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Challenges of connecting international science and local level sustainability efforts: the case of the Large-Scale Biosphere–Atmosphere Experiment in Amazonia

Myanna Lahsen [a,*], *Carlos A. Nobre* [b]

[a] *Center for Science and Technology Policy Research, University of Colorado, Boulder, CO, USA*
[b] *INPE, Av dos Astronautas, 1.758, Jd. Granja - CEP: 12227-010, São José dos Campos - SP, Brazil*

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ABSTRACT

The Large-Scale Biosphere–Atmosphere Experiment in Amazonia (LBA) is a multi-year Brazil-led international environmental science experiment funded by the U.S. National Aeronautics Space Administration, the European Union and Brazil. It is intended to inform decision making under the United Nations Framework Convention on Climate Change (UNFCCC) as well as Brazilian national environmental decision-making related to the Amazon region. Focused on the Amazon region, and primarily on the Brazilian Amazon, the LBA is a case study in issues that can arise when doing globally oriented research in a less developed country setting and a test of assumptions that such research simultaneously benefits global and local levels. This article offers a qualitative evaluation of the extent to which the LBA has achieved its goals and identifies structural obstacles within science that must be overcome to improve the fit between international science programs and efforts to nurture more sustainable use of natural resources in a less developed country.

1. Introduction

This article analyzes the fit between international environmental science and a sustainability agenda in the Brazilian Amazon. Through a case study of the Large-Scale Biosphere–Atmosphere Experiment in Amazonia (LBA), it identifies prevailing socio-cultural and political structures in international science that govern, and sometimes inhibit, the production of "sustainability science," in this case research and research processes striving to harmonize resource use with both economic development and preservation of Amazonian ecosystems.[1] An evaluation of the LBA's achievements illustrates issues that can arise when doing globally oriented research in a less developed country local setting, and serves to test assumptions that an international science project oriented towards the production of cutting-edge international science simultaneously can improve environmental sustainability at the local level. The analysis responds to calls for greater understanding of the fits and misfits between knowledge systems and sustainability agendas.

Harnessing international environmental science programs to local-level sustainability agendas is now defined by many as one of the major challenges of the 21st century (Cash and Moser, 2000; Cash et al., 2003; Clark and Dickson, 2003;

* *Corresponding author at*: c/o Jacy Silveira, Rua Agariba 79 Casa 5, Engenho Novo, 20715030 Rio de Janeiro, RJ, Brazil. Tel.: +55 21 9208 6023.
E-mail addresses: myanna@cires.colorado.edu, myannal@gmail.com (M. Lahsen), nobre@cptec.inpe.br (C.A. Nobre).

[1] Sustainability is an ambiguous concept that often is less obvious to apply in practice and that may refer to environmental as well as economic processes. In this article, we are speaking specifically of ecosystem sustainability. The goal, then, is to preserve ecosystems in ways that optimize the balance between forest preservation and humans' need to use the forests' natural resources.

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International Council for Science, 2002; National Research Council, 1999). To meet this challenge, research communities are urged to ''reform themselves by complementing [their] historic role in identifying problems of sustainability with a greater willingness to join with the development – and other communities to work on practical solutions to those problems'' (Clark and Dickson, 2003). However, there is little consensus among analysts on how to reconcile the production of knowledge with the information needs of decision makers (McNie, this issue; Smith and Kelly, 2003) in large part because of relatively few investigations into how knowledge systems work and how they might be better integrated with decision making processes at multiple levels to facilitate sustainability (Bradshaw and Borchers, 2000; Cash et al., 2003). The research gap is particularly acute for less developed countries, which is of potentially grave consequence since they contain the greater part of the world's human population and biological diversity. Strengthening knowledge systems with the potential to improve ecosystem preservation is thus of prime importance.

2. LBA goals and criteria for an evaluation

The LBA is the largest program in international scientific cooperation ever focused on the Amazon region, the largest global change science project in Brazil, and a central contributor to understanding of the role of the Amazon (including deforestation) in global environmental change. It involves collaboration between predominantly Brazilian, American and European environmental scientists and institutions and has an annual total budget of around US$ 12–15 million for the years 1998–2004, the period of intensive field campaigns.[2] These costs were shared mainly by Brazil and the U.S. National Aeronautics Space Administration (NASA), with Europe contributing a smaller part.[3]

As formulated in its planning document, the ''Concise Experimental Plan'' (LBA Science Planning Group, 1996, p. 4), the LBA's two basic research questions are:

(1) How does Amazonia currently function as a regional entity?
(2) How will changes in land use and climate affect the biological, chemical and physical functions of Amazonia, including the sustainability of development in the region and the influence of Amazonia on global climate?

Reflecting the abilities of the environmental scientific community to coordinate large-scale experiments and create active collaboration among researchers and institutions from the global North and South, the program subsumes more than 120 research projects and involves about 1700 participants (990 of whom are Brazilians) from 63 Brazilian and 143 non-Brazilian institutions (Folha Amazônica, 2004). The collaboration takes place at numerous field sites in the Amazon and around data collected at these sites.

The creation of the LBA was spurred by the wave of environmental concern expressed in the Brundtland Report and the 1992 United Nations ''Earth Summit'' in Brazil, which subsumed worries about high deforestation rates in the Amazon region. A group of Brazilian, American and European scientists shared this concern and proposed the LBA in the hope that it could simultaneously advance basic scientific understanding and preservation of Amazonian ecosystems.

The LBA was also centrally propelled by scientific interest in a continuation of research carried out in the Amazon since the 1980s, such as the Brazil–U.S. collaboration on the Amazon Boundary Layer Experiment (ABLE 2B) and the Anglo-Brazilian Amazonian Climate Observations Study (ABRACOS), among others. The LBA involves integrated, multidisciplinary research modeled after Boreas (the Boreal Ecosystem-Atmosphere Study) – a previous science program focused on the role of Northern, boreal forests in planetary processes – and, to a lesser extent, a similar program in the Sahel (Hapex Sahel). Brazilian and American scientists conceived of the LBA after having collaborated under these other scientific programs. They obtained NASA's and the European Union's support for a major part of the field experiments and associated infrastructure development. Two of the leading American scientists involved in the early planning of LBA were affiliated with NASA and stimulated a top NASA administrator's interest in the LBA's two basic questions, which also could be integrated with NASA's institutional emphasis on remote sensing technologies. Advances in satellite technology had developed the ability to detect deforestation. The growing concern about tropical deforestation and the fact that Brazil was the only country gathering extensive satellite information on the phenomena made collaboration interesting to NASA. Collaboration was also facilitated by the fact that NASA previously had sponsored research experiments (ABLE 2B) in Brazil and had a history of collaborating with the Brazilian Space Research Institute (INPE). INPE was centrally involved in the conceptualization and planning of the LBA and coordinated the LBA in Brazil for the first years of its existence.

On the Brazilian side, two key features secured governmental approval of the project: the scientific capacity building

[2] The program's first phase began in 1998 and will end by the end of 2006, marked by a final intensive field experiment to calculate regional budgets of carbon for Amazônia (the BARCA experiment). NASA is expected to continue to support collaborative synthesis activities through 2008. Since LBA is a Brazil-led project, it is up to Brazil when it ends. In late 2004, the Brazilian government introduced plans to continue the LBA as a national program in which foreign scientists would participate in a more limited fashion, and only at the invitation of the Brazilian Ministry of Science and Technology. There is thus general consensus among LBA scientists that the LBA, as they have known it so far, will end in 2006.

[3] Although NASA has contributed the largest share of direct funds, Brazil is estimated to have contributed at least half of the funding for the LBA indirectly through facilities made available to the LBA as well as salaries of LBA-involved Brazilian scientists and student scholarships. Of the circa US$6 million of NASA funding, a large part goes to U.S. institutions in the form of overhead charges. Another part goes to salaries to researchers and student scholarships. The remainder goes to the actual field campaigns and infrastructure. The money Brazil contributes directly to the LBA does not go towards overhead charges nor to salaries and scholarships. Brazil contributes more than half of the total funds for the LBA if one (1) subtracts foreign institutions' overhead charges from the LBA's budget and (2) includes scholarships made available to students by federal and state governments in Brazil.

the LBA promised and the new knowledge it could yield about Amazonian ecosystems.[4]

Overarching policy goals of the experiment are to support international diplomatic negotiations related to climate change under the UNFCCC and help nurture environmentally sustainable practices in the Amazon region through improved understanding of local and global dimensions of ecosystems and land-use in the Amazon. Underscoring its mission in the area of sustainability, the first lines of the Concise Plan read:

> Despite widespread concern and increased international efforts at conservation, the world's tropical forests continue to disappear at an unprecedented rate. Of vital importance in developing sustainable management and exploitation systems for tropical forests are the questions as to how far human intervention affects the forests' basic capacities to renew themselves and how to safeguard the basic ecological processes ... (LBA Science Planning Group, 1996, p. 7)

The Concise Plan suggests the LBA will provide useful answers in these areas by providing "the insight needed to design sustainable management systems...".

Criteria for evaluating the LBA derived from its own mission statement should thus be based on the extent to which the program has (1) produced new scientific knowledge and (2) had a bearing – or has clear potential bearing – on knowledge creation and decision making related to ecosystem preservation in the Amazon. Criteria for (1) are scientific publications, citations and the creation of resources such as databases. Criteria for (2) are more difficult to develop and apply. In this paper, evaluation of the bearing of the LBA on decision making related to ecosystem preservation in the Amazon will be gauged from the scientific capacity and infrastructure the experiment has engendered, and from the kind of knowledge created under it. Evaluation of the latter will be based on the judgment of the authors, supplemented by those of other persons similarly familiar with the LBA and with the challenge of nurturing sustainable resource use in the Amazon.

3. Evaluating the LBA's achievements

How well has the LBA performed in terms of its goals to (1) produce new scientific knowledge and (2) nurture knowledge creation and decision making related to ecosystem preservation in the Amazon?

3.1. *Scientific production*

The LBA's performance in the area of new scientific knowledge can be gauged from the publications, citations, and data banks it has engendered. In these respects, the LBA has excelled (Philippi Junior et al., 2003). It has produced an extensive, free and publicly accessible data bank and over 700 per-reviewed publications, the vast majority in international science journals. Judging from the extent to which LBA research is cited in scientific assessment reports supporting the international negotiations under the FCCC, LBA research has also been influential (see, for instance, Mata et al., 2001; Nobre et al., 2002, 2004).

3.2. *Environmental policy*

3.2.1. *Potential indirect policy impacts of LBA science*

A scientific debate that has dominated the LBA concerns the role of the Amazon in the global carbon cycle is relevant to diplomatic discussions under the FCCC. Present estimates of global carbon emissions due to tropical deforestation are highly tentative, obstructing efforts to clearly identify relative responsibility for present greenhouse gas emissions as well as the size of national carbon sinks. Because of the size of the Amazon and the high deforestation rate (the Amazon contains the world's largest contiguous tropical forest and the world's largest area of felled forest), greater specification of carbon emission- and sequestration levels in the Amazon would aid solution of the "missing carbon sink" puzzle at the global level.

The LBA has yielded significantly varied estimates of the Amazon region's levels of carbon emission and sequestration rates (Malhi and Phillips, 2004), however, providing political actors amble opportunity to choose their preferred interpretations (Lahsen, forthcoming). In other words, the LBA confirms the observation in science and policy studies that science lends itself to a variety of interpretations and that choices of facts are laden with social and political influences, values and beliefs, especially in the area of environmental policy. Oftentimes an obvious "mechanism of marketing competing political agendas" (Pielke, 2004), environmental science cannot dictate policy nor can it provide irrefutable proof upon which to base policy decisions in all but the most trivial cases (Funtowicz and Ravetz, 1992; Jasanoff, 1990a (1994); Oreskes, 2004; Sarewitz, 2004).

Physically and intellectually difficult to access, scientific publications in themselves are a poor means of reaching policy makers, managers, or the public (Peterson et al., 1997). However, LBA science has also been the source of popular media articles in Brazil and internationally, and a large quantity of them have brought attention to the importance of reducing deforestation in the Amazon.[5] To the extent that LBA basic science insights have impacted policy at the national level, it has been through the intermediary of media coverage. The effect of media coverage is difficult to ascertain and measure. However, it would seem that media coverage of LBA research in general is likely to enhance awareness and concern about threats associated with global environmental change since LBA leaders interpreting LBA data and communicating it to the public draw conclusions in support of

[4] The LBA was approved only by a narrow margin in a context of intense disagreement between representatives of various parts of the Brazilian government in a high-level inter-ministerial meeting. The meeting revealed divergent opinions as to whether or not the LBA would serve Brazilian or Northern interests. National security concerns and fears of "biopiracy" were weighed against the potential benefits. Leaders of some parts of the Brazilian government feared that the LBA would serve foreign rather than Brazilian interests.

[5] For a limited media analysis, see Lahsen (forthcoming). For examples, see Brasil (2003), BBC Brasil (2004), Capozzoli (2002), Diário do Pará (2004), Nobre (2002, 2003) and Silveira (2002).

ecosystem conservation in the Amazon, in line with the initial motivation of the LBA science leaders. In this sense, it is also a likely stimulus of policy action and a force delegitimizing long-standing denial and inaction on the issue of deforestation on the part of Brazilian political leaders (Barbosa, 1993; Guimarães, 1991; Hurrell, 1992; Schmink and Wood, 1992), although national-level receptivity to dominant national media interpretations of LBA science is uneven (Lahsen, forthcoming). In short, though the LBA is at most a single and underdetermining factor in this respect,[6] it lends force to a general transformation of Brazilian discourses and policies in favor of forest conservation.[7]

3.2.2. *Relevance of the LBA science agenda to Amazonian ecosystem sustainability*

3.2.2.1. Capacity building. The LBA has been pioneering in terms of developing scientific capacity and minimizing long-standing practices of "scientific colonialism," which is to say, use of less developed countries' human and material resources in ways that minimally benefit the poorer host countries in terms of intellectual, human, and material gains. The capacity building component contributes to the LBA's goal of advancing sustainable use of natural resources in the Amazon. Capacity building in environmental science is particularly important in less developed countries, as they have fewer financial resources and are most vulnerable to the multiple stresses that arise from rapid, simultaneous changes in social and environmental systems (Kates et al., 2001).[8]

The LBA has exceeded its own expectations in the area of capacity building. As of May 2004, the LBA has supported or is supporting the formation of close to 400 graduate students, roughly 200 at PhD level and 200 at Masters level, a majority of them from Amazonian institutions. Moreover, the LBA has put in place an elaborate infrastructure of scientific instruments, research camps, laboratories, vehicles, and skilled people. At the end of the first phase of the program, much of this infrastructure was turned over to Brazil to use as it sees fit.

The LBA has institutionalized and emphasized free-of-charge data sharing and mutually beneficial scientific collaboration between Southern and Northern researchers in which the former are not merely support staff but full collaborators. Brazilian law requires that Brazilian scientists serve as principal co-investigators in international scientific projects on Brazilian soil. Brazilian LBA scientists, supported by non-Brazilian LBA architects, have insisted that the law be observed not only on paper but in spirit. This has encouraged the formation of friendships and strong collaborative relations between junior and senior Brazilian scientists and their American and European counterparts. These personal and professional ties are likely to engender continued collaboration and exchange after the formal end of the LBA, just as the LBA was an outgrowth of collaboration around previous scientific experiments such as ABLE2B, ABRACOS, BOREAS and HAPEX-Sahel.

Building and maintaining scientific capacity is essential to improvement of the links between "international" knowledge and knowledge "on the ground," both of which are important for the development of robust knowledge and successful public policies sensitive to local human and physical conditions (Cash and Moser, 2000; Cash et al., 2003; Clark, 2003; Clark and Dickson, 2003; Guldin, 2003; Jasanoff and Long Martello, 2004; Long Martello, 2001; National Research Council, 1999; Scott, 1998). The involvement of Brazilian scientists adds important knowledge about local conditions (natural, anthropogenic, and political) that enhances the knowledge production process as well as the dissemination and impact of the results.

The long-term impact of the capacity building component of the LBA depends on the continued ability of the newly skilled persons to find jobs. LBA leaders worry that there may be too few available jobs at the national level to employ and retain the newly trained scientific workforce, as foreign funds for the LBA – and with them, job opportunities in Brazil – are winding down at the end of the first phase of the LBA. Jobs for research scientists are being created much more rapidly in the industrialized regions of Brazil (south and south-east). This could undermine LBA's efforts at advanced training, if Amazonian institutions are not capable of retaining the most talented young scientists in the region. The job situation is even more critical in other Amazonian countries, where scientific research jobs at their Amazonian institutions as a whole are rare if not inexistent.

3.2.2.2. The science agenda. Aside from scientific capacity building, the sustainability dimension is the most obvious point where LBA research could bring benefits at the local level. It is also the least developed dimension of the LBA. The

[6] For other powerful factors propelling this transformation in Brazilian official policy related to forest preservation, see Barbosa (1993) and Hurrell (1992).

[7] Important parts of the Brazilian government are beginning to formally recognize the need to reduce deforestation. This was evidenced in presentations by top officials in the administration under the Luiz Inácio Lula da Silva ("Lula") administration such as José Dirceu (Chief of Staff at the time) and Marina Silva (Minister of the Environment) during the formal celebration of the inauguration of the Kyoto Protocol (Brasília, 16 February 2005). A new feature of the administration's 2004 forestry policy is another indication of the growing resolve to reduce deforestation: for the first time forest protection is an inter-ministerial mandate rather than limited to the intra-institutionally weak Ministry of the Environment. Divisions persist on environmental issues within the government, however, and powerful pro-development interests hold important power in the House (Tabak, 2005).

[8] For present purposes, this discussion will bracket off discussion of problematic power dimensions of capacity building efforts. However, it is important to recognize the extent to which knowledge transmission preserves unequal power-structures and present local perspectives with global reach as objective and globally valid (Lahsen, 2001, 2004; Sachs, 1993). This dimension is generally overlooked in literature on capacity building. A premise of this article is that the best solution in the face of such knowledge/power links is to produce more robust natural scientific knowledge rather than refrain from producing and disseminating such knowledge in response to awareness that doing so also perpetuates problematic political structures. Robust knowledge and approaches are understood here as those which strive to avoid elitist, top-down methods, seeking instead to optimize exchange across scale and in multiple directions between scientists, decision makers, practitioners and lay persons. For discussion of such frameworks, see among many others Cash and Moser (2000), Funtowicz and Ravetz (1992), Irwin (1995) and Jasanoff (1998).

''including the sustainability of development'' clause in the second of the LBA's two central questions opened the program to a wide range of possible research related to the sustainability of the region. However, a 2003 ''mid-term'' independent review by a team of non-LBA Brazilian scientists concluded that the program had performed weakly in the area of identifying and developing social, political and economic implications of the findings, especially as concerns sustainable development in the Amazon region (Philippi Junior et al., 2003).[9] The LBA's weak performance in the area of providing knowledge directly relevant to sustainable development in the Amazon region is the focus of the remainder of this article since (1) it bears on one of the two central goals of the LBA and because (2) it is a case through which to explore difficulties of making international environmental science programs benefit local-level sustainability agendas.

Cynics might think that LBA leaders were mere opportunists who used the sustainability hook insincerely to attract funding. Opportunism – or, more kindly put, pragmatism – is a common feature when research funds are dependent on scientists' initiative and competition. However, at the deepest level, the gap bears witness to long-standing ways of organizing and thinking about science often summed up under the headings of the ''linear model'' and ''curiosity-driven science.'' The latter rest on socio-cultural ways of organizing and understanding science that connect sub-optimally with the problem-driven, short-term needs of communities seeking to reconcile development needs and sustainable resource use.

3.3. *Research gaps–missing links*

In large part, the LBA performed weakly in the area of enhancing sustainable development in the Amazon region because it emphasized natural science and advancement of basic understanding rather than social science and research designed to be of direct use to decision makers affecting land-use in the Amazon, whether government officials or practitioners on the ground. The LBA has produced some research along these lines, but it is a small fraction of the overall pool of LBA projects.

Research by Emilio Moran and others has yielded insight into demographic and economic aspects related to deforestation practices. The LBA also subsumes a relatively small number of more applied science studies related to sustainable selective logging experiments in the National Tapajós Forest in Central Amazônia (Keller et al., 2004), development of non-fire based subsistence agriculture in eastern Pará (Sá et al., 1998) and the agroforestry experiments of reforestation with valuable species in Central Amazon (Feldpausch et al., 2004; Fernandes et al., 1997).

Formal and informal evaluations of the LBA, including those of the authors, suggest that the LBA's sustainability agenda would have been served by more of this kind of research. Specifically, to achieve its sustainability agenda, the LBA should have sponsored and integrated more social science research focused on crucial human dimensions of Amazonian sustainability problems at both the macro- and micro-levels, from the effects of global economic and political structures to local-level technology choices affecting land-use practices.[10] It should have designed its research agendas on the basis of identified user needs and connected it to technology validation and development, in part by analyzing technology options and choices at the local level as well as the social, ethical and environmental consequences of the various options and choices.

Farmers associated with the Proambiente program are an example of potential users of knowledge that LBA researchers can provide. These farmers desire carbon cycle information in order to make crop decisions in ways that enhance carbon sequestration and makes them eligible for funds under mechanisms such as the Clean Development Mechanism.[11] Moreover, the farmers recognize the need for greater collaboration with scientists in order to validate sustainable practices they themselves have developed, such as non-fire based agricultural practices they believe optimize preservation of soil nutrients while also reducing the threat of damaging forest fires (Sá, 2003).

Progress in the areas identified above would, for a program the size of the LBA, require hundreds of people on the ground in the Amazon searching for empirical knowledge and practical solutions. For the knowledge to have impact, it would have to be coupled with comprehensive efforts at information dissemination and education, including technical education. Heeding important insights reaped from past failed modernization projects (Scott, 1998), such education should integrate awareness of the fallacies of top-down, insular approaches to decision making and planning, encouraging instead experimentation with more participative, ethical, and culturally sensitive approaches.

4. Explaining LBA successes and weaknesses

4.1. *Inexperience*

An important reason for the limited amount of tangible results from the LBA applicable to sustainability problems is found in the long-standing and still dominant way of

[9] It should be noted that the data synthesis is planned for 2005 and 2006 and has thus not yet been completed. However, the data to be synthesized are already collected and have limited potential to be directly relevant to the transformation of land-use practices in the Amazon, for reasons discussed in this paper.

[10] Social science research under the LBA has focused almost exclusively on micro-level processes. See, for instance, Moran and Krug (2001) and Moran et al. (2000).

[11] Proambiente is a federal program originated from the small-scale farmer's organization designed to develop systems of household level, economically viable production with environmental benefits for rural areas such as improved air and water quality, conservation of water, soils and biodiversity and reduced risks of fire. The program will be accompanied by efforts to develop mechanisms whereby these environmental services are given economic value on the national market. It establishes networks connecting researchers with small-scale farmers and households at more than a dozen sites around the Amazon (Grupo de Trabalho Amazônico, 2003).

organizing science and understanding its relationship to policy. This paradigm, often referred to as the "linear model" (Pielke, 1997, 2004; Sarewitz, 1996, 2004), assumes that basic research is intrinsically valuable and that it automatically, albeit slowly, leads to applications of benefit to society. This paradigm has long allowed scientists to pay scant attention to whether or not their research helps solve societal problems. It has been accompanied by a perceived dichotomy between basic and applied science and a valuation of basic science as more sophisticated and worthy.[12] This framework of understanding and organizing science is now being challenged. In the face of widely perceived urgent threats to public health and the global environment, analysts are advocating a new mode of knowledge production that ensures greater accountability and more obvious and rapid social benefits from publicly sponsored research (Funtowicz and Ravetz, 1992; Funtowicz and Ravetz, 2006; Gibbons et al., 1994; Lubchenco, 1998; Pielke, 1997; Sarewitz, 1996).

Calls for "sustainability science" (Clark and Dickson, 2003; National Research Council, 1999) is an expression and a stimulant of a paradigm shift in the direction of a new mode of knowledge production within the environmental sciences. Sustainability science involves modes of designing, producing and valuing environmental knowledge which challenge the long-standing tradition in science to separate knowledge production from action (Clark, 2003). Idealized models of sustainability science describe precisely the kind of research of which more was needed for the LBA to fulfill its sustainability goal:

- Sustainability science integrates research and action.
- Action does not lie outside the research domain.
- It is different in degree from traditional structures and orientations in science because it spans spatial scales and diverse phenomena such as economic globalization and local farming practices.
- It integrates the "island empires"[13] of research, monitoring, assessment and operational decision support.
- It accounts for the temporal inertia, complexity and urgency of processes involved (e.g., multiple stresses in the present causing long-term environmental degradation).
- It recognizes the expertise and important input that can be provided by practitioners without formal degrees and scientific credentials.
- It focuses centrally on the character of nature-society interactions and seeks to guide these interactions towards sustainable patterns, promoting the social learning necessary to facilitate institutional and behavioral transformation[14].

Conversations with central LBA architects make it clear that they, as a whole, genuinely wanted the program to provide knowledge in support of sustainable use of the Amazon region. They were propelled in part by the wave of concern about global environmental change, a context that also stimulated questioning of the "linear" understanding of science and of the science-policy interface. However, their inexperience in new ways of doing science combined with a lack of institutional structures to limit their ability to meet the LBA's goal in the area of ecosystem sustainability.

The Concise Plan expresses LBA leaders' sustainability ambitions explicitly. However, the Plan is conspicuously silent on details as to *how* the LBA will make its research relevant to land-use change practices in the Amazon. It awkwardly straddles the old and emergent paradigms in science, integrating central elements of the curiosity-driven or "linear" model with aspirations along the lines of sustainability science. It reflects the general state of sustainability science as an unfinished project. To date, few institutions, if any, have successfully combined the features that characterize sustainability science (Clark, 2003); the LBA is the rule rather than the exception.[15] Indeed, the sustainability science literature is itself limited when it comes to identifying exactly how prevalent norms, institutions and practices in science need to be transformed to allow for greater participation and non-linearity in the definition of research agendas (Bäckstrand, 2003; Gallopin and Funtowicz, 2001). As in the case of LBA leaders, a likely reason for this short-coming is that many leading promoters of the concept of sustainability science themselves are closer to large-scale Earth System Science and global stewardship ideas to than to local-level practices and problems, especially in the developing countries.

4.2. *Prevalence of "Global" and scientific interests*

4.2.1. *(Northern) funding institutions' interests*

The dominance of a basic science agenda over sustainability goals is reflected in the phrasing of the second of the LBA's two main questions. ("How will changes in land use and climate affect the biological, chemical and physical functions of Amazonia, including the sustainability of development in the region and the influence of Amazonia on global climate?".) The phrasing presents the natural science agenda as the overarching frame and subsumes the sustainability goal beneath it. Yet it is unclear how research into the biological, chemical and physical functions of Amazonian ecosystems can *include* sustainable development issues. It would seem more correct to conceive of the natural science agenda as a subpart of a broader sustainability agenda that has to expand

[12] John Dewey's 1916 publication reflects this value system, which is rooted in the 18th century. Dewey describes applied research as "depreciated, if not despised, as purely utilitarian, lacking in cultural significance." By contrast, basic science is sophisticated and valued because it is more "rational," "touches reality in ultimate, intellectual fashion" and is "pursued for its own sake" and aims to "terminate in purely theoretical insight, not debased by application in behavior." *Source*: John Dewey, Theories of Knowledge, 1916, quoted in Menand (1997, p. 206). I am grateful to Daniel Sarewitz (personal communication) for directing us to this passage.

[13] Clark (2003).

[14] Cash and Moser (2000), Cash et al. (2003), Clark (2003), Clark and Dickson (2003), Guldin (2003), Kates et al. (2001), National Research Council (1999).

[15] For support of this point in the environmental sciences, see Baskerville (1997), Franklin (1997), Guldin (2003) and Peterson et al. (1997).

beyond the natural sciences to integrate a more central focus on the social dimensions of sustainability problems.

Research on local dimensions and applications in the design of research projects under the LBA was restrained partly by the orientations of the international partners and funding institutions, and especially by the fact that NASA was the main funding source of the research campaigns. The latter gave NASA considerable power to shape the LBA research agenda according to its institutional mission and interests. LBA planners knew that they had to choose a research agenda that meshed with NASA's strength in sophisticated space and airborne remote sensing technology and its interest in global dimensions. European Union funding for LBA campaigns similarly came primarily from research programs focused on global environmental change. These institutional factors reinforced a focus on monitoring and diagnosis of global change processes rather than social scientific field-work-based projects focused on reducing or preventing environmental change. Yet the latter would more likely result in socially relevant projects benefiting local level practices in the Amazon.[16]

The disciplinary background in ecology on the part of key NASA administrators secured institutional interest in the LBA and helped integrate ground-based methods and research in addition to remote sensing studies. However, these administrators could not alter NASA's institutional emphasis on remote sensing technologies and monitoring in favor of local-scale, on-the-ground practitioner-oriented research integrating the natural and social sciences. NASA's institutional orientation reinforced scientists' interests in global rather than local change, and in basic science rather than knowledge creation more centrally relevant to technology development and the LBA's sustainable mission. Projects with the strongest sustainability applications produced under the LBA were often partly funded by, and perhaps inspired by, non-LBA entities with sustainability missions. In one case (Keller et al., 2004), this was the U.S. Forest Service, in another (Sá et al., 1998, 2002) the SHIFT Program (Studies of Human Impact in Forests and Floodplains in the Tropics, CNPq-Bmbf) and the Pilot Program for the Protection of Tropical Forests (PP-G7).

The LBA's institutional set-up within Brazil during the first years of the program harmonized with INPE's institutional orientations, including a basic science agenda. The LBA's sustainability mission would likely have been better met had it been led by research institutions in the Amazon such as the National Institute for Amazonian Research (INPA) and Embrapa Amazônia Oriental, institutions whose missions include local ecosystem sustainability. The first years of its existence, the LBA's headquarters were at the Brazilian Space Research Institute (INPE) in the south of Brazil, thousands of kilometers from the Amazon and in an organization whose institutional and scientific orientations were somewhat similar to those of NASA.

In Brazil, scientific and financial resources are disproportionately concentrated in the south of Brazil at the expense of the north, including the Amazon region (Silveira, 2003). However, INPE became the LBA's headquarter those first years less by privilege than by default, as the leader of INPA declined requests and invitations in 1994 for INPA to assume that function and because of INPE's experience in coordinating large-scale global change research in the Amazon. At the early planning stage at which a decision had to be reached about the LBA's headquarter, INPA was the only Amazon-based scientific institution involved.

4.2.2. *Scientists' intellectual interests*

NASA's and the EU's emphasis on basic science and on global dimensions fit with the scientific interests of the great majority of LBA scientists, including its leaders, who were trained to study global environmental impacts. LBA scientists, including its planners, were propelled foremost by their scientific interests, as also encouraged by prevailing incentive structures.

One of the key questions propelling LBA scientists concerns the Amazon's role in the global carbon cycle. New findings emerged in the early and mid 1990s suggesting that the Amazon might sequester more carbon than it releases through respiration, serving as an overall carbon ''sink.'' These findings have potential implications for international negotiations related to the allocation of responsibility for human-induced climate change and carbon trading schemes, and are also interesting to scientists because they challenge long-standing ecological theory. The perceived policy relevance of carbon cycle research, combined with scientists' intellectual interests, steered the research agenda away from a more direct and local-level sustainability agenda. While there is emerging interest in how local carbon sequestration projects might attract foreign funds, as in the case of the Proambiental farmers, such interests are not strong presently. Moreover, to the extent that carbon cycle science could be of interest to those affecting land-use in the Amazon (e.g. the Proambiental farmers), it was rarely directly linked to users because LBA scientists did little to make such links. As the mid-term review of the LBA concluded, the latter fell short in the area of communicating research findings outside of academic circles both at national and international levels. Academic incentive structures are an important reason for this weakness.

An LBA scientist lamented the scientific and political focus on the sink question, perceiving it as a distraction from the LBA's goal to be relevant to sustainability. Intimately knowledgeable of Brazilian society, politics and sustainability problems and propelled in his own work by a sustainability agenda, this scientist commented:

> For me [the carbon sink focus] has been unfortunate because Brazilians don't care about sinks. ... LBA has as a

[16] Diagnosis and monitoring of impacts are necessary and important for law enforcement and comprehension of the scale of the problems. In themselves, however, such activities do not alter the patterns of environmental degradation they detect. Brazil has a sophisticated satellite system that closely monitors deforestation in the Amazon, but this has not done much to reduce deforestation because of the absence of state action on the basis of the information. As a lawyer with Brazil's non-governmental Socio-Environmental Institute (ISA) put it, ''The monitoring acts like a big brother, it sees everything at all times. But it doesn't get us anywhere because inspection is with a broken foot. When the illegal loggers are found, they tie up the courts for 5 years. Finally when the state proves the infraction, the forest is felled and the guilty has already pocketed a fortune'' (O Estado de São Paulo, 2005).

charge to have influence on development. And all that momentum could have been targeted better to the needs of Brazilian society. Why wasn't it? Because the type of scientists in the LBA, by and large, are not concerned about policies that influence Amazon (Nepstad, 2003).

Another Brazilian LBA scientist who also strives to make her own work relevant to sustainable land-use made a similar critique, describing LBA scientists as "very competent but in very narrow domains" and as highly resistant to a greater research emphasis on the social dimensions of land-use change in the Amazon and of global change in general.[17]

The two commentaries reflect the fact that despite the wording of the Concise Plan and the intentions of at least some of the central architects of the LBA, the majority of LBA scientists are relatively divorced from concerns and agendas related to the sustainability of the Amazon.

The fact that the LBA was shaped by its planners' backgrounds and interests rather than by concrete sustainability needs distinguishes it from sustainability science models, which emphasize the need to build programs on the basis of expressed needs on the part of users. Research priorities ought to flow from dialogue with such actors (Clark and Dickson, 2003; International Council for Science, 2002, p. 9) – to engender research agendas responding not only to intellectual curiosity, but also to the need to preserve planetary life support systems in ways that also advance social aspirations for economic development as well as poverty and hunger reduction. At present, such integration of users is not general practice in international science. It is not part of the formal training of natural scientists to learn recent thinking about how to construct a more efficient and socially beneficial science-policy interface.

4.3. *Incentive structures*

The incentive structures to which LBA scientists are subjected limit the production of science of use in efforts to use natural resource sustainably. LBA scientists are dominantly academic scientists and as such evaluated on the basis of their production of publications in prestigious scientific journals. This reflects long-standing normative structures in science premised on the assumption of a dichotomy between basic and applied science, and a tendency to privilege the former as more sophisticated and worthy. While success in the environmental sciences may depend on transcending this traditional, academically oriented and compartmentalized mode of producing and conceptualizing knowledge, it is still prevalent (Baskerville, 1997; Franklin, 1997; Guldin, 2003, p. 334; Nowotny et al., 2001; Peterson et al., 1997). Research institutions change slowly and often with resistance (Jacob, 2001), partly because evaluation processes are slow in reflecting and encouraging transformations towards greater emphasis on applications (Franklin, 1997). Reflecting this, research proposals were accepted for funding and/or inclusion under the LBA on the basis of their contribution to cutting-edge, basic scientific knowledge. Funding requests for technology development projects jointly developed by Amazonian universities and local productive sectors were typically declined, such as the development of techniques for sun-drying fish and improving the quality of forest products. Such proposals usually received the standard answer that they fell outside the mission of the LBA.

The few projects with obvious applications under the LBA were accepted centrally on the basis of their contribution to basic scientific knowledge rather than on the merits of their potential applications. For instance, one project to study the impact of various methods of wood extraction was debated at length during the review process. Some LBA leaders questioned the project's eligibility on the basis that it was too applied. The project was accepted because its leader knew the culture of the LBA and focused his justification and research on the contribution of the research in terms of basic understanding of how ecosystems rebound after different types of logging. Considering the LBA's sustainability agenda, and the global sustainability challenge as a whole, more desirable institutional set-up would encourage scientists to connect basic, "cutting-edge" research science to applications.

A lack of experience and training on the part of LBA planners perpetuated the long-standing paradigm. They did not know how to realize the program's sustainability goal and had not been taught to consider themselves responsible for thinking through all the steps between research and applications.

The LBA sought to enhance its impact through educational activities (also part of the capacity building) such as workshops and the production of a textbook targeting a non-specialized body of students and hence potentially some who are or later will become persons whose decisions shape land-use in the Amazon. However, persons responsible for such outreach activities under the LBA complain that most researchers are reticent to devote the time necessary to make the endeavors successful. The academic incentive structures discourage such activities, as they weigh little in academic promotion evaluations compared to highly technical publications. Engaging in communication and policy processes can even be outright dangerous to scientists' careers when their employing organizations do not sanction or support such activities (Guldin, 2003, p. 335).

Scientists who engage most in communication and policy-related activities are generally from organizations that value such behavior. Prominent examples are the Brazilian agricultural research agency, Embrapa, and a few Amazon-based scientific non-governmental organizations (NGOs) that emerged in Brazil in the 1990s. One of the latter is IPAM (Instituto de Pesquisa Ambiental da Amazônia), which has produced accessible literature and workshops to promote sustainable agriculture in the Amazon and reduce forest fires along with many publications in prestigious scientific journals.

In the LBA, the contribution of scientists from IPAM, Imazon and Embrapa was limited because they are few in number and because they were not centrally involved in the design of the LBA. Moreover, only a few scientists from Embrapa were both (1) available and interested in engaging with the LBA and (2) able to span the worlds of cutting-edge science and applications, both technically and culturally. Many scientists in Brazilian institutions and hence relevant scientific expertise in and out of the Amazon are excluded from international science collaboration because they lack the

[17] Anonymous. Interviewed July 2003, Brazil.

necessary domestic and international connections and/or have not sufficiently accepted and absorbed the ways of international science. Aside from the necessary contacts, language barriers limit many Brazilian scientists' successful inclusion in international science, as do difficulties related to working with computers and digital data and adapting to the fast pace that characterizes social interaction and knowledge transmission and production in international forums (Sá, 2003). In other words, when it comes to North–South scientific collaboration, boundary-spanning organizations and individuals (Guldin, 2003; Guston, 1999; Miller, 2001) must also bridge the different work technologies and cultures that prevail at the international, national and local levels. Sometimes such bridging is consciously avoided, as when a subset of Brazilian researchers minimized their engagement with the LBA because their support of development and broad-scale cattle-ranching in the Amazon conflicted with the conservationist spirit pervading the LBA.

5. Conclusion

The LBA has been a valuable investment that by standard measures has been successful and productive, yielding a large number of scientific publications and new knowledge related to global environmental change and the Amazon. Stimulated by Brazilian law, it has also pioneered in the area of building scientific capacity in Brazil. Despite its stated goal to support ecosystem sustainability in the Amazon, the LBA has performed weakest in the area of "sustainability science." This paper has identified cultural, institutional and political reasons for this weakness, including the professional, normative and experiential backgrounds of LBA's planners, the norm-based incentive structures to which they are subjected, the interests and institutional mandate of its northern funders and scientists.

Perhaps the most central obstacle is the fact that sustainability science challenges long-standing, institutionalized practices and normative frameworks that structure the organization of science in the north as in the south, from how scientists select, plan, execute and communicate their own research to how they evaluate the work of others and think about the relationship between science and societal problems. Increasing the relevance of scientific research for sustainability in the Amazon thus depends on changes at these levels, as well as in curriculum content.

Change at such deeply rooted levels are slow and it remains to be seen whether future phases of the LBA, or future Amazon-focused science programs designed by LBA scientists, will be more closely relevant to efforts to ensure ecosystem sustainability in the Amazon. At the very least, natural scientists ought to be encouraged to think more about the applications of their research and how they might reshape institutional structures to maximize societal and environmental benefits also of science projects propelled by scientists' academic interests.

One might argue that the LBA has been excellent in the area of basic science and that it can and should be left to others to apply LBA research to sustainability problems. Proponents of this argument may also point out that the LBA is not the only science project in the Amazon; other projects exist which are more application oriented. The strength of this argument should be balanced against the following factors:

(1) The LBA's blueprint identifies sustainable development as a central goal. If the LBA is a basic science project that does not and should not to concern itself centrally with practical applications, this should be clearer in its self-presentation. This paper has evaluated the LBA on the basis of its own stated goal to be relevant to sustainability projects in the Amazon.
(2) An increasing body of literature suggests that solutions to sustainability problems require coupling cutting-edge academic research and applications, overcoming the long-standing, relative separation of the two realms. Contrary to the assumptions associated with the linear model, basic science and applications can and must be reconciled to a greater extent (National Research Council, 1999; Stokes, 1997). In the Amazon, many non-governmental organizations do application-oriented research but their efforts would be more effective if integrated with high-level academic knowledge. The latter might, for instance, help develop techniques that add value to forest products.
(3) The linear-model-inspired "live and let live" argument in favor of a continued relative separation between international, cutting-edge, academic environmental science such as that produced under the LBA and concrete sustainability projects in the Amazon presupposes unlimited funds and time. Institutions and scientists combining natural science with a sustainability agenda are insufficient in number and financial resources to solve the daunting challenge of nurturing ecosystem sustainability in the Amazon. The Amazon is being deforested and its natural resources degraded very rapidly, to the detriment of the global environment and the present or future quality of life of many people living in the Amazon and elsewhere.[18] Human-induced global environmental change may weaken ecological systems in the Amazon and thereby also further undermine invaluable "ecosystem services" that it provides and, with that, the livelihood of many who live in the region.

Noting urgent and unprecedented environmental and social changes in the world, the President of the American

[18] Though dominant local interests may favor development in the short-term (Becker, 2005), the associated negative environmental costs are increasingly recognized in decision-making processes that traditionally disregarded the environmental factor. This is true even for the Brazilian military, which long have prioritized national security concerns associated with the Amazon, privileging perceived threats of foreign invasions over problems associated with poverty and deforestation. Preoccupations with foreign interests and possible invasion of the region still exist (see, for instance, MacSwan, 2005) but are gradually changing. The Armed Forces are now said to consider the risk of foreign invasion improbable and to identify poverty and deforestation as the principal problems of the region (Jornal do Brasil, 2005). As an apparent part of this general transformation, Brazil's long-standing reticence to seek and accept international financial and technical cooperation focused on the Amazon is lessening (Becker, 2001).

Association for the Advancement of Science, Jane Lubchenco, has called for scientists to devote their energies and talents to the most pressing problems of the day, in proportion to their importance, in exchange for public funding'' (Lubchenco, 1998, p. 491). Heeding her words and noting limits in the time and funds available, one might argue that sustainability science should be privileged over other research projects in the Amazon with less direct and obvious applications.

This study has urged attention to user needs but has focused specifically on problems on the side of knowledge production. However, there is a need for greater understanding of, and solutions to, challenges on the user side as well. Availability of information does not necessarily translate into policy action; it must also be received, believed, and found relevant and useful, and policy makers must have the inclination and the capacity to translate the information into action. Mirroring problems on the production side presented here, studies focused on the reception side suggest an equally important role of cultural, structural and historical factors in whether or not potentially useful knowledge is in fact trusted and used (Jakobsen, 2000; Lahsen, in press; Lahsen, forthcoming; Lahsen and Öberg, 2006; Sloan, 1984). Scholars increasingly recognize the important role of extra-scientific factors in deciding what environmental information, scientific evidence or technological artifact is perceived as reliable and important (Clark and Majone, 1985; Douglas et al., 1998; Global Environmental Assessment Project, 1997; Jasanoff, 1990a (1994); Jasanoff and Wynne, 1998; Kempton et al., 1995; Litfin, 1994; Mitchell et al., 2005; Sarewitz, 2004; Schön and Rein, 1994; Snow and Benford, 1988). Yet relatively few empirical studies have probed the ways in which political and cultural dimensions shape policy makers' receptivity to various types of knowledge (Lahsen, in press; Lahsen and Öberg, 2006). This is partly because social scientists have subjected governmental actors to far less empirical, fine-grained study compared to non-governmental actors, thereby limiting understanding of the political and interpretive frameworks that shape information uptake in governmental policy formation processes.

The focus on knowledge production in this paper also runs the risk of eliding problems in the translation of potentially relevant knowledge into practical solutions. Brazil ranks high among the world's nations in terms of indexed publications but national technological innovation is tiny by comparison (Invernizzi, 2005; Ministério da Ciência e Tecnologia e a Academia Brazileira de Ciências, 2001; Neto, 2002),[19] while – as is the case for less developed nations more generally – it is weak in the area of applying basic knowledge to problems. This also limits technology development in support of sustainable resource use in the Amazon.

While solutions to sustainability problems in the Amazon in some cases might be found through technology, the problems themselves are responses to national- and global-level economic structures that perpetuate poverty, ignorance, and unsustainable, short-sighted extractive approaches to natural resource management. To truly understand and address environmental degradation in the Amazon, one must thus strengthen understanding and recognition of the connections between sustainability problems and global and regional structures of power and inequality, including the impact of capitalism and liberal globalization on environmental practices, standards and policies (Bunker, 1985; Campos Mello, 2001). Unsustainable uses of the Amazon, and the associated land-related violence, human rights violations and exploitation in the region, are influenced directly or indirectly by global markets in (and, hence, global consumption of) export commodities such as soybeans, meat and timber. Recognition of such connections render evident that the causes of local-level problems in the Amazon and their solutions are, in practice, far from purely local, suggesting that the most deep-cutting solutions depend on systemic changes at the global level.

[19] In 2003, Brazil published over 11,000 (1.55% of all papers) papers in indexed international journals as opposed to less than 5000 in 1995. For instance, in 2003 Brazil filed for 259 patents with the USPTO and had 130 patents granted, as opposed to South Korea, which filed for 10.411 and had 3.3944 patents granted (Ministério da Ciência e Tecnologia, 2005).

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Myanna Lahsen (PhD, cultural anthropology, Rice University) grew up in Denmark, France and the United States, and is presently living and doing research in Brazil. A former postdoctoral fellow at the US National Center for Atmospheric Research and Harvard University's Kennedy School of Government, she is presently research scientist with the University of Colorado's Center for Science and Technology Policy Research and Science Officer for Social Sciences for the Brazilian Regional Office of the International Geosphere-Biosphere Programme (IGBP). Her research examines cultural and political dimensions of climate change science and policy in, and between, the United States and Brazil.

Carlos Nobre (PhD, meteorology, MIT) is Senior Scientist at Brazil's Center for Weather Forecasting and Climate Studies (CPTEC), which he directed from 1991 to 2003. Nobre helped conceptualize and coordinate the Large-Scale Biosphere Atmosphere Experiment in Amazonia (LBA) and headed its Science Steering Committee from 1997 to 2004. A permanent member of the Brazilian Academy of Sciences and recipient of Brazil's National Order of Scientific Merit Medal in 1997, Nobre chairs the International Advisory Committee of the Program to Protect the Rain Forests of Brazil (PP G7), among other things, and is the current President of the International Geosphere-Biosphere Program (IGBP).