ENVIRONMENT AND DEVELOPMENT

Get the science right when paying for nature's services

Few projects adequately address design and evaluation

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Payments for Ecosystem Services (PES) mechanisms leverage economic and social incentives to shape how people influence natural processes and achieve conservation and sustainability goals. Beneficiaries of nature's goods and services pay owners or stewards of ecosystems that produce those services, with payments contingent on service provision (*1*, *2*). Integrating scientific knowledge and methods into PES is critical (*3*, *4*). Yet many projects are based on weak scientific foundations, and effectiveness is rarely evaluated with the rigor necessary for scaling up and understanding the importance of these approaches as policy instruments and conservation tools (*2*, *5*, *6*). Part of the problem is the lack of simple, yet rigorous, scientific principles and guidelines to accommodate PES design and guide research and analyses that foster evaluations of effectiveness (*4*). As scientists and practitioners from government, nongovernment, academic, and finance institutions, we propose a set of such guidelines and principles.

POLICY

Because PES mechanisms directly link payments to environmental performance, they are often viewed as more efficient alternatives and complements to traditional regulatory or protection-based conservation approaches (*5*). Unlike the polluter-pays principle common to many environmental interventions, in PES, beneficiaries pay. PES beneficiaries can be governments, nongovernmental organizations, or private entities; owners or stewards can be governments, private, or communal land holders. PES interventions are increasingly used for securing nature's services while conserving species, curtailing deforestation, mitigating climate change, and pursuing social objectives such as sustainable livelihoods and poverty alleviation (*3*). Given the centrality of the ecosystem service framework to the Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES), the Convention on Biological Diversity, and the United Nations Sustainable Development Goals, and the expectation of innovative financing mechanisms to achieve the Aichi Targets (*6*), ensuring the scientific integrity of PES will be extraordinarily important.

SCIENCE, PRACTICE, AND THE GAP. Irrespective of scale or complexity, whether national [e.g., Costa Rica's PES program (*7*)], regional [e.g., New York City's and Munich's water supply (*8*)], or smaller-scale efforts [e.g., community-scale biodiversity conservation in Cambodia (*9*)], identifying whom to compensate, what to pay (i.e., money or other forms of incentives), how much to pay, the mechanisms for payment, and verification of service delivery are essential social and economic components to PES (*10*, *11*).

Although getting the social science right is critical for PES, we focus on the natural science because of growing concerns over scientific weaknesses (*2*, *5*, *6*, *12*). Success of PES initiatives is reliant upon scientific knowledge of the ecosystem services of interest, methods for verifying delivery of services, establishing a relationship between natural resource practices and the generation of a service, the spatial and temporal scale at which the service is produced, and factors that may threaten the service or trade-offs with other beneficial nontarget services (*13*). If any of these basic principles are not considered, the ability of PES mechanisms to generate ecological and social benefits may be undermined (*3*, *14*).

However, the scientific content of PES programs and projects varies enormously. Some of this is due to environmental urgency or social and political expediency that can promote implementation in advance of scientific analyses (*13*, *15*), the lack of sufficient scientific knowledge and data, or weak capacity and resources to monitor results and assess compliance (*4*, *9*). Practitioners are frequently better attuned than scientists to limited budgets, available technical capacity in environmental science, and knowledge gaps. Thus, disconnects often exist between science and practices developed by the research community and what is accessible and feasible in the field.

Reviews of designs, metrics, analytical methods, and perceptions of PES interventions reveal a need for greater coordination among scientific researchers, practitioners, ecosystem service providers, and beneficiaries (*5*). Collecting metrics for ecosystem services varies enormously in cost, utility, and complexity. Without tools for identifying the best and most affordable metrics, PES proponents may struggle to collect scientifically meaningful, cost-effective baseline data and implement effective monitoring programs.

We developed a framework for integrating natural science into PES based on six natural science principles encompassing 33 guidelines (see the table and the supplementary materials). Based on the work on these issues in Asia, Africa, Europe, North America, South America, and Australia, the principles are designed to be applicable across a range of ecological and social contexts. Although these principles were developed with a focus on PES, they may be useful for a range of market-based conservation instruments hampered by limited scientific evidence and empirical data on effectiveness (*6*). Many may apply to ecosystem service projects that do not include payment or incentives mechanisms.

We examined the degree to which active PES projects spanning several types of ecosystem services followed the principles and guidelines (see the supplementary materials). Of the 118 projects we examined, 60% lacked adherence to the four principles (see table) deemed essential to ensuring scientific integrity in environmental interventions: (i) baseline data, (ii) monitoring of key environmental factors and services, (iii) recognizing that ecosystems are dynamic, and (iv) inclusion of metrics, specifically on risks such as climate change or invasive species.

The context-specific nature and market uncertainties surrounding PES (*16*) may make accommodating even these basic principles difficult. Consideration of the principles is recommended even if resources or capacity do not permit extensive scientific measurement or analyses. The principles are designed so that they are not onerous to

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Natural-science principles and guidelines for PES interventions

For an intervention to be successful, basic guidelines (blue) must be followed. Desirable guidelines (orange) should be followed. See the supplementary materials for further details.

PRINCIPLE: Dynamics

OBJECTIVE: Ensure project capacity to adapt to dynamic natural and anthropogenic processes.

SCIENTIFIC GUIDELINES:

- Identify key services for each service type beyond target services.
- Identify spatiotemporal scales of targeted services.
- Identify data needs, resources, and gaps.
- Identify stressors and their spatiotemporal variability.
- Identify and forecast trends in endogenous and exogenous threats.
- Identify services' production functions and sensitivities.
- Determine trade-offs and synergies among services.
- Determine how functional diversity influences resilience.

PRINCIPLE: Baseline

OBJECTIVE: Document initial conditions.

SCIENTIFIC GUIDELINES:

- Measure influences of interventions on services.
- Measure status and trends of non-target services.
- Ensure that measurements are feasible given resources.
- Assess initial state of exogenous and endogenous threats to services.
- Measure factors important for forecasting service trends.

PRINCIPLE: Multiple Services

OBJECTIVE: Recognize trade-offs and synergies among services.

SCIENTIFIC GUIDELINES:

- Assess how intervention influences the other services.
- Avoid "double counting."
- Assess impacts of intervention on non-target services.

PRINCIPLE: Monitoring

OBJECTIVE: Track factors necessary for management, trade, forecasting, and assessment.

SCIENTIFIC GUIDELINES:

- Quantify deliverables associated with target services.
- Identify spatiotemporal scales in advance of implementation.
- Use established methods/protocols and best practices for monitoring.
- Estimate uncertainties.
- Monitoring should inform decision-making.
- Monitoring should detect potential changes in baseline conditions.
- Monitor non-target services that influence target services.

PRINCIPLE: Metrics

OBJECTIVE: Robust, efficient, and versatile methods for procuring data.

SCIENTIFIC GUIDELINES:

- Must be relevant, reliable, and appropriate in scale.
- Should comply with voluntary standards, certification and regulations.
- Should reflect spatiotemporal scales as identified in Dynamics.
- Optimize balance between precision and simplicity.
- Assess progress (in conjunction with Baseline and Monitoring).
- Establish benchmarks (in conjunction with Baseline and Monitoring).
- Should measure both absolute changes and changes in trends.
- Preferentially selected to allow comparisons across service types.
- Assess how services influence each other.

PRINCIPLE: Ecological Sustainability

OBJECTIVE: Insure project durability and sustainability.

SCIENTIFIC GUIDELINES:

- Estimate short-term and long-term project or program performance.

address but, if considered to whatever degree possible, can improve the likelihood of project success, support adaptive management, help identify important knowledge gaps and potential areas of concern, and increase investor confidence. The guidelines thus serve as a reference for evaluating project design and means for comparisons with other projects. There are also benefits to including traditional knowledge (*17*) that further iterations of these guidelines could accommodate.

ESTABLISHING STANDARDS. Given the increasing importance placed on PES mechanisms to address environmental externalities and resolve conservation and development trade-offs (*1*, *4*, *18*), international commitment is needed from donors, researchers, and practitioners to test, refine, disseminate, and improve upon scientific guidelines and further develop tools, metrics, and methods. An international neutral body, such as the IPBES, would be an ideal coordinator for regular review and assessment of science guidelines for PES and could establish an expert review board to oversee guidelines for improving PES design and implementation. In the interim, those developing PES or similar projects can follow our guidelines and report on their utility and areas for improvement. Through this process, PES project standards that provide technical guidance to project developers, assurance to investors, and templates for reporting will emerge as they have for other environmental programs, such as the Verified Carbon Standard; the Climate, Community, and Biodiversity Alliance; the Business and Biodiversity Offsets Program; and voluntary standards maintained by the International Organization for Standardization.

Challenges will remain for PES, such as pressure for simplicity and quick fixes, contending with competing goals and multiple objectives, and dealing with policy- and decision-makers who often work at scales and time frames different from those of importance to scientists. Too often, science and practice are poorly linked in environmental interventions. An inclusive process in developing, testing, and refining basic science principles will ensure greater success of promising new approaches. ■

SUPPLEMENTARY MATERIALS

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REFERENCES AND NOTES

1. G. C. Daily, P. A. Matson, *Proc. Natl. Acad. Sci. U.S.A.* **105**, 9455 (2008).
2. S. Wunder, S. Engel, S. Pagiola, *Ecol. Econ.* **65**, 834 (2008).
3. J. C. Ingram *et al.*, *Ecosystem Services* **7**, 10 (2014).
4. P. J. Ferraro, S. K. Pattanayak, *PLOS Biol.* **4**, e105 (2006).
5. S. K. Pattanayak, S. Wunder, P. J. Ferraro, *Rev. Environ. Econ. Policy* **4**, 254 (2010).
6. R. Pirard, R. Lapeyre, *Ecosystem Services* **9**, 106 (2014).
7. P. Ina, Payments for environmental services: Lessons from the Costa Rican PES programme. IIED (2013). http://pubs.iied.org/pdfs/G03561.pdf
8. G. Grolleau, L. M. J. McCann, *Ecol. Econ.* **76**, 87 (2012).
9. T. Clements *et al.*, *Ecol. Econ.* **69**, 1283 (2010).
10. R. Muradian *et al.*, *Conserv. Lett.* **6**, 274 (2013).
11. S. Wunder, *Conserv. Lett.* **6**, 230 (2013).
12. R. Yin, T. Liu, S. Yao, M. Zhao, *For. Policy Econ.* **35**, 66 (2013).
13. A. P. Kinzig *et al.*, *Science* **334**, 603 (2011).
14. P. Kareiva, A. Chang, M. Marvier, *Science* **321**, 1638 (2008).
15. K. Ellison, *Front. Ecol. Environ* **7**, 60 (2009).
16. R. Muradian, E. Corbera, U. Pascual, N. Kosoy, P. H. May, *Ecol. Econ.* **69**, 1202 (2010).
17. W. J. Sutherland, T. A. Gardner, L. J. Haider, L. V. Dicks, *Oryx* **48**, 1 (2014).
18. J. Farley, R. Costanza, *Ecol. Econ.* **69**, 2060 (2010).

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