

Boundary work for sustainable development: Natural resource management at the Consultative Group on International Agricultural Research (CGIAR)

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Previous research on the determinants of effectiveness in knowledge systems seeking to support sustainable development has highlighted the importance of “boundary work” through which research communities organize their relations with new science, other sources of knowledge, and the worlds of action and policy-making. A growing body of scholarship postulates specific attributes of boundary work that promote used and useful research. These propositions, however, are largely based on the experience of a few industrialized countries. We report here on an effort to evaluate their relevance for efforts to harness science in support of sustainability in the developing world. We carried out a multicountry comparative analysis of natural resource management programs conducted under the auspices of the Consultative Group on International Agricultural Research. We discovered six distinctive kinds of boundary work contributing to the successes of those programs—a greater variety than has been documented in previous studies. We argue that these different kinds of boundary work can be understood as a dual response to the different uses for which the results of specific research programs are intended, and the different sources of knowledge drawn on by those programs. We show that these distinctive kinds of boundary work require distinctive strategies to organize them effectively. Especially important are arrangements regarding participation of stakeholders, accountability in governance, and the use of “boundary objects.” We conclude that improving the ability of research programs to produce useful knowledge for sustainable development will require both greater and differentiated support for multiple forms of boundary work.

boundary organization | extension | innovation | research policy

Sustainable development is a knowledge-intensive endeavor. Efforts to improve linkages among research programs, experiential knowledge, and action on the ground have nonetheless been only partially successful. The question for scientists, program managers and donors is therefore not whether but rather how to modify program design and practice in ways that help to realize the great potential of research programs to support sustainable development (1, 2).

Boundary Work in Theory and Practice

Previous research suggests that the concept of “boundary work” provides one potentially powerful point of departure for designing research programs that better link knowledge with action (3). Originally developed to help understand efforts to demarcate “science” from “nonscience” (4), the idea of boundary work has since been applied to the interface between science and policy (5–7) and, more broadly, to the activities of those seeking to mediate between knowledge and action (8, 9).^{*} The central idea of

boundary work is that tensions arise at the interface between communities with different views of what constitutes reliable or useful knowledge. If an impermeable boundary emerges at the interface, no meaningful communication takes place across it. However, if the boundary is too porous, personal opinions mix with validated facts, science gets mixed with politics, and the special value of research-based knowledge fails to materialize. Active boundary work is therefore required to construct and manage effectively the interfaces among various stakeholders engaged in harnessing knowledge to promote action (10).

Scholarship on boundary work is rapidly expanding (6, 7, 11, 12). In general, it hypothesizes that boundary work is more likely to be effective in promoting used and useful research to the extent that it exhibits at least three key attributes: (i) meaningful participation in agenda setting and knowledge production by stakeholders from all sides of the boundary; (ii) governance arrangements that assure accountability of the resulting boundary work to relevant stakeholders; and (iii) the production of “boundary objects,” defined as collaborative products such as reports, models, maps, or standards that “are both adaptable to different viewpoints and robust enough to maintain identity across them” (13).

There remain, however, two concerns regarding these widely shared hypotheses about successful boundary work. First, with a few notable exceptions (14), most of the relevant evidence derives from case studies of single efforts in a few countries of North America and Europe. The hypotheses are nonetheless increasingly being used to guide reform in potentially different contexts of the developing world (15, 16). Second, even where there is some agreement on the attributes that characterize effective boundary work, there is little on which strategies for organizing boundary

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^{*}The term “boundary organizations” is sometimes used interchangeably with “boundary work” in the literature. We find it more illuminating to focus on the “work” and to treat as an empirical question whether that work is performed by formal organizations or by informal networks or by individuals.

work are most likely to yield such attributes in particular circumstances (17, 18).

The research reported here sought to address these concerns through the comparative analysis of boundary work in the family of programs on integrated natural resource management carried out under the auspices of the Consultative Group on International Agricultural Research (CGIAR), one of the world's largest and most experienced global research organizations seeking to foster sustainability in the developing world. We focused on boundary work conducted within the CGIAR's Alternatives to Slash and Burn (ASB) program, "a global partnership of research institutes, nongovernmental organizations (NGOs), universities, community organizations, farmers' groups, and other local, national, and international organizations... [seeking] to raise productivity and income of rural households in the humid tropics without increasing deforestation or undermining essential environmental services" (19). ASB has been operating since 1994 and now has 12 "benchmark sites" around the world. Lessons drawn from its experience with boundary work should thus be of significant broader interest. (*SI Text* includes more information on the CGIAR and ASB). Several of the present authors have been involved in ASB's work in multiple ways (*SI Text*). We have published elsewhere detailed accounts of how ASB has functioned and of its impacts on knowledge and action relevant to sustainable development (20, 21). Here we extend that work to explore two more specific questions. First, to what extent does ASB's history of efforts to link knowledge with action confirm, reject, or call for extension of existing hypotheses about the attributes of successful boundary work? And second, what does the ASB experience have to say about how local context shapes the challenges facing boundary work, and thus the strategies for carrying it out effectively?

Reconceptualizing Boundary Work: A Framework

We discovered two big things from our exploration of boundary work in ASB. First, we encountered a far greater variety of boundary work than the literature had led us to expect. Second, we determined that much of that variety—and the success of strategies that produce it—can be understood in terms of the sources and uses of the knowledge that boundary work engages.

We developed the conceptual framework set forth in Fig. 1 as a means to better understand the variety of boundary work at ASB. The columns of the framework address the uses of knowledge, i.e., the purpose for which knowledge consumers deploy it. We distinguish use for (i) enlightenment, or the advancement of general understanding that is not targeted at specific users but may influence decisions through a diffuse process of percolation (22) (U_0); (ii) "decision support" of choices made by a single relatively autonomous user such as a farmer or minister (U_1); and (iii) "negotiation support" of bargaining or other political interactions among multiple users (U_m). The rows of the framework address the sources of new knowledge. We distinguish knowledge that is

seen by users as originating within (i) a single, relatively homogeneous community of knowledge producers sharing similar norms of evidence and argument (e.g., the discipline of soil science) (S_1); or (ii) multiple heterogeneous communities of knowledge producers with potentially conflicting norms (e.g., social vs. natural sciences, or laboratory vs. traditional knowledge; S_n). The individual cells of the framework reflect how the particular combinations of knowledge sources and uses determine the challenges facing boundary work in particular contexts. The arrows in Fig. 1 represent the potential for two-way interactions among the relevant sources and users of knowledge. Reality almost certainly offers up more of a continuum of sources and uses than our framework of discrete classes suggests. We have nonetheless found the discrete framework to be a helpful way to organize our thinking and exposition. (The conceptual framework of Fig. 1 is a simple version, adequate for this study, of the more general use/source framework that is presented in Fig. S1).

How can the "effectiveness" of boundary work be evaluated? This question is illuminated by a growing body of research showing that technical information in policy contexts is more likely to be influential to the extent that it is perceived by stakeholders as satisfying the criteria of saliency, credibility, and legitimacy (SCL; Table 1). Producing knowledge in ways that meet any one of these criteria for any one user is relatively simple. Producing it in ways that meet all three criteria in ways that are simultaneously satisfactory to multiple stakeholders is necessary for science to have much chance of advancing collaborative action, but can be very hard indeed to achieve (3, 23, 24). In this article, we build on recent work applying the SCL criteria to evaluate the effectiveness of boundary work (17, 25, 26).

The following sections present our findings regarding how such effectiveness is influenced by the way that the boundary work attributes of participation, accountability, and boundary objects are handled in each of the six use/source contexts defined in Fig. 1.

Use of Knowledge for Enlightenment

The simplest boundary work we found in ASB occurred where the relevant user was the scientific research community itself together with the diffuse debate on agricultural alternatives that scientists sought to inform. ASB often looked on new information primarily as a source of enlightenment, that is, to advance basic understanding with no concerns for immediate application (Fig. 1, U_0). The central challenge for the program's boundary work in this context was to meet the SCL credibility criterion (Table 1): sorting new knowledge claims to establish which would be accepted into the body of accepted fact that ASB, as a research program, was prepared to stand behind. If the boundary regulating such acceptance were too permeable, solid facts, idiosyncratic experience, and mere conjecture would become so mixed as to undermine the knowledge foundations on which further research sought to build deeper understanding of the world. If the boundary were too impermeable, new findings and ideas could gain no traction with the research community. Understanding would stagnate.

Boundaries Between New Discoveries and Established Knowledge. ASB addressed the same challenge facing all research communities: deciding whether to accept a particular new claim into its

Boundary Work		USE of knowledge to support....		
		Enlightenment (U_0)	Decision (U_1)	Negotiation (U_m)
SOURCE of knowledge...	Single community of expertise (S_1)	$S_1 \leftrightarrow U_0$ <i>Demarcation</i>	$S_1 \leftrightarrow U_1$ <i>Expert advice</i>	$S_1 \leftrightarrow U_k$ $S_1 \leftrightarrow U_t$ <i>Assessment</i>
	Multiple communities of expertise (S_n)	$S_i \leftrightarrow U_0$ S_j <i>Integrative R&D</i>	$S_i \leftrightarrow U_j$ S_j <i>Participatory R&D</i>	$S_i \leftrightarrow U_k$ $S_j \leftrightarrow U_t$ <i>Political bargaining</i>

Fig. 1. Context of boundary work as defined by sources and uses of knowledge.

Table 1. SCL criteria for evaluating the effectiveness of boundary work

Criterion	Concerns addressed
Saliency	Relevant to the decision or policy?
Credibility	Technically adequate in handling of evidence?
Legitimacy	Fair, unbiased, respectful of all stakeholders?

body of accepted, reliable knowledge (Fig. 1, S_1U_0). ASB usually confronted this conventional challenge of boundary work with conventional scientific processes for quality control such as significance tests and standards for experimental replicability. Not surprisingly, ASB research programs dealt quite well with these tasks through normal peer-review activities (20).

Boundaries Between Research Disciplines. More challenging were the circumstances in which ASB sought to stimulate the integration of expertise from multiple sources of knowledge, often involving multiple methods or rules of evidence (Fig. 1, S_nU_0). ASB work in this context confronted two distinct challenges of boundary work and developed distinctive strategies for dealing with them.

ASB leadership recognized early on that understanding the sustainability of alternative human land uses at the tropic forest margins would require the integration of research across the natural and social sciences (21). Such integration, however, posed significant challenges for ASB, embedded as it was in the natural science culture of the CGIAR. The initial temptation of the natural scientists who dominated the early ASB was simply to “do their best” at addressing the complex social issues they encountered at their field sites. This approach, however, produced mediocre research that threatened the credibility of the entire program. Differences among disciplines in jargon and rules of evidence, plus an initial lack of mutual respect, made the creation of knowledge judged to be credible by all seem almost beyond reach. As the program matured, however, successful strategies for boundary work did emerge and exhibited most of the attributes, noted earlier, that the literature has hypothesized.

Participation. The joint participation of natural and social scientists was initially achieved by issuing contracts for them to participate in problem-focused “thematic working groups” that encouraged two-way communication across disciplines. Especially effective was the program’s use of joint field trips to the ASB benchmark research sites. The “retreat-like” character of these field visits created “safe spaces” that were widely cited by participants as powerful mechanisms for fostering more meaningful exchanges across the gulf normally separating natural and social science researchers (21).

Accountability. The central governance challenge in the S_nU_0 context was to assure that the ASB agenda was not captured by either natural or social scientists (or their respective norms of “good research”). Such mechanisms were neither formal nor strong at ASB, especially during the early stages of the program. However, the presence on the ASB’s original Global Steering Group of international partner institutions with a relatively strong commitment to social science perspectives provided an important counterbalance to CGIAR’s natural science biases in the early stages of the program.

Boundary objects. ASB created a variety of boundary objects that were jointly “owned” by natural and social scientists. One of the first of these was the development of shared protocols for data collection developed to guide and coordinate work across the ASB benchmark sites (27, 28). There was little truly interdisciplinary scholarship involved in this work. However, the commitment of natural and social scientists to contribute their respective parts to a common whole clearly advanced mutual understanding and respect. Real interdisciplinary integration eventually followed, perhaps most clearly illustrated by the bioeconomic models developed by ASB and its partners from Brazil’s Embrapa (29). These models came to serve ASB researchers as a widely cited and emulated illustration of the potential benefits of true interdisciplinary integration, creating products judged to be credible by natural and social scientists.

Boundaries Between Context-Specific and Generalizable Research. A second challenge confronted by ASB was the integration of re-

search conducted by scientists from its “national” and “international” networks. ASB leaders were well aware that “global” research programs often end up with agendas set by “cosmopolitan” researchers drawing from their international networks. “Local” scholars—largely based in national institutions in the developing world—are then relegated to tasks of running the experiments and collecting the data. Moreover, ASB faced the broader but related challenge of integrating research focused on generalizable results with research emphasizing context-specific understanding and solutions. The key to effective boundary work for addressing these tensions in the ASB turned out to be primarily the program’s commitment to do so: its “Core Values and Operating Principles” made full partnerships between local and international researchers the touchstone of all ASB activities.

Participation. The Principles highlighted the commitment of the program to full participation of all researchers in agenda setting, resource allocation, and credit for findings and publications. Full transparency of decisions and decision making was also emphasized. These commitments were observed in practice and credited by participants with playing an important role in program success.

Accountability. Governance provisions to assure that these goals were in fact achieved came through representation of local and international researchers on ASB’s Steering Group, with a preference for national partners.

Boundary objects. The most important boundary objects created in the work of mediating between norms of context-specific and generalizable research were the program’s benchmark sites for studying human use of forest margins throughout the humid tropics. Each site developed a research program tuned to local needs and capacities, but also committed to exploring certain common questions and to using some common methods, metrics, and protocols. Research papers produced at the sites reflected shared credit across cosmopolitan and local researchers (28).

Use of Knowledge for Decision Support

ASB’s goals assured that much of its activity would take place at the interface between research and application. We found, however, that the challenges addressed by such boundary work were radically different depending on whether the “user” or consumer of information was a single, relatively autonomous decision maker (Fig. 1, U_1) or participants in a more complex negotiation among multiple political interests (Fig. 1, U_m). We address the latter case in the next section. Here we focus on the use of knowledge for decision support (Fig. 1, U_1).

The challenge for ASB’s boundary work carried out to mediate the use of knowledge for decision support (i.e., U_1) was more complex than its boundary work to foster enlightenment alone (i.e., U_0). In particular, for knowledge to be used in support of decision making, it needed to be perceived by decision makers as not only scientifically credible but also as salient to their needs (Table 1). An insufficiently permeable boundary between research and decision making risked that scientists would set their research priorities by imagining what decision makers wanted to know rather than by learning from them what they actually needed. Decision makers would remain ignorant of what good research and development might realistically have to offer. However, an overly permeable boundary risked the politicization of science, with decision makers using—and even directing—research primarily to support decisions they had already made. The same permeability, however, also risked the “scientization” of politics: decision-makers avoiding responsibility for grappling publicly with fundamental questions of “who gets what” by repackaging them as “merely” technical issues to be resolved by experts they controlled (30).

In our investigations of ASB, we found two distinctive types boundary work being carried out to address these challenges of harnessing science for decision support: one between scientists and farmers, the other between scientists and policy-makers.

Boundaries Between Scientists and Farmers. Early work by the CGIAR had used a largely one-directional “extension” model of technology transfer. By the time ASB was organized in the 1990s, the shortcomings of this approach were widely recognized. These included its failure to integrate farmers’ with researchers’ knowledge and its tendency to define agendas in terms of researchers’ solutions rather than farmers’ problems (31). Much progress had been made toward adopting a bidirectional, collaborative model of “farming systems research” and development. ASB enthusiastically adopted this model, but nonetheless struggled to shape the boundary work needed to implement it successfully. The following sections detail what we found regarding the determinants of successful boundary work.

Participation. Scientists and farmers did participate in joint priority setting, research, and evaluation activities at most ASB sites. Partnerships were formalized at a few sites but elsewhere were largely informal and opportunistic, often triggered by outsiders’ visits associated with project funding cycles or evaluations. Nonetheless, ASB’s boundary work generally succeeded in developing trust and rapport, resulting in changes to both research agendas and the uptake of new findings. Scientists participated in these partnerships partly from their perception of the value of local knowledge to their own research, partly in response to the formal commitment by ASB that its work would be “grounded in local reality through long-term engagement with farmers and community groups.” Farmers participated for a variety of reasons, ranging from interest in scientific findings to the expectation that participation in the research activities would lead to major development projects.

Accountability. Formal mechanisms to hold ASB’s farming systems research accountable to both farmers and scientists were rare, generally occurring only when required by a particular funding arrangement. Much more common were informal consultations conducted in the context of field trips and site visits. ASB’s commitment to the use of participatory research methods was the prime mechanism to guarantee farmers an opportunity for voicing dissatisfaction with the direction of ASB activities.

Boundary objects. The joint creation of tangible products by scientists and farmers played a significant role in linking research with action at the ASB sites. Drawings, maps, and physical models of relevant landscapes were the most valued knowledge products (Fig. S2 illustrates an example). Also important were collaborative field trials, on-farm nurseries, and the production of training materials on effective land use practices.

Boundaries Between Scientists and National Policy Makers. Governments in the regions addressed by ASB looked to the program for scientific information that would help them to choose among alternative land uses. ASB encountered two big challenges. First, the initial impetus for the program had come in large part from international environmental advocates who framed the problem as deforestation, the cause as slash-and-burn land use by smallholder farmers, and the solution as the development of alternatives to such practices (28). ASB’s early work showed that this initial top-down framing was at odds with scientific findings and realities on the ground. It sought to move beyond the initial framing imposed on it toward a more contextualized, bottom-up effort empowering local decision-makers to help set locally salient research priorities. Second, many of the scientists working with ASB at the local level were employed by national ministries or international NGOs that had strong political agendas of their own. This relationship called into question local scientists’ ability to conduct truly independent research. ASB’s principal challenge was then to strengthen boundaries separating these scientists’ research from their employers’ politics. ASB experimented with a variety of boundary work strategies for creating research that would support better decisions by policy-makers.

Participation. Participation of scientists and policy makers in formal joint discussions about decision-support priorities for ASB was never regularized. Rather, it occurred intermittently and informally at meetings driven by specific policy or research needs. Significantly, however, the capacity to recognize and take advantage of such opportunities depended crucially on the development of sustained collegial relationships between senior program scientists and policy makers. These were fostered formally in Indonesia, where ASB maintained a small office within the Ministry of Forestry. Informal engagement was also effective, notably in Brazil and Thailand, where the resident ASB scientists devoted substantial time to the development and maintenance of informal connections with relevant officials.

Accountability. Accountability for the collaborative development of research agendas that reflected needs of decision support was provided through a number of channels. Many of these were embedded in the informal collegiality noted above. A key role was played by “national champions”: individuals, usually scientists, who had the respect of both the research and policy communities. ASB sought to cultivate champions and bring them onto its official steering group, thus helping to assure that regional decision-support needs would find a voice in the setting of research priorities. Formal planning workshops were also convened at the national and regional levels. At these workshops, ASB scientists collaborated with staff advising relevant policy makers in the development of work plans. The tone of these workshops was generally of an advisory rather than governing nature. They were backed, however, by potential hard sanctions: ASB (like all CGIAR programs) needed official government permission to operate in host countries. However, ASB could also exit (along with its funding) from countries unwilling to work closely enough with it to achieve desired impacts on practice.

Boundary objects. Boundary objects played important roles in assuring that ASB research provided useful support to national level decision makers. These included synoptic country reports, specially prepared “policy briefs” on key issues, and models focused at regional scales. A common feature of the most influential boundary objects was their tailoring to local decision-makers’ needs and language. An especially noteworthy innovation was the “ASB Matrix,” a succinct (one page) table summarizing what ASB research had discovered about the tradeoffs among alternative land uses, denominated in economic, social, and environmental indicators, reflecting the concerns of policy-makers in a specific country (an example is provided as Table S1).

Use of Knowledge for Negotiation Support

The most complex forms of boundary work we found in ASB emerged in the context of multiple knowledge users with potentially conflicting objectives (Fig. 1, U_m). The challenge of creating useful information in such politicized situations included the previously discussed need to assure users of the salience and credibility of knowledge. However, in this context, there was an additional need to assure users of the legitimacy of processes for mobilizing knowledge (Table 1). Successful boundary work needed to convince all users that the process of linking knowledge with action had not been biased in support of another’s agenda. Failed boundary work could result in one or more parties rejecting knowledge that might have been useful for negotiations, not because of doubts regarding the credibility or saliency of that knowledge but because of perceptions that the questions asked or evidence considered may have been stacked unfairly in another’s favor (32).

Boundaries Between ASB and Multinational Negotiations. ASB’s boundary work in the S_1U_m context is illustrated through its role in the Millennium Ecosystem Assessment (MA), in which it led the component addressing the tropical forest margins: the ASB-MA (SI Text) (33). The ultimate challenge for ASB was to in-

roduce usable scientific information into the often-intense conflicts between advocates of biological conservation and of economic development at national and global scales. Its contribution was credited by major stakeholders from all sides of the political debate with creating a salient, credible, and legitimate knowledge base on which to build subsequent negotiations (20). We summarize in the subsequent sections what we found to be the most significant elements of ASB's relatively successful strategy for boundary work in the S_1U_m context.

Participation. The special challenge of participation in the ASB-MA was to find ways of effectively engaging the enormous range of interested parties. These included individual farmers in the ASB benchmark sites, ministerial users from multiple nations, representatives of diverse global organizations, and scientists working at all scales. In the face of a potentially crippling supply of interested stakeholders, ASB-MA adopted a strategic approach to participation. For scientists, it drew on the 250 researchers from 50 institutions around the world then involved in ASB research, and complemented those with an open call to qualified outside experts for expressions of interest in participating in the assessment. From this pool, the ASB-MA selected scientists from a strategic mix of countries, disciplines, and institutions. Needs of local users were systematically identified through community level assessments regularly conducted at each of the ASB benchmark sites, supplemented by surveys conducted especially for the assessment. Finally, ASB-MA conducted consultations on user needs with policy shapers at the subnational and national level throughout ASB's domain (21).

Accountability. The ASB-MA faced two challenges of accountability. First, the participants in the ASB research program needed assurances that their findings reached the MA without distortion. Second, global users from the conservation and development communities needed assurances that the assessment was not biased toward the action agenda of one or the other. ASB-MA provided such assurances by subjecting itself to the parallel but separate governance structures of the ASB and the MA (*SI Text*). No formal linkage between the ASB and MA governance mechanisms was sought or achieved, although one of the conditions for authorization of the ASB-MA by the MA Board was the existence of a broadly representative governing body for ASB, a role convincingly played by the ASB Global Steering Group.

Boundary objects. The principal boundary object created by the ASB-MA was its assessment report (34). This document—and the process that commissioned, produced, and reviewed it—effectively spanned the worlds of policy-driven concerns and science-based findings. Many subsidiary products of the assessment also served as boundary objects on narrower topics—for example, the policy briefs prepared on particular topics such as restoration of degraded landscapes and the forces driving tropical deforestation (35). The ASB Matrix that played such a prominent role as a boundary object in the S_1U_1 context noted earlier was also effectively used in the ASB-MA.

Boundaries Between Multiple Knowledge Sources and Multiple Users.

The most novel, challenging, and complex instances of boundary work we found in ASB are those taking place in the context characterized by the lower right corner of Fig. 1: multiple sources of knowledge (i.e., S_n) entrained in negotiations among multiple stakeholders (i.e., U_m). For ASB, such contexts were ubiquitous. Specific instances ranged from integration of conflicting expert views on how different regimes of land access would affect conservation and economic interests to construction of shared understanding for use in pricing payments for ecosystem services (32, 36).

To illustrate how ASB structured its boundary work in this context, we summarize here our findings on the program's boundary work to facilitate sustainable development in the forests of Indonesia's Sumberjaya region, where upland coffee production was said to be endangering downstream environmental services.

Conflict between the government and smallholders had resulted in promulgation of a new community forest management plan with new rules of forest tenure [Hutan Kemasyarakatan (HKm)], but implementation was contentious and slow (*SI Text*). ASB [and later its spinoff program, Rewarding the Upland Poor for Environmental Services (RUPES), also operating under the CGIAR] persuaded the local government to allow it to help experiment with different HKm requirements to achieve better results (37, 38). ASB-RUPES rapidly discovered, however, that merely conducting research in decision-support mode was inadequate. As two of the present authors wrote at the time, "The real-world human impact on natural resources derives from a large number of individual decisions, made with different access to sources of knowledge and information, with different technical means to organize exploitation, and with different objectives, constraints, priorities, and strategies. The best we can hope for is a process of negotiations among stakeholders that leads to modification of the individual decisions to produce superior outcomes from the broader social perspective" (32). ASB-RUPES therefore began to develop a new mode of engagement, which it eventually called negotiation support. The approach did involve a significant amount of classic agroforestry research and development, but also included unconventional elements of capacity building and mediation. Four years into this engagement, an independent analysis documented that the HKm program facilitated by ASB-RUPES had made a significant contribution to sustainable development in Sumberjaya (37, 39). Several novel features of ASB-RUPES' boundary work contributed to this success.

Participation. There was deep distrust among the stakeholders in the management of Sumberjaya forests: smallholders, regional officials, NGOs, and national forestry experts. ASB-RUPES diagnosed that, were it to provide support to only one of these stakeholders, the program would be dismissed by the others as just another advocate picking sides in the conflict. It therefore devoted substantial effort to cultivating relationships with all the major stakeholders, listening to their questions, treating their knowledge and beliefs respectfully but critically, and eventually bringing them together in carefully "neutral" meetings that produced shared knowledge.

Accountability. The deficit of trust noted earlier meant that no domestic institution existed that parties would accept as guarantor of ASB-RUPES' efforts. The program therefore invested in a variety of bilateral confidence building measures, meant to assure each stakeholder individually of the salience, credibility, and, above all, of the legitimacy of ASB-RUPES' efforts. By all accounts, this worked remarkably well, drawing in no small part on the reputation in the region of the program's "parent": CGIAR's World Agroforestry Centre [also known as the International Center for Research in Agroforestry (ICRAF)]. However, its success was even more dependent on the commitment and reputation of a few key individuals than on any formal institutional mechanism.

Boundary objects. Multiple boundary objects were created to stabilize parts of ASB-RUPES' engagement in the Sumberjaya community forestry effort. Most significant and unusual, however, was the revised HKm agreement itself, and the community forestry permits that flowed from it. These created a legally binding framework accepted by all stakeholders. The crucial contribution from ASB-RUPES was its scientific finding that coffee agroforestry could meet the income goals of farmers and the conservation goals of government. All parties were initially skeptical, but the participatory and transparent research of ASB-RUPES changed minds, and created the key "win/win" option that underpinned the HKm system.

Discussion

The present study has evaluated the role of boundary work for understanding efforts to harness research for natural resource

management in the developing world. Others have also begun to explore related questions, with most focusing on boundary work in natural resource management in developed world contexts (9, 40–42) and a few examining the special challenges of carrying out such work in the developing world (14, 15, 43). Nonetheless, a recent comprehensive survey conducted for the Overseas Development Institute (ODI) concluded that, despite consensus on the need for boundary work in strengthening science-policy dialogue in developing countries, there is no consensus on how boundary work is actually carried out there, or on how its effectiveness can be improved (17). Our research findings provide a partial remedy to this situation.

Context Matters: Differentiating Challenges of Boundary Work. We conclude that much of the lack of consensus noted by ODI is almost certainly caused by an insufficiently differentiated view of the kinds of boundary work being performed. Our study of ASB shows that there is, in fact, a rich variety of boundary work being carried out even within a single research program. Much of the observed variety can be understood in terms of context within which the boundary work is performed—in particular, the sources and uses of knowledge that it engages (Fig. 1). We propose that our contextual framework for boundary work captures not only the ASB experience, but also much of the boundary work described in the literature. [Complementary frameworks proposed by Andrews (44) and Michaels (18) are discussed in *SI Text*].

The “source” dimension of our framework is important because it differentiates situations in which who counts as an expert or what counts as knowledge are potentially at issue. A great deal of research by scholars of science, technology, and society has focused on the implications of such distinctions (45). Our studies suggest, however, that—at least for the understanding and design of boundary work—the intended use of knowledge (i.e., the columns of Fig. 1) is even more significant, primarily because it determines the criteria by which the authoritativeness or influence of knowledge is assessed by those who might act on it. We therefore organize the discussion of our results in terms of the use dimension of Fig. 1.

Enlightenment. Where the intended use of knowledge is simply enlightenment (i.e., U_o), the principal challenge for boundary work is to construct a perception on all sides of the boundary regarding the credibility of the knowledge produced. This covers the classic “demarcation” of science from nonscience (i.e., S_1U_o) as originally described by Gieryn (4) and as generally pursued through strategies of peer review. It also turns out to be the principle challenge faced by efforts seeking to advance understanding by bringing together multiple kinds of knowledge (i.e., S_nU_o), whether through interdisciplinary scientific research (25) or through the integration of indigenous and scientific knowledge (43).

Decision. Where the intended use of knowledge is the support of decision making by a single, relatively autonomous agent (i.e., U_1), the challenge of boundary work expands to include the saliency of knowledge. This is the context addressed in the work of Jasanoff (5) and Guston (46) applying boundary work concepts to the problem of science advice to governments. In the context of a single community of relevant expertise serving as the source of knowledge (i.e., S_1U_1), this covers what has been called “client-oriented advising” (44) as well as the long tradition of scientific advice to leaders in government (47). The challenge remains essentially the same, although the solutions are more complicated, when multiple communities of expertise are called on by single decision makers (i.e., S_nU_1), as in so-called farming systems research and other participatory forms of analysis in which decision-makers take an active role (41, 48).

Negotiation. Finally, when the intended use of knowledge is to inform negotiation among participants in seriously politicized contexts (i.e., U_m), the challenge of boundary work widens once again to include its legitimacy. Relatively well understood is the

case in which potentially conflicted parties may seek out a single authoritative source of knowledge (i.e., S_1U_m) in the form of scientific assessments such as the Intergovernmental Panel on Climate Change or MA (23, 49). More complex are the cases in which multiple parties are likely to mobilize the knowledge sources that support their particular interests (i.e., S_nU_m), and the role of boundary work is to move beyond the resulting politicization of science to shape a broadly accepted common knowledge base to support negotiations (32, 50).

This last case— S_nU_m in our framework, or what others have called “participatory joint fact-finding” (44)—can be seen as not only the most difficult but also the most general context for boundary work.[†] All the other contexts described here and captured in Fig. 1 can be thought of as limiting cases of S_nU_m in which the number of competing sources of knowledge or the number of competing political interests in the use of knowledge have been reduced to one. This suggests that a general theory of boundary work might begin here, rather than with the especially simple case of “demarcation” (i.e., S_1U_o) that was the focus of the seminal work on the subject. In particular, a perspective that places the S_nU_m context as the most general boundary work challenge would need to place questions relating to the politics of expertise much more centrally in discussions of the design and evaluation of boundary work and organizations than has heretofore been the case. Such a perspective would emphasize that context matters, but also that context is to some extent chosen by relevant actors. It would stress that both the producers and users of knowledge therefore have a responsibility to reflect on the political implications of the contexts in which they choose to interact with one another (8, 17, 51).

Strategies Follow Context. The different contexts of boundary work captured in the framework of Fig. 1 help to make sense of what has correctly been characterized as the lack of consensus regarding appropriate strategies for making such work successful (17). We discuss our findings under headings reflecting what the literature about boundary work in the developed world has hypothesized to be the determinants of success.

Participation. Our ASB study strongly supports the hypothesis that effective boundary work requires meaningful participation of key actors from each of the communities (potentially) divided by the boundary. However, our results suggest that who constitutes “key actors” differs with context in ways determined by the use and source of knowledge, i.e., by the position of the boundary work in the framework of Fig. 1. Moreover, successful strategies for engaging meaningful participation varied along the same dimensions. Thus, in the S_nU_o context, all the key participants were research scientists, albeit from different and sometimes apparently incompatible disciplinary traditions. Initial tensions growing from different research styles and questions of interest were bridged through formal commitments by scientists to work together on common problems. In contrast, in the highly politicized context of S_nU_m , ASB found that its boundary work needed to bring together not only scientists from multiple disciplines, but also farmers, regional politicians, and national experts. The bridges forged among these groups were less formal than in the S_nU_1 case. They were also highly pragmatic, with the potential chaos of multiple-stakeholder debates circumvented through a process built around a series of bilateral engagements between ASB and each of the other actors.

We conclude that participation of key actors is indeed necessary for effective boundary work, as has been proposed in the literature. However, the most useful guidelines for selecting which

[†]We prefer the term “negotiation support” because it better reflects the intensely political character of the boundary work we observe in such contexts for natural resource management in the developing world.

participants are “key” seem more likely to come from a negotiator or mediator’s perspective rather than a scientist’s. Important screening questions should address who would need to change their beliefs or behaviors based on the knowledge in question, who could block action based on the knowledge, and who needs to certify the knowledge as credible to those actors. Moreover, whatever the resulting list of key actors whose participation needs to be secured, it is clear that effective boundary workers will find ways to avoid engaging them all at once. Instead, they will often serve as “shuttle diplomats,” engaging key actors sequentially and iteratively rather than simultaneously.

Accountability and governance. The existing literature on boundary work in the developed world emphasizes the importance of formal governance arrangements to make boundary work accountable to the different communities involved. In contrast, ODI’s survey of developing countries found relatively little concern over governance of science–policy interactions (17). In our studies of ASB, we observed very different approaches to accountability depending on the context of the boundary work. For expert advice to government (i.e., S_1U_1), ASB’s most important contribution was to help create and strengthen a boundary separating the expert and political roles of local civil servants. These individuals, although often excellent scientists, had few safe means of separating what they knew as scholars from what regulations required of them as civil servants. By providing an independent group of scientific peers for these civil servants, ASB provided a safe space within which they could differentiate their roles. In other cases, particularly in dealing with external donors to ASB research (i.e., U_o), accountability arrangements were formal, but tended to secure donors’ interests rather than interests of local users. In highly politicized contexts (i.e., U_m), there were virtually no formal accountability arrangements, reflecting the lack of institutions to enforce them.

We conclude that the formal requirement for “dual accountability” postulated in the literature does not hold as a general matter in contexts such as those engaged in by ASB in the developing world. Instead, a much more fluid and informal set of governance arrangements—more often mediated by individuals than by organizations—seemed to be the norm for ASB’s boundary work. Its informal modes of governance may not have served as effectively as the more formal governance arrangements for advisory committees and such that are common in North America and Europe. However, they often worked in the ASB regions. They did so not by imposing unrealistic demands on the thin organizations available there, but rather through the intermediary of trusted individuals who could vouch for the fairness and thus legitimacy of ASB’s boundary work efforts. Advocates of boundary work should not uncritically impose the legalistic accountability structures with which they may be most familiar onto efforts to link knowledge with action in the developing world.

Boundary objects. Our findings support the hypothesis that successful boundary work focuses on the production of boundary objects. We documented a great variety of ways in which agreements among different communities on questions, data and conclusions were embodied in shared boundary objects. Indeed, in a number of our cases, actors’ perceptions were significantly reshaped by their shared creations—an example of the higher-order function of boundary objects that has been discussed under the heading of “standardized packages” in the literature (6, 52). Several of the boundary objects we observed appeared in multiple contexts, such as maps, models, and the ASB matrix of tradeoffs among alternative land uses. The most important finding of our work, however, is that successful boundary objects are tailored to specific contexts. Thus, the most complex boundary object we found—the HKm community forestry agreement in Indonesia (i.e., S_nU_m)—is unique to its circumstances. In addition, the models that show up almost everywhere are also differentiated: computable models in the context of boundary work across dis-

ciplines (i.e., S_nU_o), physical models at the boundary of researchers and farmers (i.e., S_nU_1), and scale-appropriate conceptual models when used in science advice to policy makers (i.e., S_1U_1). A similar pattern holds for the maps that show up as important boundary objects, but in quite different forms, across the contexts we observed.

We conclude that effective boundary work will almost always produce tangible boundary objects. However, arguments about whether maps or models or contracts constitute the most significant boundary objects may be less informative than efforts to improve the “fit” of boundary objects to the context in which they are deployed.

Generalized Findings. Beyond the context dependent findings discussed earlier, we found that an essential contribution of boundary work in rural development is building capacity to articulate users’ demand for technical information and to convey technical information into the “field.” Both of these functions are taken for granted in most of the literature on boundary work. Our research suggests they should not be.

Beyond this general need to build capacity for boundary work, our research suggested two specific challenges facing boundary workers in rural development. First is the need for boundary work to integrate multiple forms of knowledge, in particular the contextualized knowledge of practice with the generalized knowledge emerging from research. Much of the knowledge needed to inform effective action in our cases was of the former sort. Formal, generalized knowledge from international research programs clearly had a contribution to make, but only if it could be integrated with—rather than displace—the rich contextual knowledge of local farmers and researchers. This integration posed significant problems not only of communication and translation, but also of epistemology (e.g., how to combine “uncertainty” estimates of farmers with those of scientists). Successful boundary work in ASB’s rural development contexts needed to make such problems much more central to its activities than seems to be the case for most western models.

A second challenge facing boundary work in rural development is the extreme politicization of formal knowledge. The relationship between knowledge and power is not, of course, unremarked in the existing literature on boundary work in the developed world. Nonetheless, a central feature of the reality we encountered in the field was both the fact and the presumption that scientific knowledge was being used by state and business interests to control development activities of rural land users. The demands on boundary work and workers to construct the legitimacy of formal knowledge in the eyes of various stakeholders were thus much greater than those we had encountered in existing western case studies.

We conclude that boundary work may be most generally conceived of as a negotiation support process engaged in creating usable knowledge and the social order that creates and uses that knowledge. The design of boundary organizations in decision support mode that is stressed in much of the literature can be seen as a recognizable and important subset of such a general negotiation support formulation. However, for the extremely asymmetric cases of power distribution that characterized our (and others’) rural development cases, the explicit attention to managing power contained in the negotiation support formulation appears to be essential to good boundary work. Implementing this realization would constitute a major departure from the apolitical, one-directional “transfer” models that still inform much of the dialogue and practice of science for development. The principal policy implication of our work is that improving the ability of global research programs to produce useful knowledge for sustainable development will require greater and more differentiated support for multiple forms of boundary work.

Methods

Findings reported here are derived from three principal sources of data. The first is an independent assessment of the first decade of ASB experience, carried out by a team led by one of the authors (W.C.C.) at the request of the Science Council of the CGIAR. The full method and data are published elsewhere (20). The second is a systematic self-assessment of ASB run by one of the authors (T.P.T.) involving 42 ASB researchers in an online consultation. This was structured following an analytical framework on "harnessing science and technology for sustainability" derived from studies of other comparable cases (21). The third is our recently completed field

project examining the practices and evaluating the outcomes of the CGIAR's RUPES program, a spinoff of the ASB (53). Further details are provided in *SI Text*.

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Supporting Information

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CGIAR and ASB Program. According to its charter, “[CGIAR] is an informal association of 64 public and private sector CGIAR Members, from the South and North, committed to mobilizing international agricultural research supporting the sustainable development of agriculture (crops and livestock), natural resource management, fisheries and forestry in developing countries” (1). Further information is available on the Center’s Web site (<http://www.cgiar.org/index.html>) and in the most recent informal review of the Center and its activities (2).

The ASB Program operated from 1994 to 2007 as a systemwide program of the CGIAR. In 2006, it evolved into a new global “Partnership for Tropical Forest Margins,” involving more than 90 research institutions, universities, NGOs, community groups, and farmer organizations. Further information is available on its Web site (<http://www.asb.cgiar.org/aboutus>). ASB operated 12 benchmark sites around the world covering the Amazon, the Congo Basin, northern Thailand, Mindanao, and Sumatra (3). In 2005, ASB won the CGIAR’s Science Award for Outstanding Partnership for developing more environment-friendly farming techniques and slowing deforestation.

Authors’ Involvement in the CGIAR and ASB. Several of the authors of the present paper are or have been involved in the organizations described here in a number of ways. These relationships have given us special access to the data reported here and, we hope, a base of knowledge on which to interpret those data. We have been careful in the work presented here to keep our regard for the organizations and those within them from influencing our findings and conclusions. Nonetheless, in the interests of full disclosure, here are our relevant associations:

W.C.C. chaired CGIAR’s external review of the ASB program in 2005 while serving in his present position as a professor at Harvard University.

T.P.T. served as Global Coordinator of the ASB program from 2000 to 2006. From 1995 to 2000, he served in a number of positions in the CGIAR’s ICRAF. Since 2007, he has been a professor at the University of California at Davis, where he serves as the director of the Agricultural Sustainability Institute.

M.v.N. has been with CGIAR’s ICRAF since 1993, where he now serves as Global Science Advisor. He played significant leadership roles in ASB and its spin-off program RUPES.

D.C. has been a scientist with ICRAF since 1998, and now works at its Kenya headquarters.

MA. The MA, involving more than 1,300 experts worldwide, was initiated by United Nations Secretary General Kofi Annan in 2001 “to assess the consequences of ecosystem change for human well-being and the scientific basis for action needed to enhance the conservation and sustainable use of those systems and their contribution to human well-being” (4). ASB was responsible for the tropical forest margins subglobal assessment (ASB-MA), which it described as follows: “This assessment considers the impact of all drivers of deforestation and environmental degradation in the forest margins. Drivers of deforestation include not only migrant smallholders, who practice slash-and-burn agriculture, but also plantation owners, other medium- and large-scale farmers, ranchers, loggers, and state-run enterprises and projects” (<http://www.maweb.org/en/SGA.ASB.aspx>). Details of the ASB-MA were published in 2005 as “Forest and Agroecosystem Tradeoffs in the Humid Tropics” (5).

Accountability in Boundary Work of the ASB-MA. Accountability to ASB was achieved through discussion and approval of the ASB-MA by ASB’s Global Steering Group. This included representatives of both participating international research programs of the CGIAR and relevant national agricultural research organizations from ASB’s host countries. Accountability to the MA was achieved through formal approval of the ASB-MA as an official component of the MA by the MA Board. This included representatives of development organizations and conservation organizations (5, 6).

Negotiation Support in Sumberjaya, Indonesia. Sumberjaya is an upland area of southeast Sumatra originally covered in rain-forest, but with substantial tracts later converted by small farmers to coffee production. Beginning in the 1970s, however, local and state governments increasingly expressed concern that the expansion of coffee farming was endangering downstream watershed services. Lands were therefore increasingly classified as state “protective” forests, with the early 1990s seeing intensifying conflict around a series of police actions to evict small farmer “encroachers.” Government reforms followed, centered on community forest management with new rules of forest tenure (i.e., HKM), conditioned on farmers meeting a complex set of management requirements. Implementation, however, was slow. This was caused in part by farmers’ mistrust of government, and in part by the lack of agreed management practices that would meet goals of watershed conservation and agricultural development (7–9).

Related Analytic Frameworks from the Literature. A “typology of communicative contexts for analysis” with some parallels to the one we present in Fig. 1 and Fig. S1 has been developed by Andrews to explain the use of analysis in decision making for environmental protection in the United States (10). His typology differs in some details from the framework proposed here. However, it is similar in its insistence that the sources and uses of knowledge need to be considered if sense is to be made of the complex array of science-for-policy experiences encountered in today’s world. Michaels (11) presents another complementary typology. It differs from ours in being focused on strategies for communication across the science–policy boundary, rather than the conditions that give rise to such strategies.

Method Details. The new RUPES research conducted for this study consisted of an initial workshop in fall 2006 comprised primarily of scholars engaged in the research of boundary theory, organizations, and work. In this workshop, we formalized our understanding of the research questions and developed our initial protocol. Members of the team conducted research at several RUPES locations in Indonesia in 2007 involving archival research, semistructured interviews, and focus groups with farmer groups; local and regional elected leaders; researchers and field workers from RUPES and ICRAF; local, regional, and national representatives from the Ministry of Forestry and its extension workers; officials from hydroelectric companies; and representatives from local and international NGOs involved in the project. We also cohosted an additional workshop with Brawijaya University in Malang, East Java, comprised primarily of practitioners, NGOs, and government officials in addition to a few scholars of boundary work. The purpose of this workshop was to “truth-test” our findings from the fieldwork with those involved in the agroforestry and watershed sustainable development ac-

tivities. Participants provided feedback and analysis of our research findings and also received training on boundary theory

and work (12). Follow-up field work and analysis of the data occurred in 2007 and 2008.

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Boundary Work		USE of knowledge to support....		
		Enlightenment (U ₀)	Decision (U ₁)	Negotiation (U _m)
SOURCE of knowledge...	Personal expertise (S ₀)	S ₀ ↔ U ₀ <i>Contemplation</i>	S ₁ ↔ U _j <i>Decision</i>	U _k S _i ↔ U _j U _j <i>Politics</i>
	Single community of expertise (S ₁)	S ₁ ↔ U ₀ <i>Demarcation</i>	S ₁ ↔ U _j <i>Expert advice</i>	U _k S _i ↔ U _j U _j <i>Assessment</i>
	Multiple communities of expertise (S _n)	S _i U _j ↔ U ₀ S _j <i>Integrative R&D</i>	S _i U _j ↔ U _j S _j <i>Participatory R&D</i>	S _i U _k U _j ↔ U _j S _j U _j <i>Political bargaining</i>

Fig. S1. Framework for the analysis of knowledge–action dynamics (general version). This is a more general version of the framework for defining contexts of knowledge–action dynamics defined in Fig. 1. The difference here is an additional role, S₀, denoting circumstances in which the potential users of knowledge (U) defined by the columns rely on only their own personal knowledge, or no research-based knowledge at all, to inform their actions. Although this added dimension of the framework was not essential for our boundary work study, it does show the relation of our concerns to a number of common situations, e.g., decision making based on personal judgment and politics whereby power completely dominates knowledge inputs. In addition, there are close parallels between this more general version of our framework and Andrews’ previously noted typology of communicative contexts for analysis (10). An exploration of these parallels would almost certainly be useful, but is beyond the scope of the current report.



Fig. S2. Preservation of forests for humans and orangutans: a boundary object. The Batang Toru watershed in North Sumatra province, Indonesia, still contains approximately 110,000 ha of forest that harbors a genetically unique orangutan population. Proposals to gazette the area as National Park would imply people moving out. Alternative conservation strategies were proposed to respect and enhance the stability of the agriculture–agroforest–forest gradient. This illustration was developed through revisions of drafts between an ICRAF/Winrock team and villagers as a visual statement that agroforests with planted (rubber) as well as naturally established fruit trees form a buffer between the village and the remaining forest on the hills. The orangutans shown use the agroforest as part of their habitat and are not seen as a threat. The illustration, printed as a poster, served as a boundary object in negotiations among villagers, local government, and conservation authorities, supporting the gradient perspective on integrating conservation and development [Copyright: ICRAF (1)].

1. Tata MH, et al. (2010) *Human Livelihoods, Ecosystem Services and the Habitat of the Sumatran Orangutan: Rapid Assessment in Batang Toru and Tripa*. Project Report. Project Report No. RP0270-11 (International Center for Research in Agroforestry, Bogor, Indonesia).

Table S1. The ASB matrix as a boundary object

Land use system	Global environmental concerns		Agronomic sustainability			National policymakers' concerns		Smallholders concerns/ adoptability by smallholders	
	Carbon storage	Biodiversity	Plot-level production sustainability			Potential profitability	Labor requirements	Returns to labor	Household food security
		Aboveground (plants), species per standard plot	Soil structure	Nutrient export	Crop protection	Returns to land (private prices), \$/ha	Labor person, d/ha/y	Dollars per person-day (private prices)	
Forest	306	120	0	0	0	0	0	0	NA
Community-based forest management	120	100	0	0	0	5	0.2–0.4	4.77	\$ + consumption
Commercial logging	94	90	–0.5	0	0	1,080	31	0.78	\$
Rubber agroforest	79	90	0	0	–0.5	0.70	111	1.67	\$
Rubber agroforest with clonal material	66	60	–0.5	–0.5	–0.5	878	150	2.25	\$
Oil palm	62	25	0	–0.5	0	114	108	4.74	\$
Upland rice/bush fallow	37	45	0	–0.5	–0.5	–62	15–25	1.47	Consumption
Continuous cassava/imperata	2	15	–0.5	–1.0	–0.5	60	98–104	1.78	\$ + consumption

ASB created the ASB Matrix to show the relationship between alternative land uses (including natural forest) and key evaluation criteria. The matrix served as a “boundary object” at the interface of a variety of information users (who defined the rows and columns of the matrix) and scientists (who devised the metrics and conducted the measurements that fill the cells). Reproduced here is the original version of the matrix as reported in an internal ASB report in 1998 (1). A fuller discussion of the matrix and its uses, together with the final version of the matrix for a number of ASB cites, has been published in the project’s final report (2).

1. Tomich TP, et al. (1998) *Alternatives to Slash-and-Burn in Indonesia, Summary Report of Phase II, No. 8* (International Center for Research in Agroforestry, Bogor, Indonesia).
2. Tomich TP, et al. Balancing agricultural development and environmental objectives: assessing tradeoffs in the humid tropics. *Slash-and-Burn Agriculture: The Search for Alternatives*, eds Palm CA, Vosti SA, Sanchez PA, Eriksen PJ (Columbia Univ Press, New York), pp 415–440.