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Author for correspondence:
Toby A. Gardner
e-mail: tobyagardner@gmail.com

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A social and ecological assessment of tropical land uses at multiple scales: the Sustainable Amazon Network

Toby A. Gardner[1,2], Joice Ferreira[3], Jos Barlow[2], Alexander C. Lees[4], Luke Parry[2], Ima Célia Guimarães Vieira[4], Erika Berenguer[2], Ricardo Abramovay[5], Alexandre Aleixo[4], Christian Andretti[6], Luiz E. O. C. Aragão[7], Ivanei Araújo[4], Williams Souza de Ávila[8], Richard D. Bardgett[2], Mateus Batistella[9], Rodrigo Anzolin Begotti[10], Troy Beldini[11], Driss Ezzine de Blas[12], Rodrigo Fagundes Braga[13], Danielle de Lima Braga[13], Janaína Gomes de Brito[6], Plínio Barbosa de Camargo[14], Fabiane Campos dos Santos[11], Vívian Campos de Oliveira[6], Amanda Cardoso Nunes Cordeiro[15], Thiago Moreira Cardoso[3], Déborah Reis de Carvalho[13], Sergio André Castelani[5], Júlio Cézar Mário Chaul[16], Carlos Eduardo Cerri[10], Francisco de Assis Costa[17], Carla Daniele Furtado da Costa[15], Emilie Coudel[3,12], Alexandre Camargo Coutinho[18], Dênis Cunha[16], Álvaro D'Antona[19], Joelma Dezincourt[4], Karina Dias-Silva[20], Mariana Durigan[10], Júlio César Dalla Mora Esquerdo[18], José Feres[21], Silvio Frosini de Barros Ferraz[10], Amanda Estefânia de Melo Ferreira[4], Ana Carolina Fiorini[22], Lenise Vargas Flores da Silva[11], Fábio Soares Frazão[13], Rachel Garrett[23], Alessandra dos Santos Gomes[4], Karoline da Silva Gonçalves[4], José Benito Guerrero[24], Neusa Hamada[6], Robert M. Hughes[25], Danilo Carmago Igliori[5], Ederson da Conceição Jesus[26], Leandro Juen[17], Miércio Junior[11], José Max Barbosa de Oliveira Junior[27], Raimundo Cosme de Oliveira Junior[3], Carlos Souza Junior[28], Phil Kaufmann[29], Vanesca Korasaki[13], Cecília Gontijo Leal[13], Rafael Leitão[6], Natália Lima[15], Maria de Fátima Lopes Almeida[15], Reinaldo Lourival[30], Júlio Louzada[13], Ralph Mac Nally[31], Sébastien Marchand[16], Márcia Motta Maués[3], Fátima M. S. Moreira[13], Carla Morsello[32], Nárgila Moura[4], Jorge Nessimian[22], Sâmia Nunes[28], Victor Hugo Fonseca Oliveira[13], Renata Pardini[33], Heloisa Correia Pereira[19], Paulo Santos Pompeu[13], Carla Rodrigues Ribas[13], Felipe Rossetti[10], Fernando Augusto Schmidt[13], Rodrigo da Silva[11], Regina Célia Viana Martins da Silva[3], Thiago Fonseca Morello Ramalho da Silva[5], Juliana Silveira[13], João Victor Siqueira[28], Teotônio Soares de Carvalho[13], Ricardo R. C. Solar[2,17], Nicola Savério Holanda Tancredi[17], James R. Thomson[31], Patrícia Carignano Torres[33], Fernando Zagury Vaz-de-Mello[34], Ruan Carlo Stulpen Veiga[35], Adriano Venturieri[3], Cecília Viana[4], Diana Weinhold[36], Ronald Zanetti[13] and Jansen Zuanon[6]

[1]Department of Zoology, University of Cambridge, Downing Street, Cambridge CB2 3EJ, UK
[2]Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ, UK
[3]Embrapa Amazônia Oriental, Travessa Dr. Enéas Pinheiro s/n, CP 48, Belém, Pará 66.095-100, Brazil
[4]MCTI/Museu Paraense Emílio Goeldi, CP 399, CEP 66040-170, Belém, PA, Brazil
[5]Faculdade de Economia, Administração e Contabilidade, Av. Prof. Luciano Gualberto, Cidade Universitária, 05508-010, São Paulo, SP, Brazil

[6]INPA. Instituto Nacional de Pesquisas da Amazônia. Av. André Araújo, 2.936 - Petrópolis, 69080-971, Manaus, AM, Brazil
[7]College of Life and Environmental Sciences, University of Exeter, EX4 4RJ, UK
[8]Universidade Rural da Amazônia, Rodovia PA 256, km 06, Bairro Nova Conquista, s/n, 68625-000, Paragominas, PA, Brazil
[9]Embrapa Monitoramento por Satélite, Av. Soldado Passarinho, 303, Fazenda Chapadão, 13070-115, Campinas, SP, Brazil
[10]Universidade de São Paulo, Escola Superior de Agricultura "Luiz de Queiroz", Esalq/USP, Avenida Pádua Dias, 11, São Dimas, Piracicaba, SP, Brazil
[11]Universidade Federal do Oeste do Pará, Rua Vera Paz, S/N, Bairro Salé, 68040-250, Santarém, PA, Brazil
[12]Centre de coopération internationale en recherche agronomique pour le développement - CIRAD. Campus International de Baillarguet. 34398 Montpellier Cedex 5, France
[13]Universidade Federal de Lavras, Campus Universitário, CP 3037, 37200-000, Lavras, MG, Brazil
[14]Centro de Energia Nuclear na Agricultura, CENA/USP, Universidade de São Paulo, Av. Centenário 303, São Dimas, Piracicaba, SP, Brazil
[15]Universidade do Estado do Pará, Rodovia PA-125, s/n, Bairro: Algelim, 68625-000, Paragominas, PA, Brazil
[16]Universidade Federal de Viçosa, Av. P. H. Rolfs, s/n, Centro, 36570-000, Viçosa, MG, Brazil
[17]Universidade Federal do Pará, Rua Augusto Corrêa, s/n, Campus Profissional II, Guamá, 66000-000, Belém, PA, Brazil
[18]Embrapa Informática Agropecuária, Av. André Tosello, 209, Barão Geraldo, 13083-886, Campinas, SP, Brazil
[19]Universidade Estadual de Campinas, Faculdade de Ciências Aplicadas, Rua Pedro Zaccharia, 1300, Cidade Universitária, 13484-350, Limeira, SP, Brazil
[20]Universidade Federal de Goiás, Campus II, 74001-970, Goiânia, GO, Brazil
[21]Instituto de Pesquisa Econômica Aplicada, Avenida Presidente Antônio Carlos, 51, 17° andar, Centro, 20020-010, Rio de Janeiro, RJ, Brasil
[22]Universidade Federal do Rio de Janeiro, CP 68501, 21941-972, Rio de Janeiro, RJ, Brazil
[23]Stanford University, Energy and Environment Building, 4205, 473 Via Ortega, Stanford, CA 94305, California, USA
[24]The Nature Conservancy, Av. Nazaré, 280, Bairro Nazaré, 66035-170, Belém, PA, Brazil
[25]Amnis Opes Institute and Department of Fisheries & Wildlife, Oregon State University, 200 SW 35th St., Corvallis, OR 97333, USA
[26]Embrapa Agrobiologia, BR 465, km 7, 23891-000, Seropédica, RJ, Brazil
[27]Universidade do Estado de Mato Grosso (UNEMAT), Br 158, Km 148, 78690-000, Nova Xavantina, MT, Brazil
[28]IMAZON, Rua Domingos Marreiros, 2020, 66060-160, Belém, PA, Brazil
[29]U.S. Environmental Protection Agency Office of Research and Development, 200 S.W. 35th St., Corvallis, OR 97333, USA
[30]Ministério de Ciência, Tecnologia e Inovação, Esplanada dos Ministérios, Bloco E, 70067-900, Brasília, DF, Brazil
[31]Australian Centre for Biodiversity, School of Biological Sciences, Monash University, Victoria 3800, Australia
[32]Escola de Artes, Ciências e Humanidades, Universidade de São Paulo, Rua Arlindo Bettio 1000, 03828-000 São Paulo, Brazil
[33]Instituto de Biociências, Universidade de São Paulo, Rua do Matão, Travessa 14, 101, 05508-090 São Paulo, Brazil
[34]Universidade Federal Mato Grosso, Av. Fernando Correa da Costa, s/n, Coxipó, 78060-900, Cuiabá, MT, Brazil
[35]Universidade Federal Fluminense, Rua Miguel de Frias, 9, Icaraí, 24220-900, Niterói, RJ, Brazil
[36]Department of International Development, London School of Economics, Houghton Street, WC2A 2AE, London, UK

Science has a critical role to play in guiding more sustainable development trajectories. Here, we present the Sustainable Amazon Network (*Rede Amazônia Sustentável*, RAS): a multidisciplinary research initiative involving more than 30 partner organizations working to assess both social and ecological dimensions of land-use sustainability in eastern Brazilian Amazonia. The research approach adopted by RAS offers three advantages for addressing land-use sustainability problems: (i) the collection of synchronized and co-located ecological and socioeconomic data across broad gradients of past and present human use; (ii) a nested sampling design to aid comparison of ecological and socioeconomic conditions associated with different land uses across local, landscape and regional scales; and (iii) a strong engagement with a wide variety of actors and non-research institutions. Here, we elaborate on these key features, and identify the ways in which RAS can help in highlighting those problems in most urgent need of attention, and in guiding improvements in land-use sustainability in Amazonia and elsewhere in the tropics. We also discuss some of the practical lessons, limitations and realities faced during the development of the RAS initiative so far.

1. Introduction

Land-use and land-cover change associated with agricultural expansion and intensification is the most visible indicator of the human footprint on the biosphere [1–3]. Ongoing land-use change is most acute in the tropics [4], with *ca* 50 000 km^2 p.a. of native vegetation being cleared [5]. These changes are driven by increasing resource demands from a larger and wealthier human population, coupled with the effects of increasing economic globalization and land scarcity [6]. The creation and strengthening of more sustainable development trajectories in the twenty-first century depends on our ability to balance rising demands for food, energy, natural resources and the alleviation of hunger and poverty with the protection and restoration of natural ecosystems, and the critical ecosystem services they provide [7,8].

Amazonia represents a major sustainability challenge: as well as being the world's largest remaining tropical forest, the entire Amazon biome is home to more than 30 million people and provides locally, regionally and globally significant human-welfare benefits, including economic goods (e.g. timber and agricultural products) and non-market ecosystem services, such as climatic regulation and biodiversity conservation [4,9,10]. Rapid social and ecological change has left the future of the Amazon region uncertain [11–13]. In the Brazilian Amazon, in particular, recent reductions in the rate of deforestation, expansion of protected areas, increased market-based demand for more responsible land-use practices, and a strengthening of local and regional governments and civil society organizations provide some cause for guarded optimism that the Amazon economy can be set on a sustainable footing [14–16]. However, we need to ensure the right choices are made as soon as possible, thereby reducing the likelihood of costly or potentially irreversible damage to both social and ecological systems in the region [12,17]. Science can help this process by identifying the problems that need to be addressed first, and assessing the long-term social and ecological implications of land-use alternatives in planning for both regional development and ecological conservation [2,18,19].

While there is already a substantial body of social and ecological knowledge on the Amazon [11,20–22], scientists are often criticized for failing to deliver the evidence most needed to foster sustainability [23]. Criticisms include the fragmented and disciplinary nature of many research projects, a narrow focus on specific ecological or social problems and spatial scales, and a weak connection to local actors and institutions that are ultimately responsible for implementing changes in land-use policy and management [22–25].

Here, we present the work of the Sustainable Amazon Network (RAS; *Rede Amazônia Sustentável* in Portuguese), which is a multidisciplinary research initiative involving more than 30 research institutions and partner organizations. The overall aim of this paper is to present the conceptual and methodological basis of the RAS initiative while also discussing many fundamental challenges that confront research on land-use sustainability across the tropics. Building on the work of a number of earlier and groundbreaking interdisciplinary assessments in the Amazon, including the LBA (Programa de Grande Escala da Biosfera-Atmosfera na Amazônia) and GEOMA (Pesquisas de Desenvolvimento de Métodos, Modelos e Geoinformação para Gestão Ambiental) research programmes [11,21,26], RAS seeks to address some of the limitations listed above by assessing the sustainability of land-use systems in two dynamic regions of eastern Brazilian Amazonia. The research approach adopted by RAS offers three advantages for addressing this overarching goal: (i) the collection of synchronized and co-located ecological and socioeconomic data across broad gradients of past and present human use and exploitation of natural resources; (ii) a nested sampling design that allows comparisons of the ecological and socioeconomic conditions associated with different land uses to be made across local, landscape and regional scales; and (iii) a strong engagement with a wide variety of actors and non-research institutions.

Drawing upon the strengths of our approach, RAS aims to make important advances in understanding the sustainability challenges facing Amazonia with regards to four broad objectives. First, we aim to quantify and better understand the ecological consequences of forest clearance, forest degradation and exploitation, and agricultural change (including cattle farming and silviculture) at several spatial scales. We are particularly interested in assessing the relative importance of local- and landscape-scale variables, as well as the extent to which past human impacts can help explain observed patterns in current ecological condition. Our measures of ecological condition include changes in terrestrial and aquatic biodiversity, carbon stocks, soil chemical and physical condition and aquatic condition. Our second objective is to examine the factors that determine patterns of land use, management choice, agricultural productivity and profits (and hence opportunity costs for conservation) and patterns of farmer well-being. Beyond input cost, geophysical (e.g. soil type, topography) and location (e.g. road and market access) factors, we recognize the potential importance of social–cultural factors in influencing land-use behaviours, including geographical origin, technical support, credit access, social capital and the importance of supply chains. Third, we plan to use our multidisciplinary assessment to evaluate the relationships between conservation and development objectives and identify potential trade-offs and synergies. Here, we are interested in the relative ecological and socioeconomic costs and benefits of alternative land-use and management choices, and the potential for feedbacks, multiple scale interactions and dependencies and unintended ('perverse') outcomes. Last, RAS seeks to help enable future research initiatives to maximize their cost-effectiveness by examining the implications of choices made with respect to variable selection, sampling design, prioritization of research questions and analyses, and approaches for engaging with local actors and institutions and disseminating results.

The remainder of this paper focuses on describing the key methodological components and novel features of our research design. We highlight some of the practical lessons and realities faced during the development of the RAS initiative so far, and identify the possible ways in which RAS could have a lasting impact in guiding improvements in land-use sustainability in Amazonia and elsewhere in the tropics.

2. The Sustainable Amazon Network: research design

(a) A conceptual framework for assessing land-use sustainability

RAS is inspired by the now well-established paradigm of 'sustainability science'—a science that is focused explicitly on the dynamic interactions between nature and society and is committed to place-based and solution-driven research across multiple scales [27,28]. Making explicit our understanding of the interactions among and between social and ecological phenomena, and their relationship to an overarching sustainability agenda is critical to the effectiveness and transparency of such a research programme.

The challenge of realizing a more sustainable development trajectory for the Amazon region lies in identifying, protecting and restoring the balance of ecological and socioeconomic values necessary to maintain the flow of critical ecosystem services and adapt to changing conditions, while also safeguarding the ability to exploit new opportunities for human development. The starting point for any research programme on sustainability is the selection of a set of socio-ecological values that can provide a basis for assessment. Our focus in RAS is on the conservation of forest-dependent biodiversity (terrestrial and aquatic), the conservation and enhancement of carbon stocks, soil and water quality, the provision of agricultural, silvicultural, timber and non-timber forest products, and the protection and betterment of human well-being.

From this basis, the RAS research process can then address our primary objectives in helping to quantify and understand some of the social and ecological problems and trajectories faced by the Amazon region, examine interactions and the potential for costly or potentially irreversible impacts, and evaluate the social and ecological costs, benefits and trade-offs associated with proposed management interventions. We view the transition towards sustainability as a guiding vision for continuous improvements in management practices rather than a search for a static blueprint of best practice techniques. Within this framework, we see the role of research as providing both an ongoing measure of management performance and a laboratory for testing new ideas for positive change.

Building on earlier work by Collins *et al*. [19], we present a simple framework of how we view the interacting components of our social–ecological study system, and the hypothesized cause–effect relationships, assumptions and feedbacks that provide a foundation for setting specific research objectives (figure 1). Outcomes measures (i.e. changes in valued attributes, such as native biodiversity, ecosystem service provision and human well-being) are captured in both the social and the ecological dimensions, and through changes in the stocks and flows of ecosystem services. Effects on these measures are felt through the cascading effects of changes in human behaviour

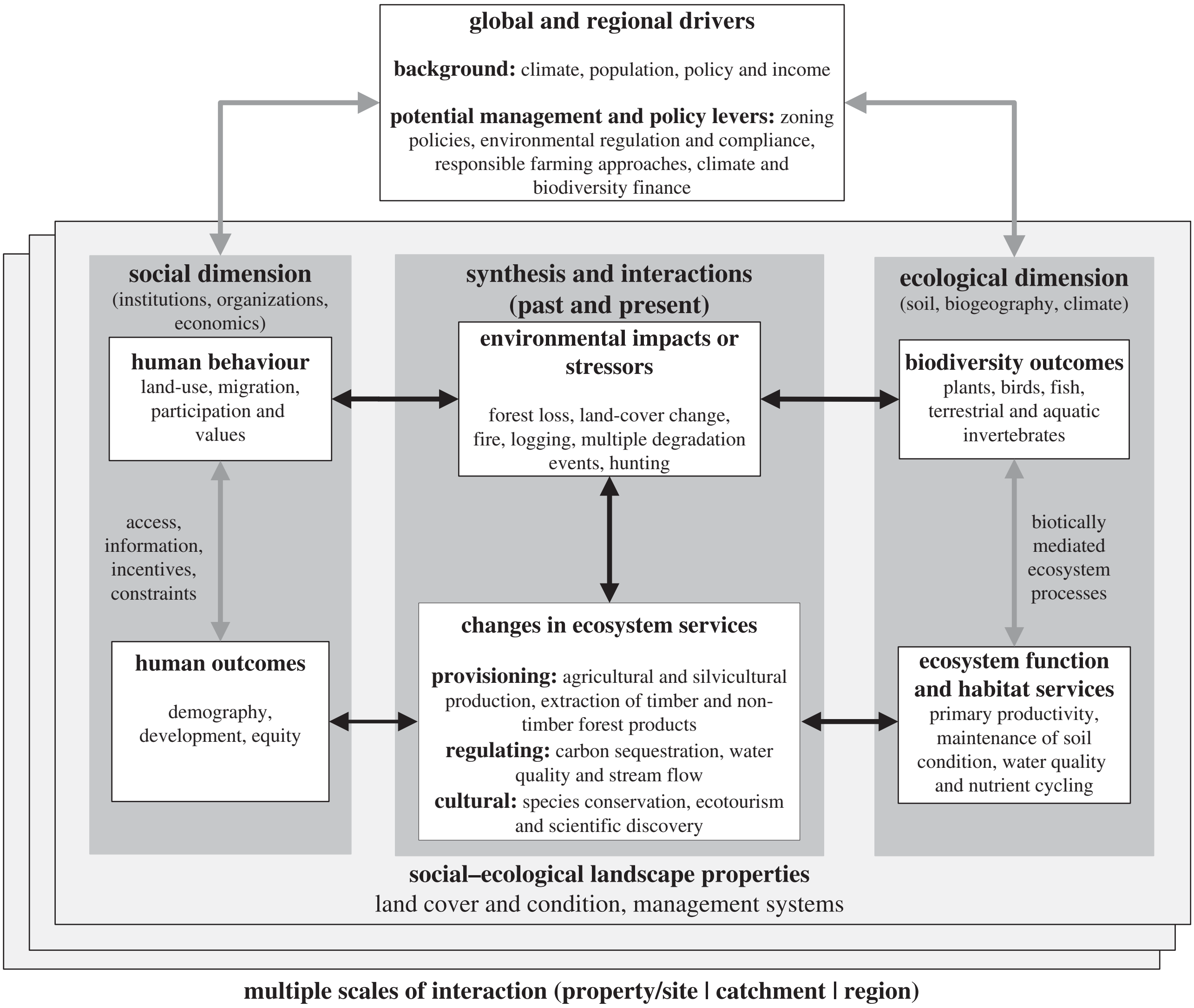

Figure 1. Conceptual model of study system under investigation by the Sustainable Amazon Network. Adapted from a generic framework presented in Collins *et al.* [19] to illustrate how we view the interacting components of our social–ecological study system, and the hypothesized cause–effect relationships, contexts (social and ecological dimensions and social–ecological interactions), assumptions and feedbacks between outcome measures (e.g. related to human well-being, biodiversity and ecosystem service provision), impacts and social and ecological processes, which together provide a foundation for setting specific research objectives. Not all influences and feedbacks are of equal importance and no attempt is made in the model to distinguish relative effect sizes. Social–ecological landscape properties are emergent and dynamic changes in landscape features that mediate relationships between social and ecological phenomena. System dynamics play out across multiple spatial scales. Variables listed are those that have been studied by RAS.

and associated environmental impacts on landscape properties and ecosystem functions. Each one of the influence arrows in figure 1 encompasses a set of specific, disciplinary research questions. The importance of diverse human impacts (both faster dynamics (such as fire and logging) and slower dynamics (such as cumulative land-use change and repeated degradation events)) in determining changes in outcome variables is examined using a space-for-time substitution across a highly replicated network of sampling locations and landholdings, coupled with detailed remotely sensed time-series analysis of past land-cover change and forest degradation. A focus of our work is understanding the extent to which landscape properties (often measurable from satellite and secondary data alone and used to compare multiple landscapes) can provide adequate proxies for understanding changes in the sustainability trajectory of the system as a whole. As much as possible, we try to ensure that the interpretation of our results takes account of the spatial scale of observation, and unmeasured factors, including the effects of external drivers such as climate change and global markets, on the study system. Last, we seek to characterize the effects of a set of potential management and policy levers on the long-term dynamics and outcomes of the study system (figure 1).

(b) Key RAS design features

RAS is an example of a research initiative that collects matched social and ecological data at multiple scales and of relevance to multiple sustainability problems (see also [29]). A number of features of the research design adopted by RAS offer clear advantages for addressing questions about land-use sustainability and management.

(i) Spatial scale of assessment

Much of the existing social and ecological research in the Amazon (and elsewhere) has not been conducted at the most relevant spatial scales for assessing and guiding the development of more sustainable land-use strategies. Research has concentrated either on the entire Amazon basin, which often depends upon very coarse-scale data and obscures critically important inter- and intra-regional processes and interactions

[30], or on detailed work on a few intensively studied research sites, which captures only a tiny fraction of the variability in environmental and land-use gradients that drive much social and ecological change (see [10] in the case of biodiversity research). While both large- and small-scale research is necessary, much more work is needed at the 'mesoscale' level (i.e. spanning hundreds of kilometres and coincident with the scale of individual municipalities in Brazil). The RAS assessment was conducted in two study regions in the Brazilian state of Pará: the municipality of Paragominas (1.9 million hectares) and part of the municipalities of Santarém and Belterra (*ca* 1 million hectares) (figure 2). There are several important advantages to working at this spatial scale. The socioeconomic and ecological data collected by RAS cover broad gradients of change in both ecological (e.g. natural factors, such as soil type and the extent of forest loss, degradation and land-use intensification) and socioeconomic variables (e.g. rural population density, property size, wealth and market access), thereby affording more confidence in the general relevance of the patterns, drivers and trade-offs inferred from sample data [31]. In addition, a focus at the mesoscale facilitates assessment of the importance of both local (farm) and regional (state and biome) processes and objectives in a way that work focused on either smaller or larger scales cannot readily achieve. Finally, municipalities (or the equivalent scale of administration elsewhere) are also the administrative unit with arguably the greatest awareness of local pressures on natural resources and social services, and the greatest responsibility for institutional linkages between local communities and states or regions [30].

(ii) Choice of study regions

The RAS study regions of Paragominas and Santarém–Belterra differ both biophysically and in their histories of human occupation and use. By collecting data from two distinct regions of eastern Amazonia, we have a rare opportunity to better understand the extent to which inferences derived from one region can be generalized to another.

The modern city of Santarém, once a centre of pre-Colombian civilization, was founded in 1661, whereas Paragominas was founded as recently as 1959. Recent development of both regions has been closely associated with the construction of federal highways. Northern Santarém and neighbouring Belterra have been densely settled by small-scale farmers for more than a century. By contrast, Paragominas had a very low population density prior to its colonization by cattle ranchers from southern Brazilian states in the 1950s and 1960s, and the boom in the timber industry during the 1980s and 1990s. Both regions are relatively consolidated, with decreasing rates of deforestation of primary vegetation, although on-going paving of the highway means southern Santarém will probably experience both increased human colonization and agricultural expansion in the near future. Large-scale, mechanized agriculture became established in both regions only in the early 2000s and has increased rapidly in recent years (usually at the expense of both pastures and secondary forest), currently occupying approximately 40 000 and 60 000 ha in Santarém and Paragominas, respectively. Paragominas has also witnessed a rapid recent expansion of silviculture (mostly *Eucalyptus* spp. and *Schizolobium amazonicum*). Both regions are distinct from the agro-industrial frontier in Mato Grosso which is dominated by large-scale mechanized farming primarily for export [32,33]. Although mechanized farming is expanding rapidly in both study regions, in contrast to Mato Grosso, the majority of properties are less than 1000 ha. Moreover, local and regional urban centres still provide significant markets for cattle, and landscapes are interspersed with a diverse array of densely populated small-holder colonies and agrarian reform settlements.

Both Santarém and Paragominas have recently embarked upon high-visibility, multi-sectoral sustainability initiatives; specifically, a moratorium on expansion of soya bean from deforested areas in Santarém, and the foundation of the *Município Verde* (Green County) initiative for promoting sustainable land-use systems in Paragominas. These processes have strong support from non-governmental organizations, farmer's unions and local government, and have facilitated the development of RAS by helping us gain trust with local actors and institutions, tailoring the research planning and design towards local priorities and needs, and increasing receptivity towards project results and recommendations.

It is not viable to repeat the scale of assessment of the RAS initiative in every tropical forest region around the world. However, by working at multiple scales and in two differing municipalities that encompass many characteristics of eastern Amazonia and elsewhere, such as large areas of extensive cattle pasture, emergent mechanized agriculture and a population that is highly mobile and dominated by small-holder farmers, we believe that our results provide a suitable laboratory for better understanding many of the risks and opportunities facing the development of more sustainable landscapes across the wider region. By concentrating our efforts in two regions that have received particular attention from existing initiatives in sustainable land use, our results almost certainly will receive greater exposure to, and engagement with, a wide range of decision makers. Last, a key focus of our work is to employ our uniquely comparable and diverse datasets to identify a subset of cost-effective ecological and social indicators that can help guide applied research and monitoring work in other study regions.

(iii) Sampling design

The RAS sampling design is based on a sample of 18 third- or fourth-order hydrological catchments (*ca* 5000 ha) in each region. Catchments are distributed over a gradient of forest cover in 2009 (10–100% in Santarém; 6–100% in Paragominas; figure 2), with detailed ecological and socioeconomic information being collected from study transects and individual farms within each catchment (figure 2; electronic supplementary material). Advantages to this nested design include the potential for determining the relative importance of drivers and constraints that operate at different spatial scales, and the capacity to make connections between local/individual (farm) and larger scale/public (municipality and state) conservation and development objectives (table 1). Sampling at the catchment scale also permits the integration of terrestrial and aquatic information, and the assessment of changes in ecological and socioeconomic variables that are highly correlated at local scales, such as cumulative deforestation, economic activities and human population density. The 36 study catchments (figure 2; electronic supplementary material, figures S1 and S2) were selected to capture the full deforestation gradient, while incorporating priority areas identified by members of the municipal governments and farming communities (e.g. agrarian reform settlements, traditional rural communities and areas of recent agricultural expansion and development).

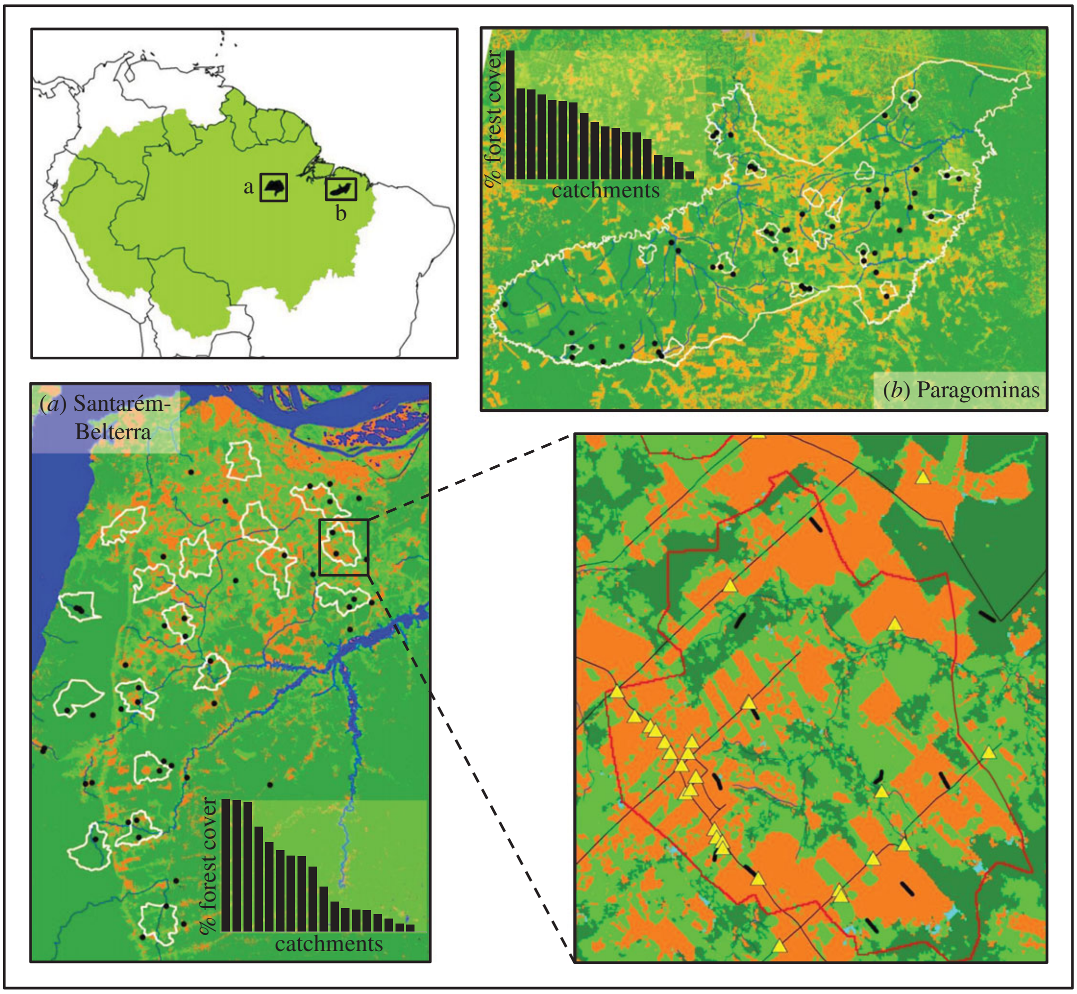

Figure 2. The Sustainable Amazon Network nested sampling design. Distribution of study catchments (white) is shown within both Paragominas (*a*) and Santarém-Belterra (*b*). Black circles show location of streams sampled during the aquatic assessment. Black bar charts show distribution of remnant forest cover across catchments. (*c*) The distribution of study transects (black lines) and the principal household of producer landowners (triangles) in the catchment of Boa Esperanca in Santarém. Land-use classification derived from Landsat 2010 image, showing primary forest (grey), secondary forest (light grey), deforested areas (white) and major water bodies (dark grey). (Online version in colour.)

Ecological data were collected from a sample of 300 m study transects in every catchment, distributed using a stratified-random sampling design, where a standard density of transects (1 per 400 ha) was distributed across the catchment in proportion to the percentage cover of total forest and production areas (encompassing agriculture, pasture, fruiticulture and silviculture; figure 2). For example, if half of the landscape was covered by forest, then half of the transects were allocated to forest. In catchments with very low levels of forest cover we sampled additional forest transects to ensure a minimum sample of three transects in all catchments. Within each of these two land-use categories (forest and non-forest), sample transects were distributed randomly with a minimum separation of 1500 m to minimize spatial dependence. The use of this stratified-random sampling design provided a balance between the need for: (i) proportional sampling of forest and non-forest areas, and a sufficient density and coverage of sample points to capture major differences in landscape structure and composition among different catchments; and (ii) a well-dispersed set of sampling points across forest and non-forest areas that captured important environmental heterogeneities within each catchment and across the region as a whole, helping to minimize problems of pseudo-replication. Aquatic sampling was conducted across 50 stream sites, each 150 m long in each region, with samples distributed along a gradient of prior human impact based primarily on the amount of remnant forest cover in the upstream catchment (and not constrained to terrestrial study catchments).

Socioeconomic data were collected from all rural properties with an ecological study transect. Owing to the stratified design, transects tended to be in larger properties and under-represent smaller farms. Therefore, we mapped all rural producers in each catchment and sub-sampled a maximum of 20 randomly selected properties (with at least 1 ha and producing in 2009). Given our focus on the producer community, this sample excluded urban and periurban areas, but could include some of the same farms in the transect-based sample. This combination of sampling techniques enables us to describe the dominant socioeconomic and demographic characteristics of different producers, and to provide a detailed socioeconomic profile of the farming population in each catchment (figure 2). Where rural properties had more than one household (e.g. where there are workers or relatives living on the property), additional surveys on household demography, origins and well-being were made according to the total number of residences (table 1).

(iv) Social and ecological field sampling

RAS project members conducted a detailed assessment of ecological and socioeconomic patterns and processes in

Table 1. Remote-sensing, socioeconomic and environmental data sampled by the Sustainable Amazon Network.

		summary characteristics			
variable type	**variables**	**Paragominas**		**Santarém**	
remote sensing	biannual land-use classification (since 1988 in Paragominas and 1990 in Santarém-Belterra); age of deforestation; frequency and timing of forest degradation events; age and frequency of secondary forest regeneration; mapping of fire and logging scars; indices of deforestation and forest regeneration trajectories; cover of mechanized agriculture since 2000 (MODIS images); land-use intensity by hydrological distances between stream networks and forest remnants				
socioeconomic	property sizes in socioeconomic survey	number	area surveyed (ha)	number	area surveyed (ha)
	0–25 ha	44	936	150	1656
	25–100 ha	47	3030	110	7587
	100–300 ha	20	3577	20	3837
	300–1000 ha	16	9222	21	12 397
	over 1000 ha	44	238 979	16	62 978
	total number of properties	171	255 744	317	88 455
	total number of households	223		400	
	survey modules	property characteristics; household characteristics, demography and well being; productivity and inputs of different production systems; fire use and impacts; forest use (and hunting)			
soil	physical structure, soil fertility, total C and N, δ13C and δ15N, phospholipid fatty acids (PLFA) analysis of soil microbes, microbial biomass, soil water soluble nutrients, soil emissions of CO_2, NH_4, N_2O	3120 and 2580 soil samples from Paragominas and Santarém, respectively. Five replicates from each transect and at three depths (0–10, 10–20, 20–30 cm). Microbial and PLFA data, soil water soluble nutrients and soil gases emissions for selected catchments from Santarém only.			
vegetation and carbon stocks	biomass and vegetation structure (including dead wood, leaf litter and structural measurements)	44 359 stems measured and identified		38 584 stems measured and identified	
	tree, liana and palm diversity	1052 species		1118 species	
	disturbance	observations of fire and logging scars and other damage on all stems			
terrestrial fauna	birds	364 species		377 species	
	dung beetles	85 species 53 113 specimens		99 species 40 664 specimens	
	ants	*ca* 300 species		430 species	
	orchid bees	28 species		34 species	
	ecosystem functions	n.a.		dung removal, soil turbation, and seed dispersal by dung beetles, and seed predation by ants	
aquatic system	physical habitat	237 measurements relating to channel morphology, substrate, habitat complexity and cover, riparian vegetation, channel–riparian interactions and disturbance			
	aquatic quality	physical and chemical parameters of water (dissolved oxygen, conductivity, pH, temperature, nitrate and ammonia)			

(*Continued.*)

Table 1. (*Continued.*)

variable type	variables	summary characteristics: Paragominas	summary characteristics: Santarém
	fish	112 species 18 669 individuals	71 species 7990 individuals
	Ephemeroptera, Plecoptera and Trichoptera	49 genera 14 113 individuals	54 genera 7937 individuals
	Heteroptera	9 genera 1847 individuals	14 genera 543 individuals
	Odonata	97 species 1990 individuals	68 species 1849 individuals

both study regions between April 2010 and August 2011 (table 1 and figure 2; electronic supplementary material). Choices of sample variables and methods were based on our research priorities, cost-effectiveness and the need to collect a large number of representative samples [34] (table 1). Sampling of terrestrial biodiversity focused on trees and lianas, birds, dung beetles, ants, orchid bees and soil microbes. In a subset of catchments, additional measurements were made of ecosystem functions mediated by beetles and ants (including dung burial, seed dispersal and seed predation). Aquatic biodiversity (and metrics of aquatic condition) consisted of fish and macroinvertebrate assemblages (table 1). Ecosystem service supply was measured for carbon stocks (above- and below-ground) and the maintenance of soil condition (physical and chemical properties). The habitat structure of both terrestrial and aquatic environments was assessed using a combination of measures of canopy openness, vegetation structure, dead wood and leaf litter, and the morphology and substrate of stream channels. Socioeconomic data were collected on the characteristics of study properties (such as land cover, legal status) and producer households (including household demography, producer origins, income, access to services, subjective measures of well-being), costs and productivity of different production systems (livestock, arable and perennial crops, silviculture and timber harvesting), fire use and effects, and the benefits and costs of maintaining forest reserves (including the extraction of timber and non-timber forest products, and risks of invasion and theft) (table 1).

Legacy effects of past human impacts are known to be important for both ecological and social systems, but have been poorly studied to date [35,36]. Remote-sensing analyses were based on a 22-year time series and provide information on changes in land use, forest extent, timing and frequency of forest degradation and age of regeneration (see the electronic supplementary material, table S2). These data provide the basis for validating remotely sensed indicators of ecological and land-use change with direct field observations (e.g. retention and loss of forest biodiversity, forest fires and land-mechanization).

3. Practical lessons and realities from the field

The acquisition of extensive and reliable knowledge about the Amazon is dependent on research networks that can effectively exploit economies of scale in shared resources and technical expertise, recognize and make explicit interconnections and feedbacks among sub-disciplines, and increase the temporal and spatial scale of existing studies [22]. However, building effective multi-sector and interdisciplinary research programmes at large spatial scales remains one of the most difficult challenges facing sustainability science [37].

One of the greatest challenges of the RAS project has been developing and maintaining engagement with partners from multiple sectors, institutions, local governments, civil society organizations and farmer associations. More than half of the remaining forest in the Amazon lies within private land [25], and one of the novel aspects of RAS is the collection of data from complex landscapes with multiple owners that encompass a broad spectrum of culture, wealth and education. Establishing contact, building a minimum level of trust, and securing permissions from more than 200 private landowners across the 36 study catchments incurred significant costs in time and resources. This was especially difficult in areas with a legacy of conflict over deforestation and the exploitation of natural resources. Such 'transaction costs' are rarely factored into or supported by funders of major research programmes.

Despite the challenges, most landowners recognized the value of research in strengthening the evidence basis for what are otherwise largely rhetorical and highly politicized debates regarding the effects and drivers of land-use change. The diversity of institutional partners that make up RAS, including local organizations, and those directly concerned with agricultural development and local conservation initiatives, was critically important in building trust. While the establishment of meaningful partnerships with very different types of landowners (including some of the poorest and richest farmers in the study regions) was critical for the success of RAS, it was also important to avoid over-promising and over-committing on the benefits to individual land owners from project outcomes. Considerable care was taken to manage expectations by distinguishing clearly the purpose of research from rural development and agricultural extension, and presenting realistic timetables for project participation and the dissemination of results.

Maintaining a meaningful level of engagement with our network of local partners is critical to help maximize the relevance of our analyses of project data to local sustainability problems [23]. We are keenly aware that the difficulties inherent in giving adequate attention to the needs and problems facing local communities can increase the chance of drawing inappropriate conservation and development recommendations from our work. We are wary of presenting and interpreting trade-offs too simply, and we acknowledge that simplified quantitative analyses and narratives that only take account of a limited set of attributes can obscure important dynamics and dimensions of value, often resulting in the marginalization of some interest groups [38]. Although commonplace in research projects such risks are rarely made explicit.

Within the RAS research network, we encountered many of the problems faced by other multidisciplinary projects, including the need to overcome differences in values, language and modes of thinking among disciplines [22,24]. There are no easy answers to such challenges, though we have found that co-location of researchers from different disciplines within the same field teams, use of a shared online management platform and group exercises (such as participation in conference symposia and writing this paper) have all helped promote constructive dialogue. RAS has its origins in three previously independent research projects that were amalgamated together with more partners and funding sources into a single initiative with shared goals, budget and management structure. While this historical trajectory led inevitably to a more complex funding and communication system, the resulting strong sense of ownership shared by many project members often led to a more open, interactive and democratic decision making process during project planning and execution.

Many of the greatest challenges in developing RAS arose from mundane problems of coordinating the collection, processing and analysis of data. There is a need for continual reassessment of the value and purpose of new measurements or additional samples, and the extent to which more data are necessary to address the priority questions. Cost-effectiveness in time and resources are often ignored in conservation research (e.g. in biodiversity surveys [34,39]), yet the effectiveness of research would be significantly improved if these considerations were consistently taken into account in project planning and development. We suggest that complex projects such as RAS establish ‘stopping rules’, both in the collection of more field samples and in cutting losses in areas where progress is slow or negligible. The marginal costs of more field data may appear to be little, but they must take account the costs of laboratory and analysis work, and the transaction costs of managing increasing project complexity.

4. Next steps: guiding improvements in land-use sustainability

Work to address our first two objectives is ongoing in many disciplines in RAS to assess and better understand the ecological and socioeconomic consequences of land-use and landscape changes, with synthesis analyses of trade-offs and scenarios scheduled from 2013. We hope that the outcomes from RAS can help guide improvements in land-use policy and management in several ways. At the simplest level, the quantification of deleterious trends in valued attributes (e.g. declines in forest biodiversity, ecosystem service production and socioeconomic values) and the identification of key stressors can both help to identify management priorities. A clearer understanding of spatial patterns of ecological and socioeconomic condition is fundamental for understanding the appropriate locations, scale, starting conditions and potential constraints associated with any future changes in management actions [40]. Such basic information is still lacking for much of the Amazon region.

RAS datasets can help reconcile social–ecological objectives and reveal trade-offs between farming and conservation at multiple spatial scales by combining data on socioeconomic and ecological values. One prominent debate concerns the effectiveness of alternative approaches for attempting to balance conservation and agricultural activities through changes in agricultural productivity and farming techniques, often referred to as land-sparing versus land-sharing [41]. Understanding of this general problem is limited by a lack of data on the conservation value of areas of remaining native vegetation available for conservation investment that are in differing stages of degradation or regeneration, farm-scale differences in agricultural productivity and other socioeconomic variables related to human well-being and poverty, and landscape-scale influences on local ecological and socioeconomic properties. RAS data can make a potentially important contribution to the development of Reducing Emissions from Deforestation and Degradation (REDD+) initiatives [42], recognizing that we currently have a very poor understanding of the relative ecological and socioeconomic costs and benefits of alternative forest conservation policies (e.g. avoided deforestation versus avoided degradation and forest restoration activities) and the interaction between such policies and the agricultural sector [43].

Data and results from RAS ultimately aim to contribute towards more sustainable land-use systems in Amazonia in five overlapping areas, namely the development of: (i) best practice recommendations for sustainable intensification and responsible agriculture, particularly in the cattle-ranching sector; (ii) cost-effective approaches to achieving compliance with environmental legislation, especially in Brazilian Forest Law; (iii) strategies for investment in forest conservation and restoration through payment for ecosystem service schemes, and particularly carbon finance; (iv) strategies for promoting fire-free agriculture; and (v) municipal-level ecological–economic zoning processes. We seek to identify potential opportunities and motivations for more sustainable development strategies in eastern Amazonia and elsewhere by combining the quantitative foundation of our sustainability assessment with input from stakeholders and work in the political and social sciences [44].

We hope that our data will be helpful to assess how changes in management incentives or regulatory conditions will influence relative ecological and socioeconomic costs and benefits. However, we also recognize that win–win solutions are rare and often misleading. Given this, our work seeks to give explicit consideration to possible conflicts, compromises and synergies among multiple objectives, unexpected interactions and feedbacks, and the broader political and institutional context [45].

Ensuring that the work being undertaken by RAS goes beyond science and successfully bridges the science–policy divide is both extremely challenging and unpredictable. There are at least three areas where we hope that our approach can help to increase opportunities for informing development and conservation decision makers. First, our interdisciplinary, mesoscale and place-based research approach increases the likelihood that our results are relevant and applicable to regional problems. Second, we believe that to be most effective the process of knowledge exchange should occur across as broad and diverse set of actors as possible. Here, the participation of such a large group of (mostly Brazilian) students and researchers on the one hand, with a large and diverse array of non-research partners and associates (including conservation organizations, farmers groups, government agencies and individual landowners) on the other has provided the basis for multiple ongoing dialogues about our research objectives and preliminary findings. Knowledge exchange should not be limited to high-level executive summaries for policy makers but must exploit opportunities for shared learning and dissemination of ideas at all levels. Last, we are developing an impact strategy that can help to target the presentation and discussion of key results through appropriate media to specific audiences and demands at local, regional and national levels.

Sustainability science needs to balance the often-conflicting timetables of research and policy processes. As scientists we strive to ensure the reliability, intellectual credit and independence of our work; a process that often requires a lot of time. However, to influence the policy process effectively, our experience is that the research process also needs to be able to respond to limited and often unpredictable opportunities for contributing to decisions on management and policy. Engaging in this process requires innovative methods for interacting with different sectors and contributing not only to the delivery of policy-relevant research outputs as outlined in this paper, but also to broader efforts to build the capacity and understanding necessary to create a more sustainable development trajectory for the Amazon region. We hope that the work of RAS can make a small contribution towards this enormous challenge.

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