

Full Length Article

Payment for Ecosystem Services 2.0: The Natural Capital Trust of Costa Rica

Marcello Hernández-Blanco^{a,*}, Robert Costanza^b, Monica Moritsch^c^a Independent Scientist, Costa Rica^b Institute for Global Prosperity, University College London, UK^c Department of Ecology and Evolutionary Biology, University of California, USA

ARTICLE INFO

Keywords:

Payment for Ecosystem Services
Common Asset Trust

ABSTRACT

We designed a new national Payment for Ecosystem Services (PES) scheme for Costa Rica using a systematic approach for the creation of governance arrangements and financial mechanisms based on Elinor Ostrom's design principles for sustainable commons management. This PES 2.0 updates significantly the almost 30-year-old current scheme by expanding the scope to all the natural capital of the country (i.e., private, public, terrestrial, coastal and marine), as well as expanding the ecosystem services that will be the focus of the different modalities of the PES. This study presents the first estimate of the annual value of Costa Rica's total ecosystem services, amounting to \$14.5 billion. Finally, to assess and enhance the efficiency of the proposed scheme, we developed a Natural Capital Priority Index (NCPI) tailored to PES schemes. The NCPI identifies areas where investments are likely to generate the highest socioeconomic and environmental returns by spatially estimating ecosystem service provision, threats to their sustainability, and zones of high conservation value. This proposal of the evolution of one of the world's best-known PES schemes will not only help the country to achieve its nature stewardship goals, but will also increase the level of participation from a wide diverse group of actors from society creating significant new opportunities to increase their livelihoods and well-being.

1. Introduction

Natural capital stewardship, from the global to the national and local scales, require, among many things, (1) the recognition of the intrinsic and instrumental value that nature has for human well-being, as well as (2) novel financial mechanisms and institutional arrangements that can incorporate these values in decision making in order to make nature conservation and restoration a good investment for people and the rest of nature. Market failures, such as the lack of the internalization of negative externalities from economic activities, have caused natural capital loss and degradation globally to go unnoticed in the name of economic growth. For example, Costa Rica had one of the highest deforestation rates in the planet during the second half of the last century due to agriculture and cattle ranching, mainly as exports commodities (FONAFIFO, 2012).

To halt and reverse the further loss of Costa Rica's green natural capital, in 1996 the country updated its Forest Law, which among other key improvements, such as banning land use change, established a nation-wide Payment for Ecosystem Services (PES) scheme. The PES

scheme was targeted to protect and restore four ecosystem services provided by forests and forest plantations: (1) greenhouse gases mitigation (i.e., carbon fixation, reduction, sequestration, storage and absorption), (2) water provision for urban, rural or hydroelectrical use, (3) biodiversity protection for its conservation and sustainable use, scientific and pharmaceutical use, research and genetic improvement, ecosystem protection and life forms; and (4) natural scenic beauty for tourist and scientific purposes.

The Forest Law also created the National Fund for Forest Finance (FONAFIFO) to manage the PES scheme. The financial mechanism of FONAFIFO is primarily funded through a fossil fuel tax, which allocates 3.5 % of its revenues to the PES scheme. The scheme also receives 25 % of the revenues collected from a water fee that every person or institution with a water concession must pay. It also receives funds from other services related to ecosystem services, such as the sale of carbon credits that are produced through forest plantations under the PES scheme to people and organizations that seek to offset their carbon footprint, however, these credits contribute only approximately 1 % of the scheme's total funding (FONAFIFO, 2020). FONAFIFO invest its funds in

* Corresponding author.

E-mail address: ecoeconomics@marcello.life (M. Hernández-Blanco).<https://doi.org/10.1016/j.ecoser.2025.101787>

Received 30 September 2024; Received in revised form 13 September 2025; Accepted 12 October 2025

Available online 7 November 2025

2212-0416/© 2025 Elsevier B.V. All rights are reserved, including those for text and data mining, AI training, and similar technologies.

two general activities on privately owned farms: (1) forest cover maintenance and (2) recovery of forest cover, each having subactivities (e.g., protection of water resources, post-harvest protection, natural regeneration, agroforestry systems and reforestation with endangered species, among others). A third category comprises mixed systems, for small farms with an area of ten hectares or less, in which a maximum of three activities of PES can be considered.

The current PES scheme operates in a Pigouvian manner (Kaiser et al., 2021), where the government serves as intermediary between the sellers (i.e., property owners who implement forest conservation and restoration activities) and the beneficiaries, which can vary significantly, from local to global scales. As the only intermediary, the government is therefore the only buyer of ecosystem services and their rights, creating a monopsony (Kemkes et al., 2010). Furthermore, the current PES is an input-based scheme, where payments are based on the implementation of particular land uses, contrary to output-based payments where buyers pay directly for the provision of a specific service (e.g., payments for tons of carbon sequestered, or cubic meters of water produced) (Engel et al., 2008). Also, the payments in the current scheme are made under a bundled approach, meaning that all activities are funded to protect or restore the four targeted ecosystem services at the same time (as well as all other services provided by these ecosystems), instead of a stacking or layering approach where payments are made for individual ecosystem services (Lau, 2013).

In the current PES scheme, the fuel tax contributes with 88 % of the total funding, the water canon with 9 % and the timber tax with 1 % (FONAFIFO, 2020). The remaining 2 % of funding is distributed among funds from agreements (0.55 %), the sale of Costa Rican Carbon Units (UCC) (0.94 %), the Clean Flight greenhouse gas emissions compensation program (0.04 %) and funds derived from penalties incurred due to breaches of PSA contracts (0.46 %).

In the period 2015–2019, mandatory funding sources (i.e., fuel tax, timber tax and water canon) had a general upward trend, contrary to voluntary sources (i.e., agreements, UCC, Clean Flight) (FONAFIFO, 2020). These trends of both types of financing sources demonstrates the potential vulnerability of FONAFIFO's financial mechanism, characterized by a high dependence on a single funding source (i.e., the fuel tax) and the inherent challenges of sustaining voluntary contributions at a stable level. This vulnerability was evident in 2020 due to the COVID-19 pandemic, which meant a significant reduction in fuel consumption at the national level as a result of the sanitary measures that the Government of Costa Rica implemented, causing FONAFIFO to suffer a cut of approximately \$2 million in its budget (Rodríguez, 2020a; Rodríguez, 2020b), which represents a reduction of 9 % of the average income from the fuel tax in the 2015–2019 period.

Of the funds collected described above, on average for the period 2015–2019, they were used almost entirely (98 %) to finance the PES scheme, where activities strictly dedicated to forest protection received an average of 83 % of all funding. It is important to assess the additionality generated by these funds, particularly given that land-use change (e.g., deforestation) is prohibited in Costa Rica according to article 19 of the Forest Law, and thus the actual positive impact of providing financial incentives to farmers for avoiding deforestation remains unclear (Daniels et al., 2010).

On the other hand, 10 % of FONAFIFO's funds are directed to reforestation activities, especially to the category of "reforestation with medium-growth species" (5 %) and to the general category of "reforestation" (4 %) (FONAFIFO, 2020). Finally, other activities that receive a significant source of funding, but in a much lower percentage, are pasture regeneration (2 %) and agroforestry systems (2 %). The remaining 4 % of the funds are allocated across a range of sub-activities, including reforestation, natural regeneration, and the implementation of agroforestry systems (FONAFIFO, 2020).

To determine the payment to landowners engaged in conservation and reforestation activities under the PES scheme, FONAFIFO relied on the valuations provided by Carranza et al. (1996) for the four ecosystem

services recognized in the Forest Law. When the study by Carranza et al. was undertaken, the discipline of economic valuation of ecosystem services was at a nascent stage, and therefore there were very few studies for each of the ecosystem services that the authors valued (Costanza et al., 2017). Because few studies were used, the value estimates had a high degree of uncertainty. Furthermore, while economic valuation studies can offer insights into the willingness to pay for certain ecosystem services, there is not necessarily a direct correspondence between the estimated value and the payment levels established under a PES scheme.

The only estimate from Carranza et al. (1996) that FONAFIFO used to calculate the payment for the forest conservation modality is the opportunity cost of the dual-purpose livestock activity (Umaña, personal communication, January 3, 2020; Navarrete, personal communication, September 23, 2020), which it was estimated at \$60 ha⁻¹ (Aylward et al., 1995). This estimate has been used since then to estimate the payments for the different modalities of the current PES scheme, where currently \$64 ha⁻¹ is paid as the base payment, and for some modalities this payment is increased by a bonus according to the prioritization criteria that FONAFIFO has established, such as in the case of areas with high hydrological importance (\$16 ha⁻¹ bonus) and high biodiverse areas (\$11 ha⁻¹ bonus).

1.1. Main opportunities of improvement

Having provided a broad overview of how the current PES scheme works in Costa Rica, we identified the following opportunities of improvement:

- a) **Definition of ecosystem services.** The current definition of ecosystem services in the Forest Law (article 3, paragraph k) has caused confusion in Costa Rica. First, public institutions (e.g., FONAFIFO, the National System of Protected Areas (SINAC), and the Ministry of Environment) mistakenly consider the terms environmental services and ecosystem services as different concepts as a result of the Forest Law. Beyond a theoretical discussion, this differentiation has even caused some institutions to argue that FONAFIFO is in charge of environmental services and other institutions such as SINAC are in charge of ecosystem services, a confusion that could affect the institutional efficiency of natural capital management. A second issue, linked to the previous one, is that there is a belief at the level of various institutions and initiatives that the ecosystem services that FONAFIFO manages are only the four established in article 3 of the Forest Law, when in reality the modalities and activities financed by the PES scheme are undoubtedly improving a greater number of ecosystem services, such as pollination, nutrient cycling, and protection against extreme events, among many others.
- b) **Approximate biophysical measurement of ecosystem services.** Although the approach of the current scheme is based on inputs (i.e., activities of conservation and restoration) and in bulk (i.e., several ecosystem services), it is necessary to estimate, at least approximately, the level of ecosystem services being conserved or restored through the financed activities. This does not imply a direct or comprehensive measurement of each individual service on every farm, as would be required under a fully output-based and layered approach. This can be very helpful to justify in a more specific way, beyond forest cover, the success of the PES scheme in generating ecosystem services for a multiplicity of beneficiaries. This opportunity for improvement has been pointed out in several studies, such as Pagiola, 2008; Porras et al., 2012 and Contraloría General de la República de CR, 2011.
- c) **Insufficient funding.** As explained before, the scheme is highly dependent on public resources (Porras et al., 2012). These resources are insufficient to meet the current demand from farmers interested in the PES scheme, and even more, this reliance renders the scheme

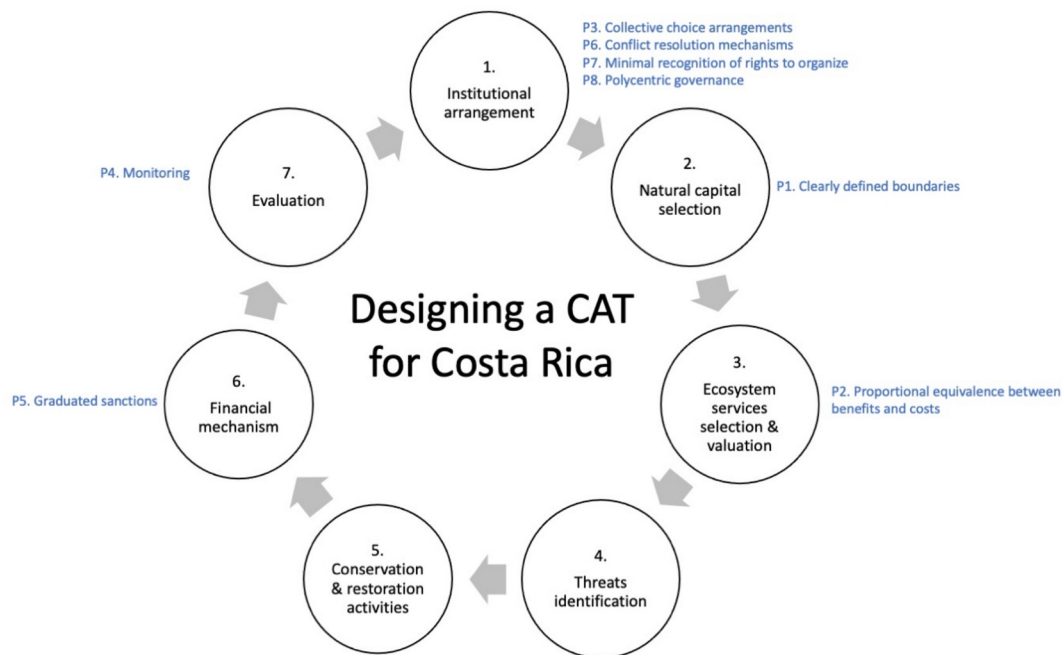


Fig. 1. Method implemented for the creation of the new PES scheme for Costa Rica. Ostrom's design principles that apply to each step of the methodology are highlighted in blue.

vulnerable to both positive policy shifts—such as the implementation of Costa Rica's National Decarbonization Plan, which may reduce revenues from the fuel tax—and adverse events, including global crises like the COVID-19 pandemic.

- d) **Enhancing the spatial prioritization of areas eligible for funding.** Although the prioritization criteria that FONAFIFO has introduced in recent years is an important step to address the challenge of increasing the effectiveness of the scheme (Porrás et al., 2012), some studies have indicated that the current scheme tends to attract participants who have a low or negative opportunity cost (Robalino et al., 2014; Robalino & Villalobos, 2014). As a consequence, the current scheme could be attracting land users (i.e., farmers and foresters) who would have adopted conservation and restoration practices anyway without the payments from FONAFIFO (Pagiola, 2008; Sanchez-Azofeifa et al., 2007), which causes a low level of additionality of the program and a high inefficiency in the resources invested. In addition, and as previously stated, the fact that the current PES scheme invests the vast majority of its funds in forest conservation practices even when land use change is prohibited by the same law that created the scheme makes this issue even more relevant (Daniels et al., 2010).
- e) **Cross-institutional coordination.** Related to the previous point, while FONAFIFO is tasked with the financial and contractual management of the PES scheme, its operations are often decoupled from the ecological planning and enforcement mandates of SINAC, leading to fragmented governance and spatial inefficiencies (Pagiola, 2008). This misalignment can result in PES investments that are not optimally targeted for biodiversity conservation or watershed protection.
- f) **Undifferentiated payments.** Although the current PES scheme has introduced “bonuses” on the payment for certain modalities according to their location (e.g., biodiversity and water), the scheme generally assumes that all locations in the country where FONAFIFO pays for any of the modalities provide the same type and magnitude of ecosystem services, and therefore the scheme offers an undifferentiated payment by modality (Sanchez-Azofeifa et al., 2007; Daniels et al., 2010; Contraloría General de la República de CR, 2011).

The following sections offer detailed recommendations for incorporating these and additional improvement opportunities into a proposed PES 2.0 scheme for Costa Rica, including the first natural capital valuation ever conducted for the country at the national level, which provides critical support for the business case underlying the proposed conservation and restoration strategies.

2. Towards a PES 2.0

More than 25 years after the establishment of Costa Rica's PES scheme—and in light of the limitations outlined above—the country now has an opportunity to reaffirm its global leadership in PES innovation by expanding both the scope and inclusiveness of the current scheme. To do this, we propose here the evolution of the scheme towards a Common Asset Trust (CAT) that will consider the entire natural capital of Costa Rica, which will require a significant redesign of both its financial mechanism and institutional arrangement (Farley et al., 2015). A CAT is a collection of agreements and poly-centrally governed institutions in support of a shared purpose, the sustainable management of public goods (as in the case of the majority of the natural capital of Costa Rica). To achieve this purpose, the design of these agreements and institutions can be guided by Elinor Ostrom's design principles for sustainable commons management (Costanza et al., 2020; Ostrom, 2008), which are not normative but serve as core functional design principles for successful cooperation in the face of social dilemmas such as managing common pool resources (Atkins et al., 2019; Wilson et al., 2013). Ostrom's design principles for effective and sustainable commons management are: (P1) clearly defined boundaries, (P2) proportional equivalence between benefits and costs, (P3) collective choice arrangements, (P4) monitoring, (P5) graduated sanctions, (P6) conflict resolution mechanisms, (P7) minimal recognition of rights to organize, and (P8) polycentric governance. Ostrom derived these design principles through empirical analysis of long-standing, community-managed common-pool resources such as forests, fisheries, and irrigation systems. Using the Institutional Analysis and Development (IAD) framework, she identified shared governance features that consistently contributed to sustainable resource management (Ostrom, 1990). Her work, grounded

Table 1

Key governance principles to design the Natural Capital Trust of Costa Rica. Costanza et al., 2020.

Guiding principle	General description
1. <i>Stewardship responsibility.</i>	The trustee has the mandate of sustainably manage the trust through conservation and restoration activities, recognizing the limits of the system, in this case the trust, to provide services and to withstand negative impacts.
2. <i>Systems thinking.</i>	PES modalities and its financial mechanisms should consider the socio-ecological system, with a focus on improving the ecosystem health and the well-being of its beneficiaries. Furthermore, the PES 2.0 should have a landscape approach for the implementation of its activities, considering the connectivity between ecosystems and the cross-scale interaction. Finally, the scheme should acknowledge that several ecosystem services are protected or restored at the same time under the conservation and restoration activities that the PES 2.0 will propose.
3. <i>No net loss.</i>	Negative impacts on natural capital from any development project must be mitigated or offsetted by measures to avoid and minimize these impacts, by carrying out restoration and, finally, compensating for residual impacts.
4. <i>Based in science.</i>	Although the proposed scheme adopts an input-based and bundled approach, it is essential to identify and, at a minimum, approximate the target ecosystem services of each modality using proxies or ecosystem service modeling techniques. Threats to each ecosystem must also be assessed both quantitatively and spatially to inform effective prioritization and intervention strategies.
5. <i>Additionality.</i>	The implementation of activities under the scheme should demonstrate additionality relative to existing initiatives or legal instruments. Consequently, paying solely for forest conservation on private lands would no longer be a priority under PES 2.0, given that deforestation is prohibited under the Forest Law and, as such, these ecosystems are theoretically already under legal protection.
6. <i>Conditionality.</i>	Related to additionality, the PES 2.0 should enforce an innovative monitoring and assessment system, through the use of modern technologies such as Earth Observation and drones, to ensure that activities are being implemented as they were designed and established under the contract with the supplier or implementer of the ecosystem services. Therefore, payments should be conditional to the successful implementation of the activities.
7. <i>Efficiency.</i>	The selection of areas for conservation and restoration investments should be guided by a set of criteria, which may include ecosystem health, degree of threat, intensity of ecosystem service provision, ecological uniqueness, and biodiversity, among other relevant factors. Socio-economic variables could be included as well. This set of criteria will ensure a targeted strategy, especially considering that funds are limited, and they should be invested in places with the highest returns/benefits. Moreover, the PES 2.0 should maintain low transaction costs, which can be achieved through the implementation of an input-based and bundled approach, as well as through the targeting strategy described before.
8. <i>Financial sustainability.</i>	The trust should secure a minimum level of annual funding through a diversified portfolio of financial mechanisms designed to be resilient to socio-economic stressors and fluctuations. These mechanisms should remain adaptable over time—subject to periodic review—allowing for the phasing out of ineffective instruments and the introduction of new ones as needed to ensure long-term financial sustainability.
9. <i>Intersectoral participation.</i>	The scheme should operate under a participatory approach, integrating sectors such as the academia, business, non-governmental organizations, and indigenous communities, among others. These sectors will help design the conservation and restoration

Table 1 (continued)

Guiding principle	General description
	activities, as well as their implementation. It is key to consider the related power dynamics that would emerge from a higher participation, and therefore the new scheme should establish clear, inclusive decision-making rules and conflict resolution mechanisms to manage power asymmetries and ensure equitable participation.
10. <i>Legally sound and policy coherent.</i>	A set of laws, regulations, and policies should be modified, created, or eliminated to ensure a coherent legal and policy framework that enables the implementation of the scheme and secures the necessary financial mechanisms for long-term sustainability.

in case studies from diverse contexts, challenged conventional assumptions about the inevitability of resource overuse and demonstrated the viability of decentralized, community-based governance (Ostrom, 2005).

To create a CAT for Costa Rica, we followed the seven-step process designed by Hernández-Blanco (2019) (Fig. 1), which is in close relation with Ostrom's design principles for managing the commons.

2.1. Step 1. Institutional arrangement

We propose to transform the institutional arrangement of the current PES scheme from a fund to a trust (i.e., a CAT). Although funds and trusts are closely related, they are different investment vehicles. A fund collects financial resources from a diverse number of investors and then invests them in a portfolio of investments. In the case of FONAFIFO, it obtains funding from sources such as the tax on fossil fuels and invest them in a conservation portfolio. A trust, on the other hand, is an agreement between two parties, in which the assets of one party (i.e., the trustor) are transferred to the other party (i.e., the trustee) that will be in charge of maintaining the assets and its use for the benefit of a third party (i.e., the beneficiary). In the context of the new PES scheme, and in accordance with the public trust doctrine, the Government of Costa Rica will serve as the primary trustee. This role may be shared with representatives from civil society, who will be responsible for implementing measures to protect and restore the natural endowment managed in trust for the collective benefit of both national and global citizens (Sax, 1970). Specifically, the new institutional arrangement will reward citizens that enhance the trust and will penalize those who cause any damage on it.

Therefore, we propose the creation of a CAT for the country, the Natural Capital Trust of Costa Rica (NCT), as the evolution of FONAFIFO and the current PES scheme, a PES 2.0 if you will. The goal of the NCT will be to protect the totality of Costa Rica's natural capital, while improving the livelihoods of the people who depend on this capital as well as those who will implement the conservation and restoration activities under the new scheme. Furthermore, the PES 2.0 will operate under a "no net loss" logic, which means that natural capital should not decrease in net terms under any form of development (Locke et al., 2021).

To achieve this goal, the basic elements and processes of the PES 2.0 must be based on guiding principles that ensure its quality and ambition. In Table 1 we propose ten principles for the design of the new generation of PES in Costa Rica, which have been globally recognized as necessary for the correct operation of any PES scheme (Engel, 2016; Engel et al., 2008; Hernández-Blanco, 2019).

2.2. Step 2. Natural capital selection

The NCT would be comprised of all the natural capital of Costa Rica. However, the new scheme could start with a portion of the national natural capital, focusing on ecosystems that have significant land and coastal cover in the country, as well as those that have been studied the

Table 2
Ecosystems that will be included in the Payment for Ecosystem Services 2.0 of Costa Rica.

Natural ecosystems	Anthropogenic ecosystems
– Private and public forests (dry, seasonal, rainy, cloud) – Wetlands (rivers, lagoons, lakes) – Mangroves – Coral reefs – Open ocean and estuaries	– Agricultural areas (rural and urban) – Urban forests – Urban wetlands

most, leaving the scheme open to the incorporation of other ecosystems later on. Additionally, the PES 2.0 will consider anthropogenic systems due to their potential to be transformed into systems that can be providers of services under sustainable land and seascape management approaches. Table 2 lists the ecosystems that are proposed for the new PES.

The expansion of the scheme to encompass public forests and a broader range of ecosystems—both terrestrial and coastal-marine—represents one of the most significant changes. It is important to highlight that some of these ecosystems are public property, necessitating a redesign of the institutional framework of the current PES scheme to ensure their effective inclusion (Beckenkamp, 2012). Currently, these public natural assets are free to use, and there is also often no cost associated with their damage by various economic sectors that derive economic benefits from them (Bromley, 1992). Broadening the scope of implementation in this regard constitutes a critical step toward reimagining a scheme that has traditionally focused on private forests.

2.3. Step 3. Ecosystem services selection and valuation

In terms of the targeted ecosystem services of the NCT, we recommend continuing with the current input-based and bundle approach, which has proven to work through the history of the current scheme (Pagiola, 2008; Porras et al., 2012; Wunder et al., 2008). Nevertheless, the NCT can be expanded to encompass six additional ecosystem services, thereby enabling the inclusion of new activities, modalities, and financial mechanisms (Fig. 2). Some of these may target the conservation or restoration of a specific service—such as pollination in agricultural landscapes—while others may simultaneously address multiple services, such as climate regulation and the moderation of extreme events in mangrove ecosystems; recognizing at the same time that although the new scheme focuses on certain prioritized ecosystem services, other services will be improved collaterally, and therefore our list rather than prescriptive should be used as a guide. For the identification of ecosystem services, we used the typology of ecosystem services from TEEB (2010) and Brander et al. (2024) throughout our analysis.

One of the central ideas from expanding the new scheme to

encompass a broader range of ecosystem services is to go “beyond carbon” (i.e., climate regulation), which is the service that the current PES scheme focuses on, with the aim of raising the level of ambition and innovation of the new PES.

2.3.1. The value of natural capital of Costa Rica

The natural capital of the NCT was valued at national scale (see Supplementary Material for methods). We found that the median values per hectare of the ecosystem services of each ecosystem vary significantly. For example, in the case of forests, pollination is the most valuable service (\$1,047 ha⁻¹year⁻¹), followed by erosion prevention (\$309 ha⁻¹year⁻¹) and climate regulation (\$167 ha⁻¹year⁻¹). It is striking that the two most valuable services are not contemplated in the current PES scheme, and even pollination is valued at six times more than the climate regulation service, the latter being the dominant focus of the current scheme. These values support our argument about the need to expand the current PES to other ecosystem services from different ecosystems. Table 3 provides the value per hectare per year of all the ecosystem services that we propose to incorporate in the PES 2.0.

The total annual value per hectare for each ecosystem is calculated by summing the median per-hectare, per-year values of all associated ecosystem services. Mangroves are the ecosystems that per hectare provide the greatest economic benefit to society (\$8,744 ha⁻¹), followed by coral reefs (\$3,051 ha⁻¹), forests (\$1,760 ha⁻¹) and oceans (\$184 ha⁻¹). However, when multiplying these values by the area of each ecosystem, oceans are the most valuable ecosystem in Costa Rica (\$9.8 billion year⁻¹) due to their vast extent, followed by forests (\$4.4 billion year⁻¹), mangroves (\$317 million year⁻¹) and lastly coral reefs (\$21 million year⁻¹) (Table 4). Altogether, the estimated total annual value of the ecosystem services provided by all ecosystems is \$14.5 billion, demonstrating the significant contribution that nature provides to local and global human well-being, as well as the potential economic cost that the degradation or loss of these ecosystems would represent.

Finally, applying the pluralistic discounting approach from Costanza et al. (2021), Table 5 presents the net present value of Costa Rica’s natural capital, valued in its entirety at \$845 billion.

Our estimates of the value of the natural capital of Costa Rica are the first of its kind at the national level in the country, representing an important contribution to science and decision-making. Our results update the study by Carranza et al. (1996), often mentioned by governmental officials in Costa Rica (e.g., from FONAFIFO) as one of the fundamental studies for establishing the payment amounts of the current PES scheme. The values we estimated are significantly higher than those of Carranza et al. (1996), mainly due to the fact that when this last study was carried out, there were few studies on the valuation of natural capital in the literature (Costanza et al., 2017).

Furthermore, it is important to note that the economic value of nature is one of several criteria that must be considered for decision



Fig. 2. Expansion of the new PES to 10 ecosystem services. The current one only includes 4 services. The names of the ecosystem services of the current PES were modified from their original ones as they are in the Forest Law to better compare them with the standardized categorization that we used.

Table 3

Number of estimates and values extracted from the literature to carry out the value transfer. Refer to the Supplementary Material for the complete list of studies from which the economic values were derived.

Ecosystem service	Estimates	Ecosystem service value per hectare (\$Int ha ⁻¹)				Standard deviation
		Minimum	Maximum	Mean	Median	
Forests						
Climate regulation	7	15	3,248	751	167	1,163
Air quality regulation	5	0.82	1,518	309	13	676
Medicinal resources	45	0.03	46	5	1	9
Existence and bequest values	8	4	17,539	2,222	17	6,189
Maintenance of life cycles	1			19	19	
Water	7	0.001	191,266	27,480	9	72,223
Opportunities for recreation and tourism	5	0.58	263,331	52,702	68	117,745
Erosion prevention	6	5	1,861	504	309	702
Pollination	4	507	1,775	1,094	1,047	528
Moderation of extreme events	7	2	809	208	108	281
Total	95			85,294	1,760	
Mangroves						
Food	73	0.47	5,426,248	221,063	324	951,574
Moderation of extreme events	25	0.38	180,754	8,382	277	35,983
Climate regulation	24	19	40,828	2,660	381	8,328
Existence and bequest values	16	8	12,907	1,713	321	3,221
Maintenance of life cycles	5	0.14	3,726	2,417	2,697	1,431
Medicinal resources	9	23	53,098	7,373	2,517	17,195
Waste treatment/water purification	13	1	26,871	3,396	996	7,228
Opportunities for recreation and tourism	50	0.004	61,779	3,885	144	12,349
Erosion prevention	11	5	5,924	2,161	1,084	2,366
Total	226			253,051	8,744	
Rivers						
Food	3	0.69	238	110	91	120
Water	10	43	6,081	1,214	222	2,127
Moderation of extreme events	1			8	8	
Waste treatment/water purification	4	106	88,509	23,261	2,215	43,511
Opportunities for recreation and tourism	3	82	869	353	108	447
Medicinal resources	2	1,778	2,714	2,246	2,246	662
Existence and bequest values	5	76	3,260	814	116	1,379
Total	28			28,007	5,007	
Coral reefs						
Food	62	0.01	125,689	5,559	376	20,217
Moderation of extreme events	30	0.01	825,241	67,165	1,097	204,830
Existence and bequest values	37	0.03	11,073	972	132	2,231
Opportunities for recreation and tourism	112	7	3,593,558	55,680	1,445	352,341
Total	241			129,377	3,051	
Ocean						
Food	2	29	56	42	42	19
Climate regulation	1			69	69	
Opportunities for recreation and tourism	101	0.43	1,525,692	20,317	62	154,325
Medicinal resources	1			9	9	
Existence and bequest values	1			2	2	
Total	106			20,439	184	

Note: Ecosystem services indicated in *italics* are not directly proposed as part of the PES 2.0, but we decided to incorporate them since data was available and therefore could provide a more comprehensive understanding of the value of natural capital in Costa Rica.

Table 4

Summary of the economic values of the ecosystems of the Payment for Ecosystem Services 2.0.

Ecosystem	Total annual value per hectare (\$Int)	Total annual value (\$Int)
Forests	1,760	4,380,376,420
Mangroves	8,744	316,981,685
Coral reefs	3,051	21,351,218
Ocean	184	9,780,009,352
Total		14,498,718,674

Note: median values.

Table 5

Net present value of the natural capital of Costa Rica.

Ecosystem	Net present value (\$Int)
Forests	280,190,518,803
Mangroves	19,935,633,915
Coral reefs	1,097,099,168
Ocean	544,146,014,917
Total	845,369,266,803

Note: median values.

Table 6

Trends on the condition of the ecosystems from the Payment for Ecosystem Services 2.0. MINAE et al., 2018.

Ecosystem	Tendency
Tropical dry forest	↑
Tropical humid forest	↓
Montane forest	→
Lagoons	↓
Rivers	→
Mangroves	↓
Coral reefs	↓
Open sea	↑

↑ = ecosystem health improvement, → = ecosystem health is maintained, ↓ = ecosystem health decreases.

making. For example, biological criteria such as the fragility or uniqueness of an ecosystem could have more weight when selecting a project or policy, as well as social criteria in the case of the intrinsic value of natural capital, especially for indigenous communities who have a close relationship with nature (Pascual et al., 2023; Pascual et al., 2022; Rea & Munns, 2017).

It is also key to highlight the main limitations of the method we used to estimate these values. First, the estimated value of each ecosystem service depends on several factors that can significantly alter the result, such as the number of estimates drawn from the database we used and the quality of the data. In addition, when estimating the total value of the ecosystem, it depends on the amount of ecosystem services evaluated. Second, the total values per ecosystem represent the potential supply of ecosystem services, since it is assumed that the entire extension of the ecosystem provides in equal magnitude all the ecosystem services, which does not occur in reality due to the particular biophysical characteristics of the natural capital throughout its extension, as well as the location and demand of the beneficiaries. In order to have a more exact value that simulates the demand for services, more complex value transfer methods can be applied, such as the transfer modified by expert opinion or the one modified by spatial modeling such as the one conducted by Hernández-Blanco et al. (2021) for the mangroves of the Gulf of Nicoya in Costa Rica, or transfer function *meta*-regression analysis. Ideally, primary valuation studies should be the preferred approach whenever feasible.

A third key limitation of the economic valuation lies in the inherent uncertainty associated with the use of value transfer methods, which do not account for site-specific biophysical or socioeconomic differences between the study and policy sites. To partially address this, we report the range of economic values found in the literature for each ecosystem service, including the minimum and maximum values. While such range reporting does not offer a formal confidence interval, it provides a basic indication of variability. Moreover, existing literature suggests that simple unit value transfers may yield transfer errors averaging between 40 % and 70 %, and in some cases exceeding 100 %, depending on the heterogeneity between source and target contexts (Rosenberger and Stanley, 2006). These factors underscore the need for cautious interpretation of the results and highlight the value of future efforts to calibrate values through primary data collection or locally adjusted transfer functions.

Lastly, since these economic values are a first approximation, which due to the method used may have a significant degree of error, they cannot be used directly to establish particular financial instruments such as fines for environmental damage or the price per hectare to be paid in the scheme of PES. However, the economic values of ecosystem services can be used as a scientific guide for these two instruments, as well as for prioritizing the ecosystem services of the natural capital that will be the conservation and restoration objective of the proposed PES scheme.

2.4. Step 4. Threats identification

Despite having approximately 5 % of the planet's biodiversity (MINAE, 2015), Costa Rica's ecosystems are undergoing negative transformations driven by activities associated with key economic sectors, including agriculture, energy, and infrastructure. Additional pressures stem from chemical pollution—particularly the use of agrochemicals—and the expansion of unplanned urban development (MINAE et al., 2018) (Table 6). Therefore, the identification and prioritization of threats to natural capital and ecosystem services is key in order to invest in the solutions that are most needed, thus increasing the effectiveness and efficiency of the PES 2.0 (Schomers & Matzdorf, 2013). In addition, the identification and quantification of threats will form part of the baseline from which the success of the implemented solutions will be compared, thus incorporating the central principle of additionality into the scheme (Engel et al., 2008). Finally, determining the threats, and consequently the environmental impacts, will be the basis for the determination of fines that the new scheme could collect with the idea of punishing those who deteriorate the trust (i.e., natural capital), and using that funding to pay those who improve the trust (Kadambe & Segerson, 1998).

2.5. Step 5. Conservation and restoration activities

The PES 2.0 should focus on the conservation and restoration activities that improve the extent and condition of the targeted natural capital. The identification of these activities should be carried out mainly by a scientific team of the new scheme in conjunction with other experts to ensure an efficient and effective allocation of resources, and above all the health of the ecosystem. These activities must address the main threats each ecosystem is currently facing. Table 7 summarizes all the modalities and activities we propose for the PES 2.0.

It is worth highlighting that these modalities and their activities for each ecosystem represents a first iteration of options, leaving open the possibility of incorporating new modalities in the future according to aspects such as new conservation and restoration needs, technological innovations, and required adjustments in the financial mechanism, among others. Thus, the NCT would work under an adaptive model, capable of evolving whenever necessary without having to go through complicated bureaucratic and/or political processes.

One of the most relevant changes of the PES 2.0 is that most of the modalities and activities would be carried out on public property, such as urban forests, mangroves, rivers, coral reefs and the open sea, among others. For this reason, conservation and restoration activities in these public domain ecosystems would be carried out by a new figure of actors who we call “implementers”, which are the providers of ecosystem services in these ecosystems and who would receive the payments to carry out management activities to protect these natural resources. The implementers may be Non-Governmental Organizations (NGOs), the academia, business, indigenous communities, community associations and individuals (general public), among others. The new PES scheme should establish mechanisms that allow implementers to apply for funding based on the prior identification of required conservation and restoration activities, as well as clearly defined technical and administrative eligibility criteria. In terms of the payments to the implementers or providers, the scheme should at least cover the ecosystem service provider's provision costs. Provision costs include the loss of profits from changing activities (i.e., opportunity costs), as well as the transaction costs involved in changing activities and enrolling in the PES scheme. Conversely, the maximum payment would reflect the total value that beneficiaries attribute to the enhanced provision of ecosystem services resulting from the transition to conservation or restoration activities (Engel, 2016).

As previously explained, the payments currently made by FONAFIFO for the different modalities are based on the opportunity cost, which was determined in relation to agricultural and livestock activities. This

Table 7

Proposed modalities and activities for the Payment for Ecosystem Services 2.0.

Ecosystem	Modality	Activity
Private forests	All current FONAFIFO modalities	All current FONAFIFO activities
Public and urban forests	1. Improvement of forest management in protected areas	1.1. Control and monitoring (new technology, citizen science, fire control) 1.2. Management of buffer zones and biological corridors
	2. Green infrastructure	2.1. Urban reforestation and afforestation
Agricultural farms	1. Sustainable agriculture	1.1. General sustainable agriculture practices 1.2. Creation or enhancement of bird habitat within coffee agroecosystems 1.3. Creation or enhancement of habitat and other ecological conditions to support pollinator populations 1.4. Low carbon coffee production
Wetlands (rivers and lagoons)	1. Conservation	1.1 Protection of adjacent systems (e.g., forests, farms) 1.2. Urban river management
	2. Rehabilitation	2.1. Practices to improve wetland water quality (e.g., cleaning, elimination of invasive species, reduction of discharges)
Mangroves	1. Conservation	1.1. Improved management of protected areas 1.2. Establishment of breeding, shelter and feeding areas for species
	2. Recovery	2.1. Effective water management 2.2. Reforestation or rehabilitation of degraded mangrove forests
Coral reefs	1. Conservation	1.1. Improved management of protected areas 1.2. Payment to fishermen for the conservation of keystone and/or endangered species (e.g., parrotfish)
	2. Restoration	2.1. Restoration with artificial reefs 2.2. Restoration of natural reefs
	3. Sustainable fishing practices	3.1. Subsidize improvements or changes in fishing gear 3.2. Compensate or subsidize the closure of fisheries during the reproduction season or spatio-temporal closures
Open sea and estuaries	1. Conservation	1.1. Establish marine protected areas or marine reserves 1.2. Establish fishing recovery zones or no-fishing zones
	2. Recovery	2.1. Recovery through the promotion of fishery management and sustainable fishing measures 2.2. Recovery through incentives to improve control and surveillance of resources and fishing areas

Table 8

Mean, standard deviation, minimum, maximum prioritization index by ecosystem.

Ecosystem	Mean	SD	Min.	Max.
Coffee Farms	21	9	3	63
Mangroves	24	7	8	53
Forests	16	7	0	56

payment approach is consistent with the recommendations of [Engel \(2016\)](#), and we propose that the PES 2.0 continue to be based largely on this approach, both for activities on public and private property, under an input-based approach. The opportunity cost will depend on the type of ecosystem service provider and the activity being undertaken. This cost—reflecting the foregone benefits of not pursuing an alternative activity—may be estimated based on the expected returns of that alternative activity or, in the case of implementers operating on public land, the foregone wages associated with conservation or restoration efforts. Furthermore, payments can be differentiated on the basis of costs of provision (paying higher amounts to higher-cost providers) or on the basis of environmental benefits (paying higher amounts where sites provide services more intensively).

2.6. Step 6. Financial mechanism

The funding sources for the new PES scheme can be grounded in the internalization of externalities generated by both national and international economic activities. These resources can come both from economic incentives and fees, as well as from regulatory mechanisms. Here we provide a first selection of these financial solutions.

2.6.1. Green taxes

Certain crops that are harvested extensively in the country with high environmental impact can be a source of funding through a green tax created with the goal of internalizing these environmental costs, and therefore aiming to transform the industry towards a more sustainable one ([Barbier, 2022](#)). For example, pineapple production, which is the third largest export product in the country after medical devices and bananas, does not have any tax burden like fishing, coffee and bananas, besides having significant environmental and social impacts that are still mostly unaddressed ([Carazo & Aravena, 2016](#)). We therefore propose the introduction of a tax on pineapple exports, designed to be simple to calculate and collect—similar to the existing tax on coffee exports. The proposed tax would amount to 1.5 % of the free on board (FOB) value and would be implemented incrementally over a period of three to five years. We estimate that this tax could generate approximately \$16 million per year based on 2019 FOB values for pineapple.

Another potential incentive involves revising the current air travel entry and exit tax applied to passengers arriving in and departing from Costa Rica. At present, three distinct types of such taxes are in place: (1) 5 % tax on the value of flight tickets sold in Costa Rica, (2) \$15 tax to foreigners arriving in Costa Rica, and (3) \$29 tax to leave the country, no matter the traveler's nationality. In some way, these incentives are a sort of carbon tax on air travel, and therefore address this externality mainly for the ecotourism industry of the country. The government of Costa Rica could increase the first one by 1 %, and the last two by \$1. Based on the collection of these three taxes in 2017, we estimate that these increases could generate approximately \$9 million per year, which can be distributed as 90 % for the new PES and the rest for the Costa Rican Institute of Tourism.

A third example of tax that could become an important source of funding for the PES 2.0 is a tax on plastic. [Pacheco et al. \(2018\)](#) proposed one for Costa Rica, consisting of a 10 % tax for plastic supplies, 15 % for multi-use, long-lasting plastic products, 25 % for single use plastics, and 25 % for styrene polymers in primary forms. The authors estimated that this tax could collect on average \$21 million in the first 5 years. This average takes in consideration a tax erosion rate between 3–9 % depending on the plastic product, in order to reflect a reduction in the use of these products and consequently the transformation of this industry.

2.6.2. Repurposing subsidies

It is widely known that changing certain subsidies can have a significant positive impact on natural resources management (Pearce, 2003; van Beers & van den Bergh, 2001; Green, 2006). In the case of Costa Rica, the import of agrochemicals is currently tax exempt, besides the country using approximately the triple of these chemicals compared to the rest of OECD countries (Vargas, 2021), which represent a high negative impact to the Costa Rican natural capital (Hernández-Blanco & Chavez, 2022). To address this, Rodríguez-Garro (2020) estimated that the government of Costa Rica is failing to perceive around \$45 million due to this subsidy. These funds, if collected, could be redirected to the PES 2.0, specifically for activities on sustainable agriculture.

2.6.3. User fees

In line with our proposal to incorporate public-owned ecosystems, which many are inside the national parks network of the country, we propose to update the entrance fees to these protected areas and direct a percentage to the NCT. Protected areas, in addition to provide the ecosystem service of recreation and ecotourism, deliver a wide variety of other services on which the sustainable development of the country directly depends on, such as the provision of water, pollinators for key crops (e.g., coffee), protection against extreme events, climate regulation, and of course the conservation of biodiversity that has various use and non-use values. Therefore, these positive externalities provided by protected areas can be internalized in some way to ensure the conservation of this natural capital. Hernández-Blanco et al. (2020) estimated that a \$1 increase per visitor to national parks in the country could mean an annual income of \$2 million, which could be allocated completely or partially to the NCT (funds can be shared between the NCT and SINAC).

2.6.4. Conservation banking

A final instrument with the potential to address several of Costa Rica's principal environmental impacts—while simultaneously generating a stable source of funding for the NCT—is the establishment of a nature compensation bank. Generally speaking, a compensation bank is a site, or set of sites, where resources (i.e., natural capital) are restored, established, enhanced, and/or preserved for the purpose of providing compensatory mitigation for future impacts (Mandle et al., 2019; Bovarnick et al., 2010; U.S. Fish & Wildlife Service, 2019). This bank could be called the Natural Capital Bank of Costa Rica (NCBCR), the first of its kind in the country and possibly one of the first ones in the region. The NCBCR will comprise all private and public ecosystems where the NCT is financing conservation and restoration activities. For each hectare of area intervened by these activities, a credit can be generated, which we call a Natural Capital Credit (NCC). These credits are based on the current PES scheme, in which FONAFIFO acquires the property rights of credits generated by the modalities that it finances.

It is important to highlight that since the new PES scheme contemplates the ecosystem services provided by public property, these areas may produce credits if the conservation and restoration activities there are additional to those currently carried out, which would apply to national parks. In addition, private properties that become part of the NCBCR could still carry out some activities such as tourism and agriculture, as long as they ensure that the conservation or restoration conditions established with NCT are met, and therefore representing an additional incentive for owners to become part of the bank.

The generation of NCCs by the NCBCR will create a NCC Market, which would mainly have buyers defined by regulatory mechanisms, but the NCCs would also be available to voluntary buyers, to ensure the scheme remains flexible and capable of mobilizing funds from a diverse array of financing sources. Regarding the buyers defined by regulatory mechanisms, these could be different actors that are contemplated in the following administrative processes: (1) compensation of the environmental impact of new projects to obtain the environmental viability granted by the Environmental Technical Secretariat (SETENA), and (2) the established fines for environmental damage through the

Environmental Administrative Court (EAC).

In the case of SETENA, the main buyers of credits will probably be developers in the construction sector, which currently represents an average of 54 % of environmental viability applications to SETENA (SETENA, 2020). Another sector that could be an important buyer of credits is electricity, gas and water, which on average requests 30 % of these permits (SETENA, 2020). An important aspect to highlight is that NCCs must be bought by both private and public developers. Furthermore, the NCBCR could function as a market where municipalities that have implemented natural capital conservation and restoration activities can sell the credits generated by these activities through NCT to other municipalities that need to develop infrastructure and other types of projects with high environmental impacts. In terms of the EAC, the objective is for social actors responsible for environmental degradation to compensate for their impacts through the purchase of NCCs. This approach would provide greater assurance that environmental damage is effectively compensated through conservation and restoration activities that are either already demonstrating successful outcomes or are implemented using the funds generated from the credit purchases.

The prioritization of all of these financial solutions will ultimately depend on policy developments in related sectors, which can either enable or constrain their implementation. For example, fiscal and tax policy will determine the viability of introducing green taxes or repurposing subsidies, while trade policy may influence the feasibility of levies on agricultural exports such as pineapples or bananas. Similarly, tourism policies affect the adjustment of park entrance fees or air travel taxes, and environmental and land-use regulations will shape the scope for conservation banking and fines for environmental damage. Even social policies play a role by ensuring equity and participation of local communities and indigenous peoples in the scheme. Therefore, the country needs to recognize these interdependencies in order to design a robust and adaptable financial strategy for the PES 2.0 scheme, taking in consideration that not all financial solutions are equally politically viable.

2.7. Step 7. Evaluation: The Natural Capital Priority Index for PES schemes

It is key to determine where investments from the NCT will yield the highest socioeconomic and environmental results. The goal is to make the PES scheme more efficient, providing resources to the areas of the country where they are most needed both in terms of reducing natural capital loss and degradation (especially in priority conservation areas), as well as optimizing the provision of ecosystem services. Consequently, identifying the locations of threats to natural capital, regions with high conservation value, and areas with significant ecosystem service provision will serve as critical parameters in determining where PES 2.0 payments are likely to yield the greatest economic and environmental benefits within the country. Furthermore, this approach needs to consider the interdependencies between ecosystems, and therefore the connections and related impacts between threats. For example, one of the main threats to coral reefs is sedimentation due to deforestation that occurs in the mountains (Kappelle, 2016), and therefore the necessary interventions for the conservation of one ecosystem must be carried out in another ecosystem.

To evaluate and increase the efficiency level of the new scheme, we developed The Natural Capital Priority Index (NCPI), a novel spatial-explicit method to prioritize the investments of the NCT. The NCPI is a composite index that utilizes spatial mapping to assign scores based on three key dimensions: (1) the level of ecosystem services provided, (2) the degree of threats to their continued provision, and (3) the presence of areas of high conservation significance. We applied our index-based targeting method for three case study ecosystems and their respective services in Costa Rica: (1) agriculture, with a focus on pollination in coffee; (2) mangroves, with a focus on carbon sequestration (i.e., climate regulation) and coastal protection (i.e., moderation of extreme events);

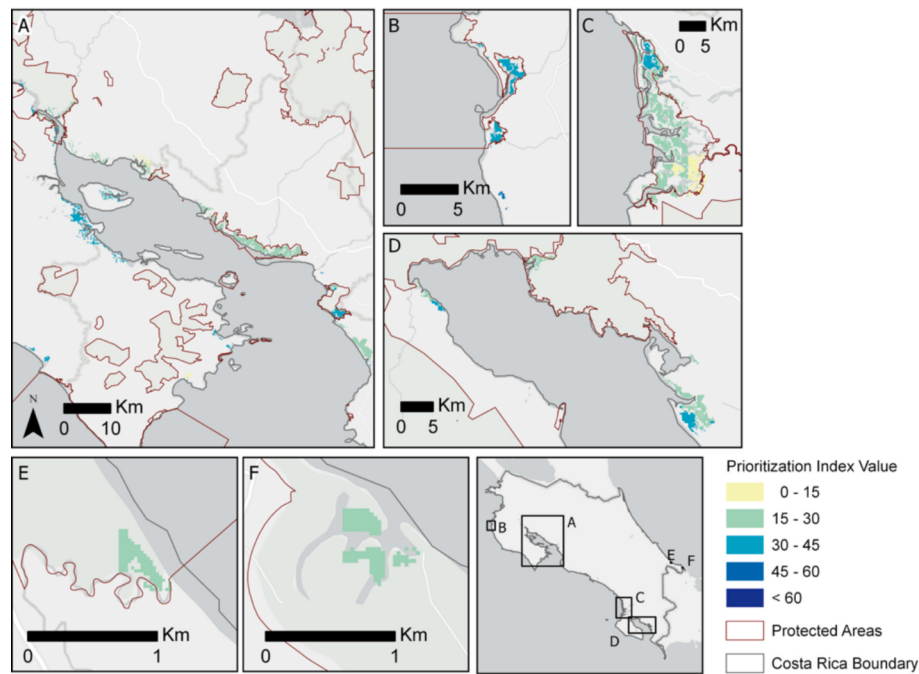


Fig. 3. Map of prioritization index for mangroves. Coastal segments are shown in the inset.

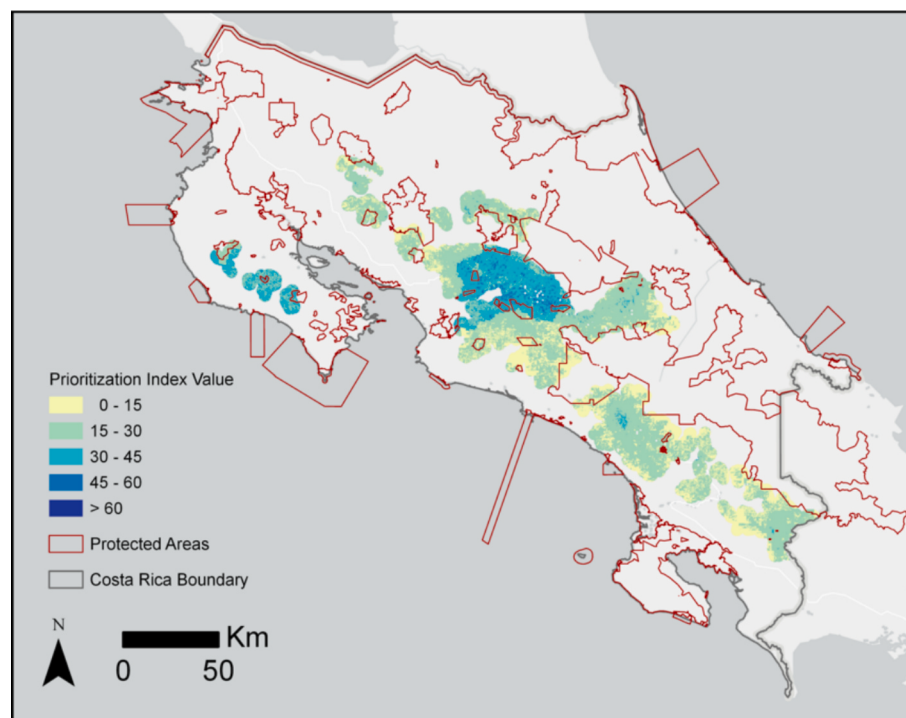


Fig. 4. Map of prioritization index for coffee farms and their surrounding 3 km buffer.

and (3) forests, with a focus on carbon sequestration.

We found that the mean prioritization index was below 25 points (out of 100) for all ecosystems, with maximums above 50 points (Table 8). Lack of values close to the maximum point value indicated that areas with high average threat values and areas with high average ecosystem service levels did not frequently align. Mangroves frequently overlapped with protected areas (Fig. 3). Coffee farms had limited

overlap with protected areas, but those locations generally had moderately to high prioritization index scores (Fig. 4). Due to their large extent, forests had the most overlap with protected areas, though mostly in locations with prioritization scores ≤ 15 points (Fig. 5). The protected forested areas on the Nicoya Peninsula had moderately low prioritization scores (≤ 30 points). In all ecosystems, highest priority areas concentrated in watershed basins with high water stress.

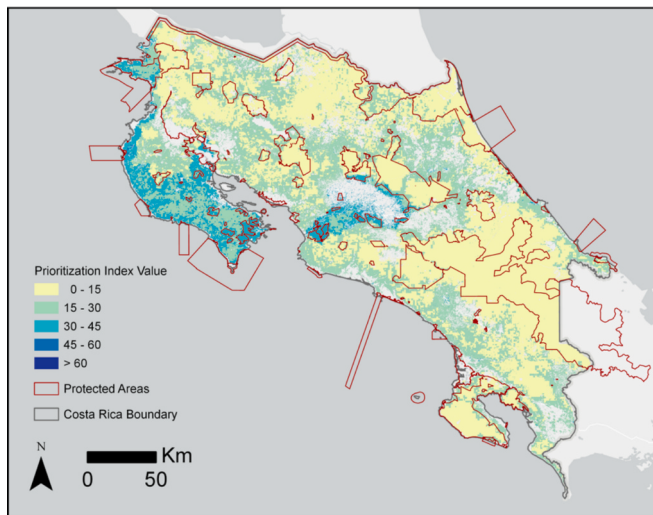


Fig. 5. Map of prioritization index for forests.

Furthermore, we found that the majority of current PES contracts overlapped with at least one key habitat. However, only two PES-dense location substantially overlapped with high bonus value: one along the northern border and the second near the central west coast (Fig. 6). Many of the country's areas that had no key habitats present also had a low density of PES contracts below 0.05 per km². Using a 10 km radius to estimate density identified the most distinct clusters of PES farms compared to a 2 km or 30 km radius.

We caution against relying on this prioritization index alone for decision-making. This index is intended to serve as a guide for further developing spatial priorities of a PES scheme with users of the country's ecosystem services. This method addresses ecological benefits and pressures, but we have not incorporated socioeconomic or logistical constraints. To avoid fragmentation of the landscape, we also suggest these maps be used as a tool to identify clusters of similar-priority locations rather than to exclusively invest on the highest-scoring pixels.

3. Conclusion

Costa Rica is known globally as a leader in natural capital conservation. From having one of the highest deforestation rates in the region three decades ago, to currently having around 60 % of its terrestrial area with forest cover and protecting 27 % of its land and 28 % of its ocean, all of this while increasing its Gross Domestic Product and being classified consistently as one of the happiest countries in the planet, represents a unique success story at the national level that has inspired many other countries to follow this path towards sustainable development. The creation of Costa Rica's national PES scheme contributed significantly to the country's conservation and restoration of its natural capital, providing a myriad of benefits to Costa Ricans and the global community. The proposal of a PES 2.0 through the NCT represents a significant evolution, not only for Costa Rica but also as a replicable model for other countries seeking to align economic development with ecological stewardship.

A central contribution of this proposed scheme lies in the new methodological approach to designing CATs. Grounded in Ostrom's design principles, our approach systematizes the steps needed to establish polycentric, inclusive, and adaptive institutions for managing shared natural capital. We also provided the first comprehensive assessment of Costa Rica's natural capital value. Our findings, valuing annual ecosystem service flows at approximately \$14.5 billion and the net present value at \$845 billion, demonstrate the significant contribution that terrestrial and marine ecosystems make to well-being and the economy. Our estimates provide a powerful evidence base for policy design, fiscal planning, and investment prioritization.

Moreover, the financial innovations proposed under the PES 2.0 mark another critical advance. The inclusion of green taxes on high-impact sectors such as pineapples and plastics, the repurposing of harmful subsidies, updated user fees, and the creation of the NCBCR with tradable NCCs all diversify funding sources. These instruments aim to reduce dependence on volatile revenue streams, such as the fuel tax, while embedding the true costs of environmental degradation into market transactions. Furthermore, the suggested evolution of the PES scheme provides a higher level of participation from a wide variety of social actors, with a focus on local communities who are the ones who depend more on nature for their well-being, and who can be direct stewards of the country's natural resources, creating a new generation of blue and green jobs.

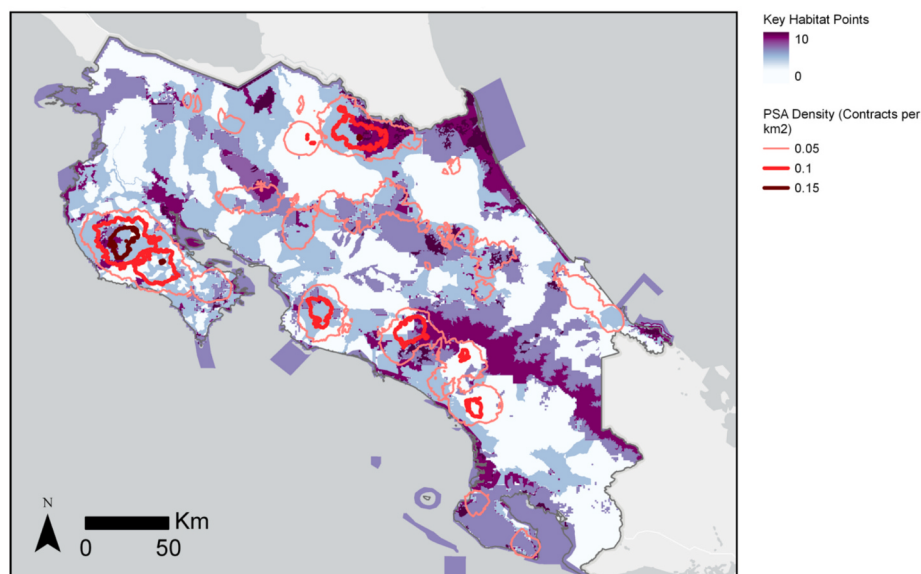


Fig. 6. Map of key habitat bonus points (purples). Polygons representing density of PSA contracts starting between 2016 and 2018 are overlaid (reds). We estimated density of PSAs using a moving 10 km radius across the country.

The implementation of the ideas we proposed here will potentially face important political discussions among stakeholders, and therefore we do not expect that the entire institutional arrangements and financial mechanisms described here will have an equal political viability. Our goal is to expand considerably the discussion of how one of the most successful PES programs in the world can evolve to address new socio-economic and environmental challenges that are now much better understood in a systemic and transdisciplinary way. The success of PES 2.0 will depend on stakeholders' ability to transcend sectoral silos and recognize the needs and opportunities that stewardship-based systems—such as the one proposed here—offer for advancing low-emissions, nature-positive development.

CRedit authorship contribution statement

Marcello Hernández-Blanco: Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Robert Costanza:** Writing – review & editing, Writing – original draft, Supervision, Formal analysis, Conceptualization. **Monica Moritsch:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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.

Acknowledgements

We are grateful to the team of experts who provided key inputs that informed the ideas presented in this paper, in particular María José González-Bernat, Mariano Castro-Jiménez, Julio Espinosa-Rodríguez, and Francisco Pacheco-Jiménez. We also thank the UNDP-BIOFIN team—Ana Lucía Orozco-Rubio and Fernando Rodríguez-Garro—and the FONAFIFO team—Gilmar Navarrete-Chacón and Jorge Mario Rodríguez-Zúñiga—for their valuable support. Special thanks are extended to former Minister of Environment of Costa Rica Carlos Manuel Rodríguez for his enduring vision and leadership regarding Costa Rica's PES scheme. Finally, we are grateful to the two anonymous reviewers whose insightful comments greatly improved an earlier version of this manuscript.

Funding

This research was funded by the Biodiversity Finance Initiative from the United Nations Development Program (contract #254 IC-2019-095).

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ecoser.2025.101787>.

Data availability

Data will be made available on request.

References

- Atkins, P. W., Wilson, D. S., & Hayes, S. C. (2019). *Prosocial: Using evolutionary science to build productive, equitable, and collaborative groups*. New Harbinger Publications.
- Aylward, B., Echeverría, J., & Barbier, E. (1995). *Economic incentives for watershed protection: A report on an ongoing study of Arenal, CR* (CREED Working Paper Series #3).

- Barbier, E. (2022). *Economics for a fragile planet*. Cambridge University Press. https://books.google.com/books?hl=en&lr=&id=19teEAAQBAJ&oi=fnd&pg=PR8&dq=economics+of+a+fragile+planet&ots=CrwCxG8lo_&sig=dQmJ1fgMMUXQnECjaMCoM0-EfEA.
- Beckenkamp, M., 2012. *Institutions and trust in commons: dealing with social dilemmas. The Wealth of the Commons—A World beyond Market and State*. Leverlars Press.
- Bovarnick, A., Knight, C., Stephenson, J., 2010. *Habitat Banking in Latin America and Caribbean: a Feasibility Assessment*. United Nations Development Programme.
- Brander, L.M., De Groot, R., Schägner, J.P., Guisado-Goni, V., Van't Hoff, V., Solomonides, S., McVittie, A., Eppink, F., Sposato, M., Do, L., 2024. Economic values for ecosystem services: a global synthesis and way forward. *Ecosyst. Serv.* 66, 101606.
- Bromley, D.W., 1992. The commons, property, and common-property regimes. *Making the Commons Work* 3–16.
- Carazo, E., & Aravena, J. (2016). *Condiciones de producción, impacto humano y ambiental en el sector pino en Costa Rica*. OXFAM Germany.
- Carranza, C., Aylward, B., Echeverría, J., Tosi, J., & Mejías, R. (1996). *Valoración de los servicios ambientales de los bosques de Costa Rica*. Centro Científico Tropical.
- Contraloría General de la República de CR. (2011). *Informe acerca de los efectos del Programa de Pago por Servicios Ambientales (PSA) implementado por el Estado costarricense*.
- Costanza, R., Atkins, P.W., Hernandez-Blanco, M., Kubiszewski, I., 2020. Common asset trusts to effectively steward natural capital and ecosystem services at multiple scales. *J. Environ. Manage.* 280, 111801.
- Costanza, R., de Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., Farber, S., Grasso, M., 2017. Twenty years of ecosystem services: how far have we come and how far do we still need to go? *Ecosyst. Serv.* 28 (Part A), 1–16. <https://doi.org/10.1016/j.ecoser.2017.09.008>.
- Costanza, R., Kubiszewski, I., Stoeckl, N., Kompas, T., 2021. Pluralistic discounting recognizing different capital contributions: an example estimating the net present value of global ecosystem services. *Ecol. Econ.* 183, 106961.
- Daniels, A.E., Bagstad, K., Esposito, V., Moulart, A., Rodriguez, C.M., 2010. Understanding the impacts of Costa Rica's PES: are we asking the right questions? *Ecol. Econ.* 69 (11), 2116–2126.
- Engel, S., 2016. The devil in the detail: a practical guide on designing payments for environmental services. *Int. Rev. Environ. Resour. Econ.* 9 (1–2), 131–177.
- Engel, S., Pagiola, S., Wunder, S., 2008. Designing payments for environmental services in theory and practice: an overview of the issues. *Ecol. Econ.* 65 (4), 663–674.
- Farley, J., Costanza, R., Flomenhoft, G., Kirk, D., 2015. The Vermont Common Assets Trust: an institution for sustainable, just and efficient resource allocation. *Ecol. Econ.* 109, 71–79.
- FONAFIFO. (2012). *Costa Rica: Bosques tropicales un motor del crecimiento verde*.
- FONAFIFO. (2020). *Fuentes de financiamiento y destino de los fondos del programa de PSA*.
- Green, A., 2006. You can't pay them enough: subsidies, environmental law, and social norms. *Harv. Envtl. L. Rev.* 30, 407.
- Hernández-Blanco, M., 2019. *The Treasure of the Commons: Valuing and Managing Natural Capital in Costa Rica* [PhD Thesis]. The Australian National University (Australia).
- Hernández-Blanco, M., & Chavez, N. (2022). *Potential impact of agrochemicals on natural capital and its ecosystem services in Costa Rica*. PNUD.
- Hernández-Blanco, M., Costanza, R., Cifuentes-Jara, M., 2021. Economic valuation of the ecosystem services provided by the mangroves of the Gulf of Nicoya using a hybrid methodology. *Ecosyst. Serv.* 49, 101258.
- Hernández-Blanco, M., Pacheco-Jimenez, J.F., Elizondo-Barboza, H., 2020. *Propuesta para la actualización de tarifas para áreas Silvestres Protegidas*. BIOFIN-UNDP.
- Kadambe, S., Segerson, K., 1998. On the role of fines as an environmental enforcement tool. *J. Environ. Plan. Manag.* 41 (2), 217–226. <https://doi.org/10.1080/09640569811722>.
- Kaiser, J., Haase, D., & Krueger, T. (2021). Payments for ecosystem services: A review of definitions, the role of spatial scales, and critique. <https://edoc.hu-berlin.de/handle/18452/23868>.
- Kappelle, M., 2016. *Costa Rican ecosystems*. The University of Chicago Press.
- Kemkes, R.J., Farley, J., Koliba, C.J., 2010. Determining when payments are an effective policy approach to ecosystem service provision. *Ecol. Econ.* 69 (11), 2069–2074.
- Lau, W.W., 2013. Beyond carbon: Conceptualizing payments for ecosystem services in blue forests on carbon and other marine and coastal ecosystem services. *Ocean Coast. Manage.* 83, 5–14.
- Locke, H., Rockström, J., Bakker, P., Bapna, M., Gough, M., Hilty, J., Lambertini, M., Morris, J., Polman, P., & Rodriguez, C. M. (2021). *A nature-positive world: The global goal for nature*. <https://library.wcs.org/doi/ctl/view/mid/33065/pubid/DMX3974900000.aspx>.
- Mandle, L., Ouyang, Z., Salzman, J., Daily, G., 2019. *Green Growth that Works*. Island Press.
- MINAE. (2015). *Política nacional de biodiversidad 2015-2030 Costa Rica*. Programa de las Naciones Unidas para el Desarrollo (PNUD).
- Minae, Sinac, Conagebio, & Fonafifo. (2018). *Resumen del Sexto Informe Nacional de Costa Rica ante el Convenio de Diversidad Biológica*. Programa de Naciones Unidas para el Desarrollo.
- Navarrete, G. (2020, September 23). *Estimación de los montos a pagar por PSA* [Telephone].
- Ostrom, E., 1990. *Governing the commons: the evolution of institutions for collective action*. Cambridge University Press.
- Ostrom, E. (2005). *Understanding institutional diversity* Princeton University press. New Jersey, pp. 393–432.

- Ostrom, E., 2008. The challenge of common-pool resources. *Environ. Sci. Policy Sustain. Dev.* 50 (4), 8–21.
- Pacheco, J. F., Hernández-Blanco, M., Rodríguez, F., Córdoba, M., & Elizondo, H. (2018). A law proposal to tax plastic in Costa Rica. UNDP.
- Pagiola, S., 2008. Payments for environmental services in Costa Rica. *Ecol. Econ.* 65 (4), 712–724.
- Pascual, U., Balvanera, P., Anderson, C.B., Chaplin-Kramer, R., Christie, M., González-Jiménez, D., Martin, A., Raymond, C.M., Termansen, M., Vatn, A., 2023. Diverse values of nature for sustainability. *Nature* 620 (7975), 813–823.
- Pascual, U., Balvanera, P., Christie, M., Baptiste, B., González-Jiménez, D., Anderson, C. B., Athayde, S., Barton, D. N., Chaplin-Kramer, R., Jacobs, S., Kelemen, K., Kumar, R., Lazos, E., Martin, A., Mwampamba, T. H., Nakangu, B., O'Farrell, P., Raymond, C. M., Subramanian, S. M., Vatn, A. (2022). Summary for Policymakers of the Methodological Assessment Report on the Diverse Values and Valuation of Nature of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat.
- Pearce, D. (2003). Environmentally harmful subsidies: Barriers to sustainable development. *Environmentally Harmful Subsidies: Policy Issues and Challenges*. OECD, Paris, pp. 9–32.
- Porras, I., Miranda, M., Barton, D., Chacón, A., 2012. *DE RIO a RIO+:* Lecciones de 20 años de experiencia en servicios ambientales en Costa Rica. International Institute for Environment and Development, Londres.
- Rea, A.W., Munns Jr, W.R., 2017. The value of nature: Economic, intrinsic, or both? *Integr. Environ. Assess. Manag.* 13 (5), 953.
- Robalino, J., Sandoval, C., Villalobos, L., Alpizar, F., 2014. Local Effects of Payments for Environmental Services on Poverty. *Environment for Development*.
- Robalino, J., & Villalobos, L. (2014). Efectividad de las políticas de conservación en Costa Rica. Programa Estado de la Nación.
- Rodríguez, S. (2020a). *COVID hit to Costa Rica's gasoline tax stalls funding for forests*. Reuters. <https://www.reuters.com/article/us-costa-rica-forests-environment/covid-hit-to-costa-ricas-gasoline-tax-stalls-funding-for-forests-idUSKBN25U213?fbclid=IwAR0VtKPqYtIwDzeIrUAlN53GfBIYEBPZgTqT-FrYorBLaCQc799LQ4cmMs>.
- Rodríguez, S. (2020b). *Por baja recaudación fiscal, nuevo presupuesto rebaja \$1.012 millones a protección de bosques*. Ameliarueda.Com. <https://www.ameliarueda.com/nota/por-baja-recaudacion-fiscal-presupuesto-rebaja-1.012-millones-bosques?fbclid=IwAR2mLwtNiqLeNqperVrL7181MRlAzPaWf1vPREVJFh8GvVzdm8pydzUPGE>.
- Rodríguez-Garro, F. (2020). Elementos básicos de una reforma fiscal verde: Propuesta para Costa Rica. Programa de Naciones Unidas para el Desarrollo.
- Rosenberger, R.S., Stanley, T.D., 2006. Measurement, generalization, and publication: sources of error in benefit transfers and their management. *Ecol. Econ.* 60 (2), 372–378.
- Sanchez-Azofeifa, G.A., Pfaff, A., Robalino, J.A., Boomhower, J.P., 2007. Costa Rica's payment for environmental services program: Intention, implementation, and impact. *Conserv. Biol.* 21 (5), 1165–1173.
- Sax, J.L., 1970. The public trust doctrine in natural resource law: Effective judicial intervention. *Mich. Law Rev.* 68 (3), 471–566.
- Schomers, S., Matzdorf, B., 2013. Payments for ecosystem services: a review and comparison of developing and industrialized countries. *Ecosyst. Serv.* 6, 16–30. <https://doi.org/10.1016/j.ecoser.2013.01.002>.
- SETENA. (2020). *Composición de expedientes*.
- TEEB. (2010). *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB*.
- Umaña, A. (2020, January 3). *PSA en Costa Rica* [Skype].
- U.S. Fish & Wildlife Service. (2019). *Conservation Banking—Incentives for Stewardship*.
- van Beers, C., van den Bergh, J.C., 2001. Perseverance of perverse subsidies and their impact on trade and environment. *Ecol. Econ.* 36 (3), 475–486.
- Vargas, E. (2021). *Uso aparente de plaguicidas en la agricultura de Costa Rica*. PNUD. <https://impactoplaguicidas.cr/repositorio/analisis-sobre-el-uso-de-plaguicidas-en-la-agricultura-en-costa-rica-2/>.
- Wilson, D.S., Ostrom, E., Cox, M.E., 2013. Generalizing the core design principles for the efficacy of groups. *J. Econ. Behav. Organ.* 90, S21–S32.
- Wunder, S., Engel, S., Pagiola, S., 2008. Taking stock: a comparative analysis of payments for environmental services programs in developed and developing countries. *Ecol. Econ.* 65 (4), 834–852.