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Connecting ecosystem services science and policy in the field

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Conservation and provision of ecosystem services (ES) have been adopted as high-level policy in many countries, yet there has been surprisingly little application of these broad policies in the field; for example, ES are rarely considered in permit issuance or other discrete agency actions. This large implementation gap arises in part because the science that drove general policy interest in ES differs from the science needed for practical application. A better understanding of the environmental policy toolkit can guide more effective research to support agency decisions. Here, we outline the framework used to teach environmental policy instruments through the "Five P's": prescription, property, penalty, payment, and persuasion. We then discuss the discrete ES research required to effectively implement each tool. To support greater conservation of ES in the field, scientists and policy makers must clearly recognize what each needs from the other.

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Despite its influence on broad policy goals, ecosystem services (ES) science has had little effect on governmental decision making in the field. A mere two decades ago, "ecosystem services" was an obscure term in science and policy; for example, in 1997, only six scholarly articles contained the term "ecosystem services". Interest in ES has exploded since then (Costanza *et al*. 2017); in 2019, over 4000 research articles spanning fields from ecology and economics to hydrology, psychology, and human health included the term. Thanks in large part to this intense research effort, numerous governance institutions have embraced conservation of ES as a broad policy goal (Ruhl and Salzman 2007; Scarlett and Boyd 2015), but this goal is mostly aspirational, as consideration of ES rarely influences permitting and other day-to-day decisions carried out by government agencies (Salzman *et al*. 2014; Posner *et al*. 2016; Sharon *et al*. 2018; Bell-James 2019; Kieslich and Salles 2021).

In a nutshell:

- There is a persistent gap between high-level policies for conservation and practical implementation of ecosystem services (ES)
- Agencies rarely consider ES in permitting and other field-level decisions
- There is a need for more research specifically designed to support agency decisions
- Understanding the environmental policy toolkit – the "Five P's" – will guide more effective research design
- We show the specific research needs for each policy tool that will drive conservation of ES in the field

What explains this implementation gap? Why has there been such success linking major scientific research to high-level policy pronouncements about ES on the one hand, yet so little integration of ES in practical decision making? We argue that the research that drove general policy interest in ES – where they come from and how much they are worth – is not the same kind of research needed to drive implementation on the ground. Agency statements about the importance of ES are not self-implementing. They take effect in the field through specific policy tools, such as permits or subsidies, and require more ES research for widespread implementation (Bai *et al*. 2018; Chen *et al*. 2019; Chan and Satterfield 2020).

On the basis of their study of the ES science–policy interface, Posner *et al*. (2016) argued that ES science will have greater impact on policy if scientists better understand decision-making processes. To that end, this article is directed primarily toward scientists, with the goal of demonstrating how their research can support specific policy tools like environmental permitting or urban planning. We explain the environmental law and policy toolkit, highlighting its applications and the specific ES research questions demanded by each tool.

The ES implementation gap

The rapid expansion of ES research in the scientific community drove the rapid endorsement of ES conservation in

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the policy community (Ruhl and Salzman 2007). The 2005 Millennium Ecosystem Assessment spoke directly to the policy community, assessing the state of the world's ecosystems through the metric of service provision (MA 2005). Governments took notice (Reid 2006) and have since launched an international effort to inform decision making through regular scientific assessments (IPBES 2019).

In the US, the Army Corps of Engineers and the Environmental Protection Agency issued joint regulations in 2008 stating that they would consider the impacts to ES of their decisions regarding wetland development permits (USACE/EPA 2008); likewise, the US Forest Service (USFS) adopted a regulation in 2012 on the importance of managing ES in national forest management plans (USFS 2012). The EU has adopted similar policies, such as the EU Commission's 2013 green infrastructure policy, which incorporates ES provision as the primary goal (EC 2013).

The scientific community's success in advancing ES at high policy levels, however, has not translated down to the scale of day-to-day practical implementation (Carpenter *et al*. 2009; Olander *et al*. 2017). To be sure, political opposition, inadequate funding, institutional fragmentation, and agency inertia have hindered implementation of robust ES protections (Arnold 2007; Salzman *et al*. 2014; Scarlett and Boyd 2015). However, the failure to move from policy adoption to effective field-scale implementation is not the result of these obstacles alone – the focus of scientific research plays a role as well. Natural and social scientists must work together to shift from establishing the *general importance* of ES provision to answering *practical application* questions, such as how to measure the impact of a development on the flow of services to specific beneficiaries, and how and where to compensate for losses (Chan and Satterfield 2020).

This type of targeted science has been developed for "payment for environmental services" (PES) programs (Liu and Yang 2013; Zheng *et al*. 2013), but much less so to support decision making in other contexts. For example, although EU Commission staff have issued guidelines for implementing the 2013 green infrastructure policy (EC 2019), explicit implementation of ES goals and metrics in local urban plans and policies has been slow (Cortinovis and Geneletti 2019). Similarly, although the USFS's 2012 planning rule adopts an ES framework, national forest plans issued since then contain almost no mention of ES beyond those included in previous plans: timber, water, and recreation (Ruhl and Salzman 2020). The same is true for methods and metrics for measuring ES losses from wetlands mitigation (Womble and Doyle 2012; Adusumilli 2015).

Scientists who can view the world from the same perspective as regulators and planners can better design relevant research. Equally, policy actors can better articulate, and then fund, the kind of scientific research that supports discrete decisions in the field (Posner *et al*. 2016). In short, those working in the ES policy community need to think more like scientists, and those working in the ES science community need to think more like policy actors.

We contribute toward this mutual learning process by explaining the basic toolkit used to implement environmental protection in the field. We then demonstrate the type of research, both natural and social science, to support use of those tools.

An ES policy toolkit primer

Passing an environmental law or issuing a high-level policy that promotes ES will not in itself improve the provision of ES. To have an effect on the ground, an ES policy must be translated into actionable law (such as statutes and agency regulations) and then individually applied in discrete decisions (such as issuance of permits).

Although environmental law can be dauntingly complex, the toolkit used to apply policy and law can be distilled to just five instruments. Law schools typically teach the environmental policy toolkit through the mnemonic of the "Five P's": prescription, property, penalty, payment, and persuasion (Salzman 2013). Used individually or in combination, these tools provide the *regulatory* capacity to protect and enhance flows of ES to people – so long as the appropriate science is available. The Five P's are described individually in the following sections.

Prescription

Prescriptions either prohibit a specified action or mandate requirements. Prescriptive regulations are the foundation of most environmental law globally. Laws ban wide classes of actions *unless* a governing authority has granted prior approval through the issuance of a permit. For example, state and local regulations frequently restrict development in coastal dune areas to preserve flood control and other ES.

Property

A classic solution to overconsumption of common resources is to privatize the resource by creating property rights. Clear and enforceable property rights can promote market forces to encourage environmentally protective behavior. The property tools most common in the ES setting are mitigation banking offsets, which permit land development in exchange for purchasing a government-created property in the form of tradable credits of restored habitat.

Penalty

Fines and liability rules require actors who cause harm to property or resources to pay for the damage, restore the damaged area, or both. For example, statutory regimes governing oil spills and contaminated lands can require responsible parties pay compensation for the lost and damaged natural resources, including the loss of ES. Local regulators can levy impact fees on development that will harm ES resources.

Payment

The flip side of penalties, payments (money or other incentives) are provided by compensation programs to owners of natural capital in exchange for preserving or improving flows of ES. This is the core approach of PES programs, such as paying farmers to fallow land for migratory bird habitat. Although PES has dominated policy attention with regard to ES, it is effective only under limited conditions (Salzman *et al.* 2018).

Persuasion

Persuasion programs rely on the generation and analysis of information to guide behavior. For instance, the US National Environmental Policy Act requires federal agencies to evaluate the environmental impacts of proposed major actions expected to have substantial adverse environmental consequences. Agencies can use these analyses to identify loss and gain of ES from different alternative actions.

Summary

A number of important policy mechanisms combine these tools. For example, habitat offset programs link prescription and property: development of a species' habitat is prohibited unless the developer obtains a permit (prescription), and the permit requires the developer to purchase an adequate number of government-created offset credits (property) for restored habitat.

To visualize the Five P's in action, consider the tools available for a government agency to protect an endangered bird species. Prescriptive regulation might ban actions that harm the birds or degrade their habitat without obtaining a permit. Property rights could be used to create a trading program using breeding pairs as the currency of exchange – landowners who modified their habitat could mitigate their actions by purchasing offset credits of habitat for breeding pairs established elsewhere. Financial penalties could be imposed on landowners who make habitat less suitable to local endangered species. Conversely, payments could be made to landowners who improve habitat to make it more suitable to breeding pairs. Likewise, regional planners could use persuasion by mapping where voluntary actions would most enhance the birds' habitat.

The research needs of the policy toolkit

With an understanding of the policy toolkit, we can now consider the natural and social sciences needed to incorporate ES meaningfully into operational practices. Natural science researchers can inform an urban planner how much a particular component of green infrastructure can provide ES for a specific community, but only social science research can reveal the community priorities, resulting valuations, and distributional economic and cultural effects (Salzman *et al.* 2014).

Implementing any of the Five P's involves considerable risk, because both ecological and social systems are highly dynamic and unpredictable (Suding *et al.* 2016). While economists and regulators typically acknowledge biophysical risk (for example, it is often factored into the number of credits required to mitigate for wetland losses), calculations are rather ad hoc and not well supported by science (Tallis *et al.* 2015; Zambello *et al.* 2019). Science is therefore also needed to inform these risk calculations for application in the field. For instance, how does the risk of failure vary as a function of the type of restoration and management action, the biophysical context, and likely changes in climate and land use (Palmer *et al.* 2014)? Even if the biophysical outcome is as hoped for, how might social, cultural, and economic changes prevent the intended supply of ES to the intended beneficiaries (Kapustka *et al.* 2016)? Research questions like these cannot be answered by the science that supported adoption of high-level ES policy goals. To help close that gap, we present a range of resource management examples below to illustrate how each policy tool dictates a particular management strategy with information needs, and therefore particular ES research questions.

Prescription

Under the US Clean Water Act, developments that affect wetlands and streams must avoid, minimize, and then mitigate ecological losses (Salzman and Ruhl 2000; Lave and Doyle

Figure 1. Regulatory programs protect natural resources, such as this coastal marsh on a popular barrier island adjacent to Bogue Sound in North Carolina, that provide ecosystem services (ES) to local and distant populations. Decisions regarding avoidance, minimization, and mitigation of impacts to ES depend on research that links source to beneficiary and measures impacts at the appropriate scale.

2021). To implement that hierarchy with attention to ES provision, the regulator needs to know both the biophysical loss of discrete services from filling a wetland and who is losing the benefit of each service. For example, if the wetland filters a drinking water supply, will the loss of 20 ha or 200 ha require a downstream community to begin treating its water supply to comply with drinking water standards (Figure 1)? The vast majority of such regulatory decisions occur at the margin (eg what the impacts of removing 25 ha, as opposed to 15 ha, of forested land from an urban area might be). The possibility of nonlinear threshold effects from the accumulation of many field-level decisions makes research at this scale crucial for decision makers (Garmestani 2014).

The metrics for measurement of loss and gain are particularly important. Although academic and agency researchers have proposed many ES indicators (Czúcz *et al.* 2018; Ma *et al.* 2019), few are relevant to policy formulation (Mandle *et al.* 2021). For instance, hectares of wetland loss or water holding capacity do not provide information about the impacts of the development on specific human communities due to changes in provision of their water services – who will be affected and by how much (Mandle *et al.* 2021). More useful are benefit-relevant indicators, such as assessment of the impacts of reduced sediment capture or water storage on water quality and flood control, respectively, for downstream communities (Watson *et al.* 2019; Mazzotta *et al.* 2019; Olander *et al.* 2018). Social science research can build on these indicators to help regulators understand how people value different ES and the equity effects of ES resource depletion.

Figure 2. Some regulatory programs allow mitigation requirements to be satisfied by purchasing "credits" from a "banking" project that has restored a similar resource. Calculating the required credits must account for the risks that the restored resource, such as this streambank below a waterfall on the Cumberland Plateau in Tennessee, will degrade due to factors like climate change and nearby land uses.

Taken together, indicators and valuation make clear the costs and benefits of different development permit conditions, showing how changes in ES will benefit or harm people and informing field-scale decisions, such as whether to grant a permit or development conditions. More research is required across a broad array of ES resources to identify indicators that are credible scientifically, relatively easy to calculate using existing information, relevant in different spatial and temporal contexts, and widely acceptable to stakeholders (van Oudenhoven *et al.* 2018). Research can also help incorporate variability in the risk of reductions in or loss of ES into the regulatory response concerning a particular ecosystem and beneficiary community.

Property

Under the US streambank mitigation offset program, entrepreneurs who have restored streambanks in the watershed can certify "mitigation banks", whereby the government grants them property rights in the form of offset credits that can then be sold to developers to offset the impacts of their projects on streams (Salzman and Ruhl 2000; Lave and Doyle 2021). In approving mitigation in offset programs like this, the regulator should be in a position to determine (1) how many credits the bank should be awarded when approved; (2) the number of credits needed to mitigate for the resources lost to a particular development; (3) whether the credits represent ES that are comparable in type and kind to those services lost; and (4) whether the communities losing services are the same as those benefiting from the services that the mitigation bank would provide. As noted above, each of those determinations must also account for the risks associated with biophysical and social change (Figure 2). For example, if riparian habitat is destroyed in one location and restored elsewhere, who benefits from the new services, are they the same people who lost the same or different services from the destroyed habitats, and how certain are we that a mitigation credit project will successfully compensate for those losses?

To address these questions, the regulator must assess ES loss at the development site as well as ES provided by the mitigation site and have a means for comparing the two. This evaluation will depend critically on the types of services lost and beneficiaries in each location (Womble and Doyle 2012). For instance, when a wetland is destroyed, groundwater recharge and carbon sequestration will likely be easier to mitigate throughout a watershed, whereas flood protection or water purification will have impacts only directly downstream. Without appropriate data, the regulator cannot determine whether the offset fully replaces the lost services.

As with prescriptive tools like permits, the value assigned to an offset credit (eg 100 linear stream meters or 30 ha of wetland) can require more than biophysical data. Fully accounting for ES offsets requires information about the impact on the flow of services to people and communities, and how much it matters to them. Wetland mitigation in a remote area may mitigate ES for fewer people and provide far less value than the same areal extent in a dense urban area (Ruhl and Salzman 2006; BenDor and Brozović 2007).

Penalties

Under programs such as the US Oil Pollution Act, financial penalties are imposed on polluters under natural resources damage laws for harm to coastal ecosystems and the cost of restoration measures (EPA 2018). In assessing penalty levels for lost ES provision, a regulator must first know the types and magnitude of lost service flows and which community or communities each service flowed to. However, much of the baseline information about ES flows is simply nonexistent, making it difficult to assess actual damages and subsequently flows. Social science methods can then determine the value of these lost services to assess compensation to injured communities.

Assessing costs of restoration provides even more opportunities for ES research, requiring knowledge of how well and how quickly different kinds of *physical* restoration (eg water-blasting petroleum off of rocks versus the use of chemical dispersants) promote recovery of ES and whether there are trade-offs among restoration choices regarding how well, how quickly, and in what order services return (Palmer and Filoso 2009). Social scientists can then provide assessments of how services will be distributed to communities, community preferences, and how to value the trade-offs in services lost and gained (eg recreational fishing opportunities/revenue versus commercial oyster harvest opportunities/revenue versus subsistence fishing opportunities; du Bray *et al*. 2019).

Payments

PES programs reward landowners, such as upper watershed landowners who are compensated for maintaining or enhancing provision of ES related to water filtration and soil stability (Figure 3; Salzman *et al*. 2018). Officials implementing PES must determine how much to pay, what to pay for, and how to ensure compliance – each of which raises unique research questions. Despite a vast literature on the economic value of particular services, these findings are largely irrelevant because PES payments are based instead on individuals' opportunity costs (eg making it worth the landowners' efforts to restore and conserve the wetlands rather than put their land to other productive uses).

Very few PES programs pay for performance – that is, for the actual provision of services – because measurement and monitoring costs are often too high or too inaccurate to be practical. Instead, payments are based on land management practices that modeling predicts will result in the desired change in (or preservation of) service flow (Salzman *et al*. 2018). These models must be robust enough to ensure that specific changes in land management (eg installing riparian buffers or swales) will improve a specific outcome (eg flood resilience) by a specific amount. Social science research can improve not only the understanding of local land manager behavior and the appropriate level of incentives to alter practices (Allred and Gary 2019), but also how to build risk associated with dynamic biophysical and social conditions into payment design.

Persuasion

Impact assessments, resource management plans, and urban land-use plans must project future changes in service flows under different scenarios (Armatas *et al*. 2018). For example, an urban green infrastructure plan may contemplate different mixes, quantities, and locations of green infrastructure components (wetlands, forests, meadows, swales, green roofs) providing different suites of ES to various populations (Lovell

Figure 3. A "payment for ecosystem services" (PES) program would pay landowners in this forested upper watershed – located in the Blue Ridge Mountains in western North Carolina (elevation approximately 1006 m or 3300 feet) – to avoid land-use practices that impair flows of ES, such as water filtration and soil stability. Research linking specific land-use practices to incremental reductions in ES flow will assist in the design of payment incentives.

and Taylor 2013; Richards and Thompson 2019). Science supporting such "service-shed" level planning should be able to identify and analyze the differential levels of ES distributed across the service-shed, as well as trade-offs between scenarios and among groups of beneficiaries (Kremer *et al.* 2016). Unlike measuring aggregate service provision, this information alerts policy actors to the risk of environmental justice concerns (eg a wealthy upstream community may benefit from a development while a poor downstream community must now improve its drinking water treatment because of a reduction in the wetland service of water purification; Mandle *et al.* 2015). Identifying impacted parties under each scenario allows policy actors to educate individuals and communities about the benefits they receive from ecosystems and alert them to critical changes. Once assessment or planning is complete, these impacts can be addressed in the permitting process, accounted for in a compensation program or liability scheme, or mitigated to ensure equity.

Conclusions

ES research has traditionally focused on biophysical production and monetary valuation – where ES derive from and how much they are worth. This has greatly advanced the ES framework in high-level policy pronouncements, and continued research of this kind remains valuable. However, as we have demonstrated, field-level conservation of ES has lagged behind. It poses different questions, including who benefits (and who loses) from particular decisions and by how much. These cannot be answered by the science that drove adoption of high-level policies. To reinforce the practical conservation of ES, scientists and policy actors must collaborate to identify the specific research needs demanded by specific policy instruments. A greater understanding of the environmental policy toolkit will help scientists engage in this collaboration.

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