessary conditions, there are several factors that facilitate PWS program operations and that can reduce administrative and transaction costs (Table A.2). Similarly, the degree to which a program employs potentially efficiency-enhancing design features such as payment differentiation (based on opportunity costs and/or ecosystem service provision or a proxy thereof) and targeting of interventions, or implementation features such as payment conditionality (Wunder et al., 2018, 2020), affects both total program as well as administrative and transaction costs.

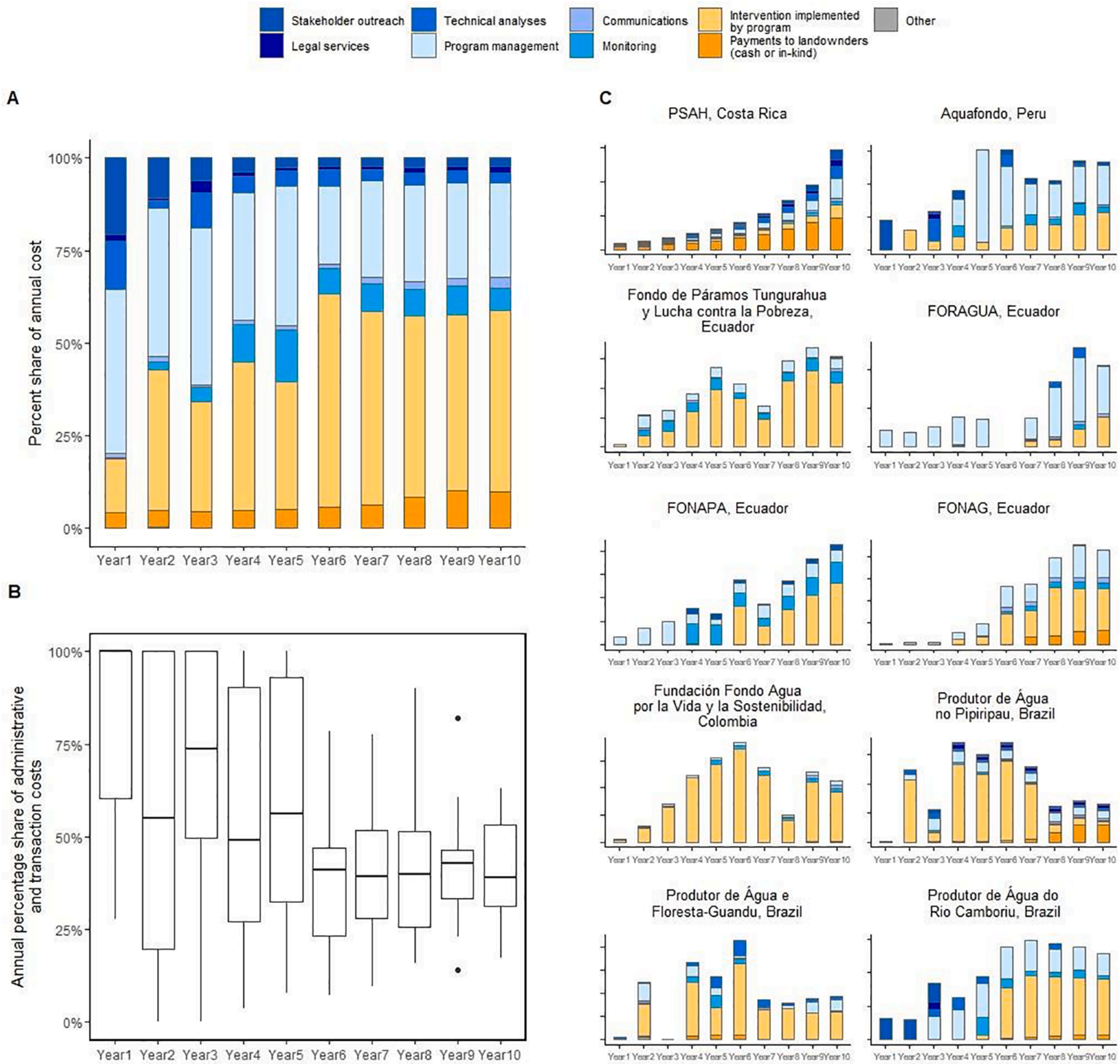

Fig. 5. (A) Composition of annual costs by major activity category, averaged across programs with at least ten years of actual cost data (n = 10). (B) Box plot showing the median, 25th and 75th percentiles, the interquartile range (whiskers), and outliers (dots) of the combined share of administrative and transaction costs in total annual costs across the ten programs. (C) Distribution of costs in each activity category over the first ten years for each program.

Given the large differences among programs' intervention portfolios (Table B.1) and local enabling context, design and implementation features (Table B.2 and Fig. 6), the observed large differences among the administrative and transaction cost shares of programs are not surprising. The wide range in total program costs in our sample also is not surprising given substantial differences in the size of intervention areas, which range from 133 ha (Longwu Water Fund, China) to over 100,000 ha (FORAGUA, Ecuador). Yet, those size differences do not explain the observed variation in total costs (see Fig. B.5 panel A) or per-hectare costs (see Fig. B.5 panel B), again highlighting the importance of local program context (specifically, the presence or absence of the necessary or facilitating conditions for PWS programs), composition of program intervention portfolios (restoration vs protection, and the specific interventions implemented), and program design and implementation characteristics (e.g., presence and sophistication of targeting and conditionality; impact monitoring and analyses) as cost drivers. Given the substantial differences in these factors among the sampled programs (Tables B.1 and B.2; Fig. 6), the absence of a clear correlation between costs (total or per hectare) and intervention area is not surprising.

The composition of intervention portfolios also can have a large impact on average annual per-hectare costs (and, hence, total program costs), which varied more than 50-fold among surveyed programs with at least ten years of data (Fig. B.5 panel B), after excluding one outlier (FORAGUA) whose reported intervention extent resulted in an estimated average program cost of PPP$1 $yr^{-1}\cdot ha^{-1}$. A comparison of the Brazilian and Ecuadorian programs in our sample illustrates this point. The annual mean per-hectare costs of the Ecuadorian programs on average are one-tenth those of the Brazilian programs (PPP$ 29 $yr^{-1}\cdot ha^{-1}$ vs PPP$ 277 $yr^{-1}\cdot ha^{-1}$; Table B.3). This large difference is at least partly due to two factors: in the Ecuadorian program portfolios, protection of public and community-owned lands accounts for a larger share of total intervention area and involves interventions with comparatively low per-hectare costs such as training park guards and developing community conservation agreements. In contrast, most of the Brazilian programs have large active (planting, often with fencing) and assisted (enrichment, sometimes with fencing) restoration components, which have much higher per-hectare costs than forest protection (e.g., Crouzeilles et al., 2020; Fiorini et al., 2020), and often engage dozens to hundreds of private landowners with generally property-specific intervention plans and conditional, differentiated payments,

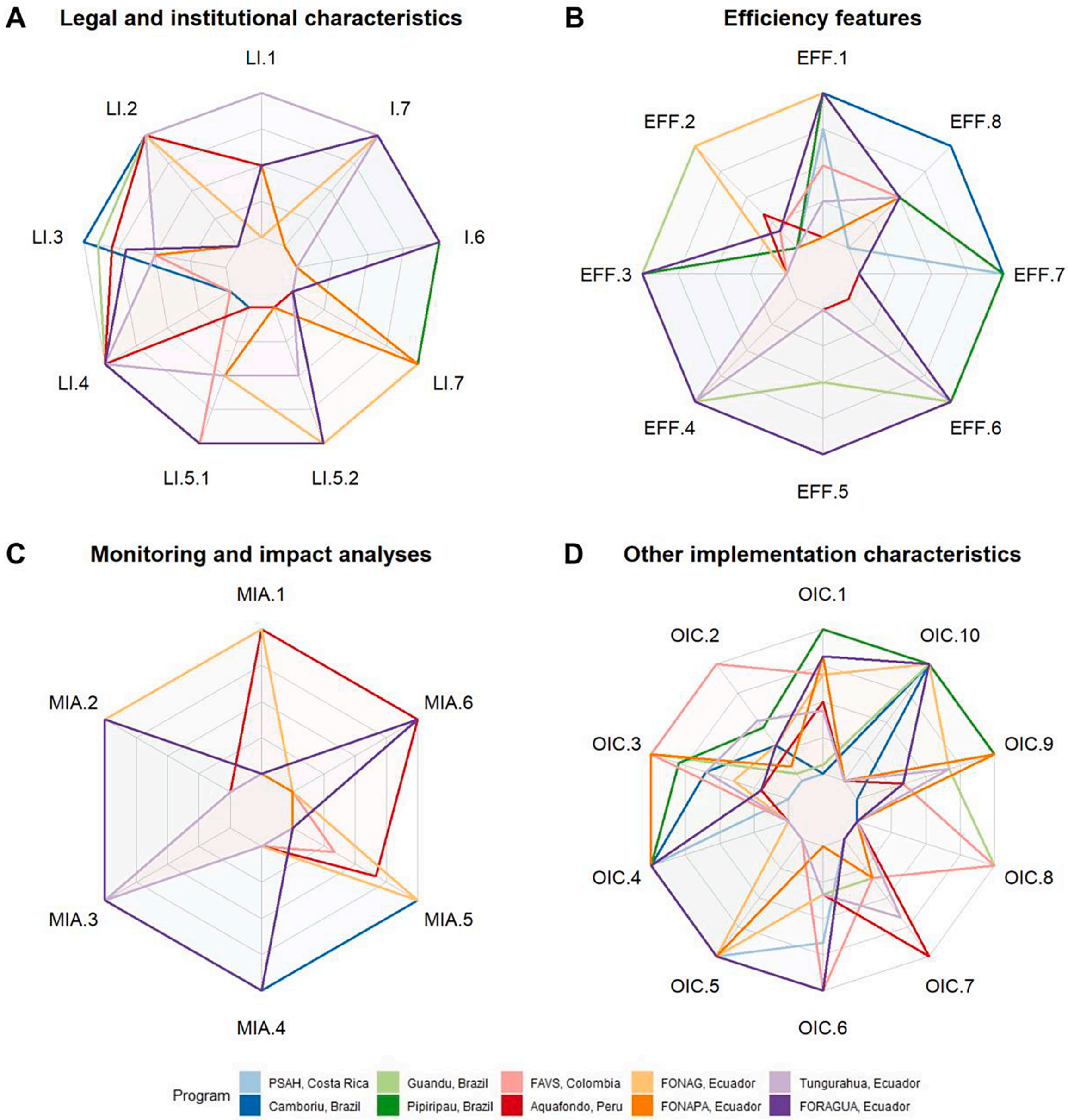

Fig. 6. Differences in programs' (A) efforts to establish the necessary and facilitating conditions for PES implementation; (B) efficiency-enhancing design and implementation features (EFF); (C) monitoring and impact analyses (MIA); and (D) other implementation characteristics (OIC). See Table B.2 or Appendix D for legend. Individual graphs for each program can be found in Fig. D.1 Notes: I – informational; LI – legal-institutional.

resulting in high transaction costs. Second, the Brazilian programs have much higher opportunity costs requiring commensurate compensation, because of comparatively higher-value competing land uses on private lands. We acknowledge that the small sample size of this study and lack of comparable data on annual intervention extents precluded more robust analyses of the potential relationships between program costs, scale and type of NbS intervention, pointing to the need for further research.

The finding that within the first 10 years total annual costs of some programs peak and then decline while for others they keep increasing (Fig. 5 panel C) may be explained largely by differences in budgetary constraints or by ambitions for impact that increase over time. Some programs manage to attract funding sufficient for a rapid scale-up of activities across their target implementation extent. An example of this is the Greater Cape Town Water Fund which, driven in part by the 2018 water crisis, has been able to catalyze significant funding towards its six-year "high impact phase" target of alien invasive plant removal – the fund's main intervention – across the entire 54,300 ha of priority watershed intervention areas. Other programs expand their activities more gradually as budgets allow or ambition for impact grows. For example, until 2011, the Quito Water Fund's (FONAG) annual budget was largely determined by annual income from FONAG's endowment. Since 2007, the city's water company makes mandatory annual contributions to this endowment, equal to 2 % of its income from water sales, leading to robust increases in the endowment. Moreover, in 2011, the endowment trust was modified, permitting FONAG to spend up to 30 % of the annual contributions to, in addition to the income from, the endowment (Coronel, 2019).

While our study contributes to the evidence base of the costs of collective-action watershed investment programs, our findings should be considered preliminary. First, our small sample ($n = 18$) is not adequately representative of the full population of collective action PWS programs globally, notably those in Southeast Asia, Africa, and North America. Moreover, despite respondents' best efforts, for some studied

Table 3
Literature estimates of combined administrative and transaction cost shares of municipal-scale collective-action PWS programs.

Program name (country)	Source	Admin & TAC cost share	Mean/median Admin & TAC share
Pimampiro (Ecuador)	Wunder et al., 2008	17 %	
Vitória, Espírito Santo (Brazil)	Pagiola et al., (2019)	23 %	
Moyobamba Rewards for Hydrological Ecosystem Services Mechanism (Peru)	Montoya-Zumaeta et al., (2021)	85 %	31 %/20 %
Quiroz Water Fund (Peru)	Montoya-Zumaeta et al., (2021)	10 %	
Produtores de Agua e Floresta, Guandu (Brazil)	Fiorini et al., (2020)	20 %	
Range		10 % – 85 %	
This study*		10 % – 84 %	46 %/46 %

Note: * Cost shares shown are for the 10 programs in our sample with at least 10 years of actual cost data.

programs, reported costs may not reflect full costs of all program partners. This may introduce a low bias in the total program costs and particularly in the share of administrative and transaction costs reported here: because the cost data presented here are for the main implementing entity(ies), partner institution costs not reflected in the reported data are expected to be dominated by administrative and transaction costs. Moreover, the small sample size did not allow us to statistically test the relative importance of cost drivers. More research is needed to understand the main cost drivers of watershed investment programs as well as their context-dependence and scale-dependency. This would allow identification of contexts in which watershed investments generally may be more cost-effective, and of opportunities for program design to take advantage of economies of scale. Such efforts would benefit from improved, standardized and systematic cost tracking and sharing that adopts the cost categories employed in our study and includes all program partner costs, or at a minimum clearly identifies omitted costs. The need for such improved cost tracking and sharing is not unique to watershed investment programs but rather affects conservation interventions in general (e.g., Iacona et al., 2018; Pienkowski et al., 2021; White et al., 2022), but that does not detract from its urgency.

Our data collection effort highlighted additional challenges programs face that likely also contributed to the low response rate. Most programs are severely capacity-constrained, and operational activities such as systematically archiving historic cost data or setting up detailed and flexible expense accounting approaches have not been a priority. In combination with staff turnover, institutional knowledge of historic contributions of partner organizations in some cases has been lost. Cost tracking formats and procedures vary among programs, often driven by external reporting requirements that may change over time. In addition, even where they are available, locating, accessing, and analyzing historic cost data is a time intensive undertaking.

5. Conclusion

Implementing standardized, systematic cost tracking and sharing would add to the existing reporting burdens of programs that often already are severely resource constrained. Yet, in our view, this incremental effort would be well worth it to programs for the improved internal planning and fundraising it would enable. Furthermore, it would help build the nascent evidence base on the cost of implementing watershed-scale NbS, benefiting policymakers and funders, and reducing uncertainty for prospective watershed investment programs. While cost-effectiveness is not the only motivator for watershed investment programs (e.g., Bremer et al., 2020; Santos de Lima et al., 2019), an improved understanding of the financial costs of such programs is critical to scaling up global ambitions. We strongly urge watershed investment programs and their funders to invest in such systematic cost tracking.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoser.2022.101507.

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