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A critical assessment of INPA's scientific cooperation based on publications from 2004 to 2014

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ABSTRACT

In the 1990s, scientific cooperation at the National Institute for Amazonian Research (Instituto Nacional de Pesquisas da Amazônia – INPA), one of the oldest research institutions in Amazonia with the highest regional international cooperation, was dominated by research conducted by INPA's foreign partners. In this article, the evolution of this situation is evaluated, with the hypothesis that, as the internal and the external environments have changed over the past decade, this should be reflected in more symmetrical research cooperation. The analysis was based on a 2004 to 2014 Web of Science search of scientific production at INPA, from which 786 papers were recovered. The results indicated an increase in scientific production but without a corresponding increase in symmetrical cooperation. The level of symmetry varied according to the type of cooperation; it increased when Brazilian institutions were exclusively involved, although these papers tended to be published in journals with a low impact factor. However, the scientific relationships remained relatively asymmetrical when only foreign institutions were involved, although these papers were published in journals with high impact factors. Network analyses indicated that most international scientific cooperation was concentrated in just two INPA research departments: Biodiversity and Environmental Dynamics. In contrast, INPA's other two research departments, Technology & Innovation and Society, Environment & Health were peripheral, fragmented and benefited little from international cooperation.

KEYWORDS: Amazon cooperation, co-authoring, international cooperation, research networks, scientific production

Uma avaliação crítica da cooperação científica do INPA baseada em publicações entre 2004 e 2014

RESUMO

Na década de 1990, a cooperação científica no Instituto Nacional de Pesquisas Amazônica (INPA), uma das instituições de pesquisa mais antigas da Amazônia e que concentra grande parte da cooperação internacional regional, foi dominada por pesquisas realizadas pelos parceiros estrangeiros do INPA. Neste artigo, a evolução desta situação é avaliada, com a hipótese de que, à medida que os ambientes interno e externo mudaram ao longo da última década, isso deve refletir-se em uma cooperação cientifica mais simétrica. A análise baseou-se em um levantamento da produção científica do INPA na *Web of Science* de 2004 a 2014, em que foram recuperados 786 documentos. Os resultados indicaram um aumento na produção científica, mas sem um aumento correspondente na simetria da cooperação. O nível de simetria variou de acordo com o tipo de cooperação; aumentou quando estavam envolvidas exclusivamente instituições brasileiras, embora esses artigos tenham sido publicados em revistas com baixo fator de impacto. No entanto, as relações científicas permaneceram relativamente assimétricas quando apenas instituições estrangeiras estavam envolvidas, embora esses trabalhos tenham sido publicados em revistas com fatores de impacto mais altos. As análises de rede indicaram que a maior parte da cooperação científica internacional se concentrou em apenas dois departamentos de pesquisa do INPA: Biodiversidade e Dinâmica Ambiental. Em contraste, os outros dois departamentos de pesquisa do INPA, Tecnologia & Inovação e Sociedade, Ambiente & Saúde foram periféricos, fragmentados e pouco se beneficiaram da cooperação internacional.

PALAVRAS-CHAVE: cooperação Amazônica, coautoria, cooperação internacional, redes de pesquisa, produção científica

INTRODUCTION

Scientific cooperation is a requirement of modern science and is one of the main factors determining the productivity of an institution and the success of scientific research. Researchers and institutions cooperate to reduce time, costs, and personal investment both through the provision of expert input as well as through shared skills, knowledge, information, ideas, equipment, and research results (Bordons and Gomez 2000). Therefore, analysis of the scientific cooperation within an institution can reveal both the spontaneous and the induced tendencies to support the planning, implementation, and evaluation of key strategic institutional developments. Although the analysis of the scientific cooperation should be routine in academic institutions, it is virtually non-existent in most Brazilian science and technology institutions. At the National Institute for Amazonian Research (INPA), one of the main tropical research institutes in the world and one of the oldest government institutions in the Amazon region, the assessment of scientific cooperation was limited up to the 1990s and was focused almost exclusively on international scientific cooperation (see Velho and Velho 1996; Toni and Velho 1996; Machado 1999, 2005; Gama and Velho 2005). These studies revealed that in general the scientific relationships at INPA were asymmetrical as the foreign partners dominated the research agenda, resources, and ownership of the generated results, particularly in regard to publications. In addition, most international scientific cooperation programs remained distant from the demands and development needs of the local populations.

Velho and Velho (1996) summarized their analysis under five main points. First, INPA was the institution chosen as the Brazilian counterpart not because of its scientific vocation, but because of its strategic location within the Amazonian region and its ability to facilitate fieldwork logistics and access to study sites. Therefore, unlike in developed countries where academic research partnerships are established because each side has an interest in what the other can provide in terms of knowledge and training, cooperation between developed and emergent or undeveloped countries has been mainly in the interests of the more developed countries who wish to have access to scientifically challenging and/or unexplored regions. Second, the participation of Brazilian researchers in the negotiation and management of projects was very low as they were usually in a subordinate role and were required to only subscribe to the closed research proposals of the foreign counterpart. Third, Brazil systematically failed to fulfill its part in financing approved cooperation projects. As a result, given its financial constraints in the 1990s, INPA was highly dependent on insufficiently discussed international projects in which the external scientists had the resources and therefore made the key decisions. Velho and Velho (1996) stated that "international cooperation has been used in INPA as an 'expedient' to solve cash problems or hire staff". These conditions favored projects of interest to the foreign counterparts which did not necessarily coincide with the scientific goals of the recipient country. Fourth, INPA's international cooperation was also asymmetrical in terms of the human resources involved in the projects, with much greater technical capacity of foreign participants who frequently valued the contributions made by Brazilian technicians and field assistants more than those made by the Brazilian scientists. Finally, while INPA's international cooperation projects resulted in significant scientific co-authorship, the foreign scientists usually appeared as the first or main authors.

In the same line of analysis, Toni and Velho (1996) studied scientific cooperation between Brazil and France with a focus on cooperative agreements with the Office de la Recherche Scientifique et Technique d'Outre-Mer (ORSTOM) and the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD). The authors concluded that the formal cooperative agreements highlighted significant institutional weaknesses at INPA and the National Council for Scientific and Technological Development (CNPq). As these agreements were not institutionally evaluated by INPA, for a long time French scientists were able to work unilaterally on issues and topics that were being simultaneously researched at INPA. As a result, significant aspects of the scientific cooperation were channeled toward the primary scientific interests of the French counterpart. They also found a great imbalance in scientific production, which was highly favorable to the French scientists. These observations reinforced the perceived lack of organizational initiative, the scientific fragmentation, and the lack of institutional objectives by the Brazilian counterparts, as pointed out by Machado (1999).

This study sought to identify the evolution of INPA's scientific cooperative framework in the context of the new Brazilian science and technology scenario. Among Brazil's most productive research institutions, INPA is the only one in the Amazon Basin (Leta *et al.* 2006), and concentrates most of international science cooperation in the region (Gama and Velho 2005). The approach used for the analysis in this paper included both bibliometric analysis, traditionally used in co-authorship studies, and social network analysis, which is based on the theory of graphs and allows the analysis of the structure and relationship network as a whole (Ding 2011). The working hypothesis was that the changes since the 1990s in both the external environment and INPA's internal environment were positively reflected in more symmetrical international cooperation. The following questions drove the research analysis: What was the role of scientific cooperation in INPA's productivity from 2004 to 2014? What areas of knowledge

showed the strongest scientific cooperation during that period? and Which countries and institutions were key partners for the scientific production at INPA during that period?

MATERIALS AND METHODS

The science and technology indicators for cooperation at INPA were accessed through Thomson Reuters' multidisciplinary database, the Science Citation Index/Web of Science (WoS), because of its scope and representativeness. The WoS was chosen because it is responsible for indexing documents from various fields and records the complete bibliographic data for each paper, including the institutional addresses of each author. The membership data indexing process for all authors is fundamental to the study of scientific cooperation through co-authorship. The descriptors for article recovery were, therefore, affiliations such as "INPA", "Inst* Nac* Amazo*" and "Nat* Ins* Amazo*", which were effective in recovering more than 70 different affiliation indicators for INPA. The search was restricted to 2004 to 2014 and the search was finalized on March 27, 2015.

Velho and Velho (1996) and Toni and Velho's (1996) analyses of INPA's scientific production considered only the first author as the prime author of a paper. In contrast, in the analysis in this study, prime authorship was defined as those authors who had contributed more substantially to the research in terms of skills, knowledge, information, ideas, equipment, and research results, but at different degrees (Primack *et al.* 2014). In practice, the team leader is often the first author, the last author, or the corresponding author (Primack *et al.* 2014). The first author is usually the student or researcher who undertakes most of the research work and is also responsible for analyzing the data and preparing the manuscript. The corresponding author and the last author are usually senior researchers who provide the intellectual input and designs, approve the protocols to be followed in the study, and provide the material means for the research development. The corresponding author is also responsible for manuscript correction, proofreading, correspondence with editors during paper submission, and the handling of revisions and the re-submission of revised manuscripts up to manuscript acceptance. Therefore, in this study, we considered the prime authors of a paper to be the first and corresponding authors, who were usually the last author.

As only research articles in journals were considered, survey documents categorized as book reviews, editorial material, letters, meeting abstracts, or proceedings papers were excluded. The surveyed journals were divided in two tiers based on the impact factor (IF) in 2014: journals with IF ≤ 0.99 and journals with IF ≥ 1. The impact factor is a measure of the average number of citations per article published in scientific journals and is frequently used to judge the relative importance of a journal. To identify the number of articles from the Amazon region, titles, keywords and abstracts were searched for the presence of the following words: "Amazon", "Amazonia", "Amazonian", "Colombia", "Ecuador", "Peru", "Guyana", "Suriname", "Venezuela", "French Guiana", "Acre State", "Amapa State", "Amazonas State", "Para State", "Rondonia State", and "Roraima State". In the classification of knowledge areas, only the main journal subject was used; for example, although scientific journals such as Agricultural and Forest Meteorology accept articles in the areas of Agriculture, Forestry, Meteorology, and Atmospheric Sciences, all articles were classified as Agronomy. The database was treated with Vantage Point software.

Authors belonging to INPA's permanent staff, as listed on the "INPA Researcher List" on the institutional website (INPA 2015) (excluding visiting researchers, postdoc fellows, and graduate students) were distributed across the four main research departments: (1) Biodiversity (COBIO), which coordinates research related to biological diversity in the Amazon region and its origin, distribution, evolution, biogeography, ecology, environmental interactions, bioprospecting, monitoring, conservation and management, and traditional use; (2) Environmental Dynamics (CODAM), which heads research related to Amazonian ecosystem biogeochemistry, environmental services, and human components; (3) Society, Environment & Health (COSAS), which coordinates research on the dynamics of human populations in the Amazon and their interaction with the environment; and (4) Technology & Innovation (COTEI), which heads research on the development of techniques, processes, and products that meet the socio-economic and sustainable development demands in the Amazon.

Some variables in the time series were tested using chi-square to identify statistically significant increasing ($A > 0$) or decreasing trends ($A < 0$). For the research network analysis, only publications with at least one INPA permanent staff researcher (INPA 2015) as author and only authors or institutions with at least five articles within the study period were used. The co-occurrence matrices for authors and institutions were assembled and analyzed using the metrics of "centrality" in UCINET software (Borgatti *et al.* 2002), which incorporates NetDraw and Pajek software. According to Everett and Borgatti (2005), a central position is one of the most widely used concepts to identify the main actors in a social network. The various properties of the centrality of a given node are based on the relationships that the corresponding actor has with other actors in the network. Therefore, each actor has a value within the network that is comparable with that of other actors. There are three types of centrality based on the properties of the most visible central node: (a) "betweenness centrality," which makes it possible to

locate the actors who serve as bridges and facilitate the flow of information in a given network (Otte and Rousseau 2002); (b) "closeness centrality," which refers to the virtual proximity of a given actor to other actors in the network (the ability to reach another actor using the smallest possible number of contacts), with the idea being that an actor who can quickly interact with other actors is central; and (c) "degree centrality," which corresponds to the number of links that a particular actor establishes with other actors; the node with the highest level is the most central node in the network as it has direct contact with a larger number of other nodes or vertices.

RESULTS

Overview

A total of 786 articles were recovered from the WoS database for the period 2004–2014 after the exclusion of four publications that indicated INPA as a new affiliation for the corresponding author. After a period of relative stagnation between 2004 and 2007, the number of published scientific articles increased and showed a significant jump in 2011 (Figure 1). The same trend was observed for the impact factor of the journals, with an increasing trend in the two categories considered. The average number of citations per article also increased throughout the period (Figure 1), indicating that there was an increase in the relevance of INPA publications within the scientific community.

Over 97% of scientific production was co-authored. The number of co-authored publications was proportionately high from the beginning and showed a slight increase throughout the period. The average number of authors was 5.2 ± 1.8 at the beginning of the study period (n = 39), reached a peak of 7.5 ± 1.04 in 2013 (n = 115), and then fell slightly to 6.25 ± 1.07 in 2014 (n = 110). From 2008 onwards, it was common to find publications with over 20 authors.

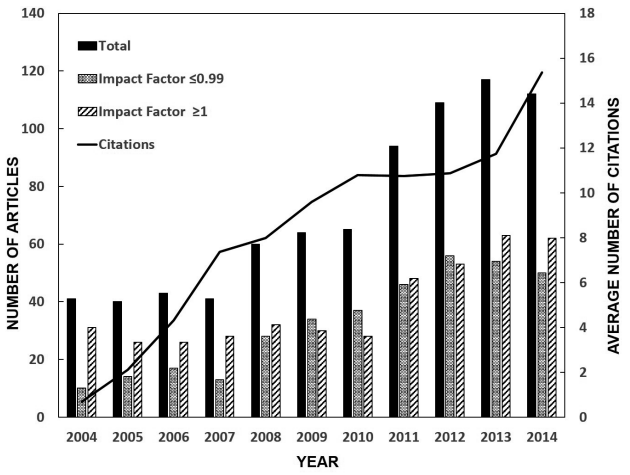

Figure 1. Frequency of the number of articles (total and grouped by impact factor) and average number of citations per article of articles with at least one author affiliated with INPA in a sample of 786 articles indexed by the multidisciplinary database of Thomson Reuters (WoS) from 2004 to 2014.

Only 19 publications were not co-authored. Of these, ten papers were written by authors who were not permanent INPA research staff; four were written by foreign researchers who developed activities at INPA under cooperative agreement frameworks and indicated affiliation both to INPA and their home institutions, and six were written by graduate students of programs maintained by the institution. For the co-authored scientific papers, 119 were written exclusively by researchers affiliated with INPA, and 648 (over 84%) had co-authors affiliated with INPA as well as with other Brazilian and/or foreign institutions (Table 1, Figure 2a, b). Publications resulting from national inter-institutional cooperation were generally more numerous than other authorship combinations, particularly in the group of journals with lower impact factor, while international cooperation was of greater importance in publications with higher impact factors (Figure 2a, b). In approximately 80% of publications, the first author was also the corresponding author, and 150 articles had two prime authors; the first author and a corresponding author; whose assignation varied between the second author (36%) and the last author (64%).

Table 1. Distribution of scientific co-authored articles with at least one author affiliated to INPA indexed by the Thomson Reuters (WoS) database from 2004 to 2014 according to the affiliation of prime authors and journal impact factor. Numbers in parentheses indicate the number of first authors and corresponding authors, respectively.

Type of cooperation	Prime author from INPA		Prime author from partner institutions		Number of articles
	Permanent staff	Graduate students and visiting researchers	Brazilian	Foreign	
Impact factor ≤ 0.99					
No cooperation	(13+6) 19	(59+2) 59			72
National	(20+6) 26	(85+4) 89	(104+10) 114		209
International	(3+1) 04	(10+1) 11		(18+3) 21	31
National and international	(6+0) 06	(7+1) 08	(15+1) 16	(10+0) 10	38
Impact factor ≥ 1					
No cooperation	(05+17) 22	(42+1) 43			47
National	(17+13) 30	(47+3) 50	(83+34) 117		147
International	(11+2) 13	(25+1) 26		(73+9) 82	109
National and International	(06+9) 15	(30+3) 33	(33+14) 47	(45+8) 53	114

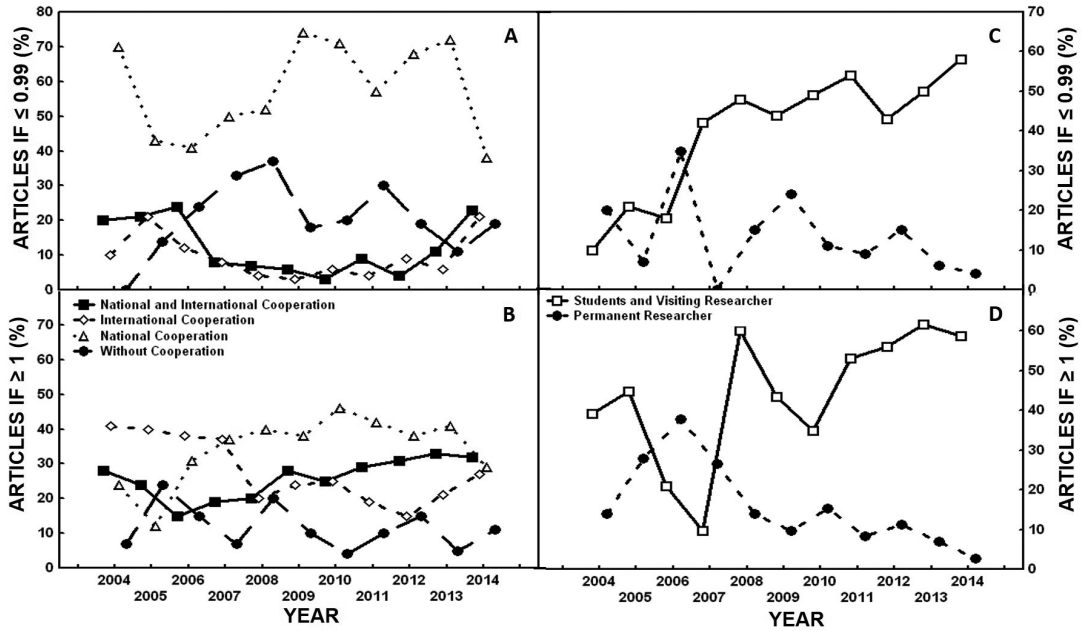

Figure 2. Evolution in the number of 767 co-authored articles with at least one author affiliated with INPA indexed by the Thomson Reuters (WoS) database from 2004 to 2014 according to types of scientific collaboration (A and B) and the institutional status of the prime author with INPA affiliation (C and D) in journals with impact factor ≤0.99 (A and C) and ≥1 (B and D).

The cooperative symmetry was higher when exclusively Brazilian institutions were involved but remained relatively asymmetrical when only foreign institutions were involved, although the participation of other Brazilian institutions in international cooperative research projects contributed to an increase in Brazilian leadership (Table 1). Asymmetry was highest in 57 publications where the first author indicated affiliation both with INPA and another Brazilian or a foreign institution. In 22 of these publications, there was no participation by any of INPA's 210 permanent staff researchers, indicating that INPA's role in these publications had been limited to logistical support for the visiting researchers' projects. Regarding prime authorship with INPA affiliation, there was a notable increase in articles with graduate students or visiting researchers as prime authors in the study period ($A > 0$, 1 df, chi-square = 12.57, $p < 0.001$, to journals with IF ≤ 0.99, and $A > 0$, 1 df, chi-square = 9.81, $p < 0.001$, to journals with IF ≥ 1). In contrast, articles with permanent INPA staff researchers as prime authors showed a decreasing tendency ($A < 0$, 1 df, chi-square = 6.33, $p < 0.01$, to journals with IF ≤ 0.99, and $A < 0$, 1 df, chi-square = 13.88, $p < 0.0002$, to journals with IF ≥ 1) (Figure 2c, d).

Knowledge areas and cooperation

Most of INPA's scientific production during the study period was in the natural sciences. Overall, 72% of the studies were carried out in the Amazon region and 90% were limited to 16 areas of knowledge, with each including from 1% to 21% of the articles (Figure 3). The areas with the greater number of articles were also those with a larger share of both national and international scientific cooperation. These same areas also had several articles that had been developed without cooperation, indicating the presence of consolidated research groups within the institution. The only areas of scientific production developed exclusively in cooperation were Meteorology and Atmospheric Sciences, Genetics and Heredity, and Life Sciences and Biomedicine (Figure 3). International cooperation was proportionally higher in Environmental Sciences and Ecology and in Multidisciplinary Sciences than in the other fields, even though the international cooperation and national cooperation was proportionally higher (Figure 3). Zoology, Agriculture, Biodiversity and Conservation, Plant Sciences, Science and Technology, Life Sciences and Biomedicine, and Parasitology showed an increasing trend in the number of articles over the time series, although only Zoology ($A > 0$, 1 df, chi-square = 4.21, $p = 0.04$) and Multidisciplinary Sciences ($A > 0$, 1 df, chi-square = 4.38, $p = 0.0365$) were statistically significant. Environmental Sciences and Ecology, Entomology, Forestry Sciences, Freshwater Biology, Biochemistry and Molecular Biology, Fisheries Studies, Food Science and Technology, and Genetics and Heredity showed decreasing trends, although only Environmental Sciences and Ecology ($A < 0$, 1 df, chi-square = 5.52, $p = 0.018$) and Biochemistry and Molecular Biology ($A < 0$, 1 df, chi-square = 6.194 $p = 0.013$) were statistically significant. Another 29 knowledge

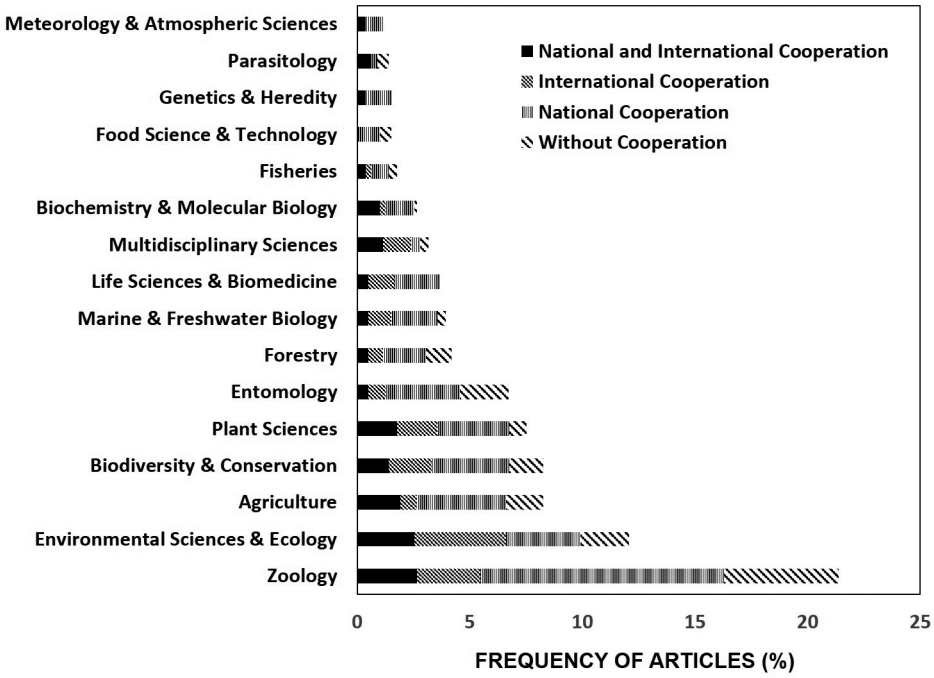

Figure 3. Knowledge areas that concentrate most of INPA's co-authored research articles with at least one author affiliated to INPA indexed by the Thomson Reuters (WoS) database from 2004 to 2014. Patterns indicate the different origins of scientific collaboration for the article.

areas accounted for only 10% of the articles, including areas examining the social context of the Amazon and those dealing with biotechnology, such as Tropical Medicine, Infectious Diseases, Anthropology, Chemistry, Microbiology, Mycology, Pharmacology, and Biotechnology.

Institutions and countries

The authors of the surveyed articles represented more than 200 Brazilian institutions and 527 foreign institutions in a long-tail distribution. Approximately 38% of authors belonged to the top ten Brazilian partner institutions. Two groups of institutions were identified: Amazonian institutions linked by regional affinity, with the Federal University of Amazonas as the main partner, and institutions based in the southeast of Brazil, where most Brazilian scientific production is concentrated, with the University of São Paulo as the main partner (Table 2). Most papers that involved national cooperative scientific production were published in low impact factor journals (Table 2).

The top ten foreign institutions affiliated approximately 14% of foreign researchers (Table 2). However, this figure was somewhat skewed because the authors of the articles from partnerships between INPA and the Smithsonian Tropical Research Institute (STRI) under the Biological Dynamics of Forest Fragments Project (BDFFP) usually did not belong to INPA or STRI but to a third institution, and they indicated affiliation to both INPA as STRI through their association with BDFFP. The number of national and foreign co-authoring institutions increased throughout the period from 31 to 69 and from 54 to 136 (Figure 4). The foreign institutions involved belonged to 67 countries; however, 69% of the foreign researchers were from only 10 of these countries and most of the scientific production was published in higher impact factor journals (Table 3). Institutions in the USA co-authored 141 articles, making up the largest part of INPA's international scientific cooperation (Table 3). Colombia was the only Amazonian country in the top ten list with 15 co-authored articles (Table 3). As already highlighted, cooperation with Panama appeared in the top ten through cooperation with STRI in the BDFFP, which is one of INPA's main international cooperation projects. All scientists who indicated affiliation with STRI also indicated affiliation with other institutions.

Research networks

Only 116 (55%) of INPA's 210 permanent staff researchers had at least one article in the WoS database from 2004 to 2014, and only 52 met the criterion of five or more articles during the study period, most of whom were research group leaders or deputy leaders (Supplementary Material, Table S1). The research network analysis based on these authors resulted in a network of 97 researchers and eight components. Three components were formed by multiple co-authors and

Table 2. Number of co-authored articles from the top ten Brazilian and foreign partner institutions of INPA in a sample of 767 scientific co-authored articles indexed by the Thomson Reuters (WoS) database from 2004 to 2014, with at least one author affiliated with INPA grouped by journal impact factor (IF).

Institutions	Total number of co-authors IF ≤ 0.99	Total number of co-authors IF ≥ 1	Total number of articles
Brazilian			
Universidade Federal do Amazonas	48	47	95
Universidade de São Paulo	24	44	66
Universidade Estadual de Campinas	10	28	38
Universidade Estadual Paulista	18	18	36
Museu Paraense Emilio Goeldi	11	16	25
Universidade Estadual do Amazonas	11	14	25
Universidade Federal do Rio de Janeiro	13	12	24
Universidade Federal do Para	8	14	21
Instituto Nacional de Pesquisas Espaciais	1	19	20
Universidade Federal do Espirito Santo	16	2	18
Foreign			
Smithsonian Tropical Research Institute	3	33	36
Louisiana State University	1	13	14
Duke University	1	12	13
Harvard University	3	10	13
University of Florida	2	10	12
McMaster University	0	12	12
Max Planck Institute for Chemical	0	12	12
University Leeds	0	12	11
James Cook University	0	11	11
Universidad Nacional de Colombia	1	15	10

Table 3. Number of authors from the top ten countries with partner institutions of INPA in a sample of 767 scientific co-authored articles indexed by the Thomson Reuters (WoS) database from 2004 to 2014, with at least one author affiliated with INPA, grouped by journal impact factor (IF).

Country	Total number of co-authors IF ≤ 0.99	Total number of co-authors IF ≥ 1	Total number of articles
USA	30	308	141
England	9	91	52
Germany	6	50	40
Panama	3	33	36
Australia	1	45	31
Canada	2	44	30
France	4	27	23
Scotland	0	26	21
Netherlands	2	31	16
Colombia	1	30	15

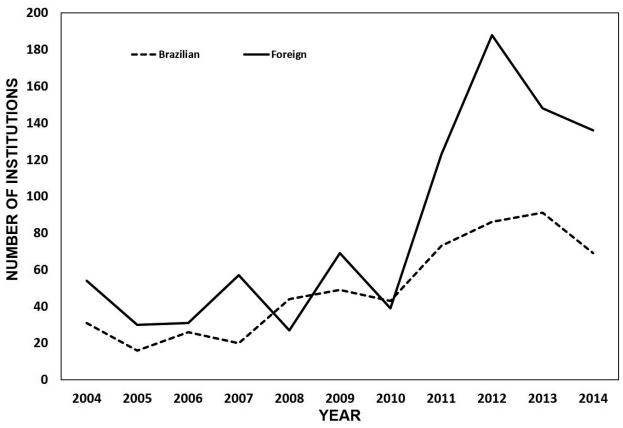

Figure 4. Evolution in the number of Brazilian and foreign partner institutions with INPA for co-authored articles with at least one author affiliated with INPA indexed by the Thomson Reuters (WoS) database from 2004 and 2014.

five components were formed by a single researcher (Figure 5). Each component addressed one or more specific research topics. The overall network density was approximately 8.9%, a relatively low value because of the several single components in the network. Among the departments, the fragmentation level was larger in COTEI and COSAS than in COBIO and CODAM. However, the high betweenness centrality for researchers belonging to partner institutions also indicated a research network fragmentation level in COBIO because the connections are outside INPA (Figure 5). International cooperation was restricted to components that included researchers from COBIO and CODAM, but was separated into two sets connected by the same researchers from partner institutions with high betweenness centrality (Figure 5). Surprisingly, the three researchers who had the highest degree centrality did not belong to INPA's permanent research staff but were associated with the BDFFP as database managers for this long-term project.

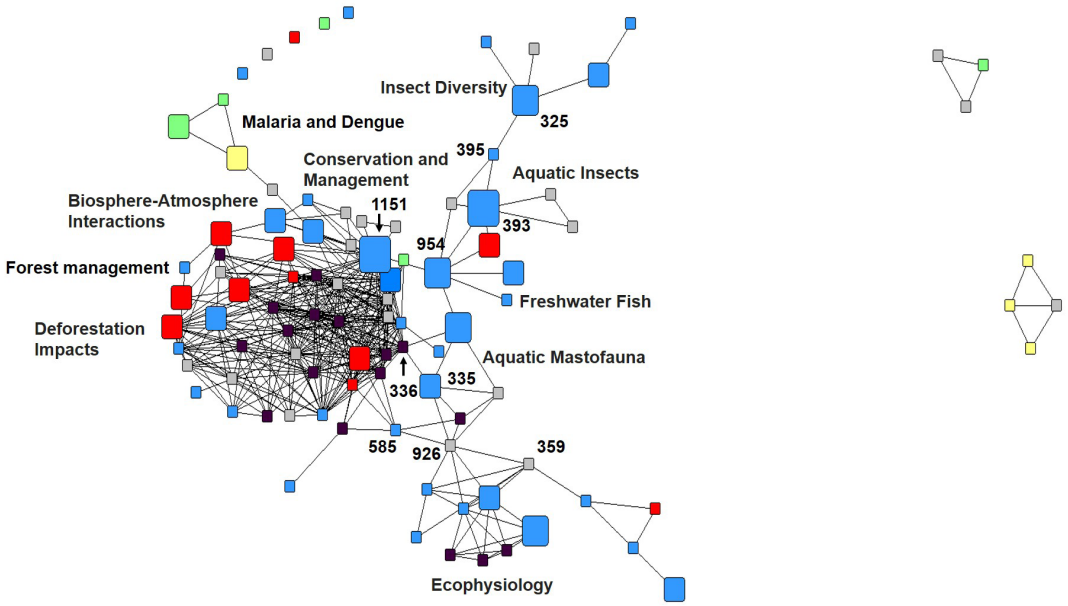

Figure 5. Scientific collaboration network for INPA based on researchers belonging to the permanent staff with at least 5 articles published between 2004 and 2014. Each square represents one author and each line connecting two authors indicates the presence of at least one co-authored publication. Square size is based on the number of publications. Researchers from INPA are marked according to their affiliation with one of the four research departments: COBIO, Biodiversity – blue squares; CODAM, Environmental Dynamics – red squares; COSAS, Environment & Health – yellow squares; COTEI, Technology & Innovation – green squares. Authors affiliated with Brazilian institutions are highlighted in gray squares and authors affiliated with foreign institutions are marked with black squares. The numbers indicate the ten highest betweenness centrality values. The network includes 97 authors, 828 connections, and 8 components. This figure is in color in the electronic version.

The same pattern was observed in analysis centered on the partner institutions, with the concentration of Brazilian institutions and foreign institutions at opposite poles and COBIO and CODAM having the highest degree centrality and betweenness centrality and smaller values for closeness centrality (Figure 6, Table 4). As COBIO had the largest number of links, it was identified as playing a key role in INPA's collaborative network structure. The importance of COBIO was not limited to the number of direct contacts but also to the number of intermediated contacts. Therefore, COBIO was an important intermediary in the INPA institutional research network. In contrast, COSAS had the lowest values in the INPA research network.

COTEI and COSAS had peripheral positions in INPA's research network and were located at the Brazilian partner institutional pole (Figure 6). The research network also showed that geographical location was a decisive factor for the establishment of partnerships: three Amazonian institutions (Federal University of Amazonas, Emilio Goeldi Museum, and EMBRAPA/Eastern Amazon) showed high degree centrality and betweenness centrality and low closeness centrality (Supplementary Material, Table S2). High degree centrality and betweenness centrality were also observed for the University of São Paulo-USP (Brazil), the Smithsonian Tropical Research Institution-STRI (Panama/USA), the University of Campinas (Brazil), the Wildlife Conservation Society-WCS (USA), and the University of Leeds (England). The Federal University of Rio de Janeiro and the Federal University of Pará also had high betweenness centrality, indicating that these institutions functioned as bridges between non-adjacent institutions in the network. The University of Oxford (England) and Duke University (USA) also had high degree centrality. The network density of 32% indicated reasonable connectivity, using the range of density values given by Carpenter *et al.* (2009).

Table 4. Centrality measures for the four main research departments of INPA in a collaboration network based on researchers belonging to INPA's permanent research staff with at least five articles published between 2004 and 2014.

Research department	Number of articles	Centrality Degree	Betweenness	Closeness
Biodiversity	395	538	608.99	85
Environmental Dynamics	121	261	238.72	100
Technology & Innovation	64	101	41.03	136
Society, Environment & Health	46	65	55.37	139

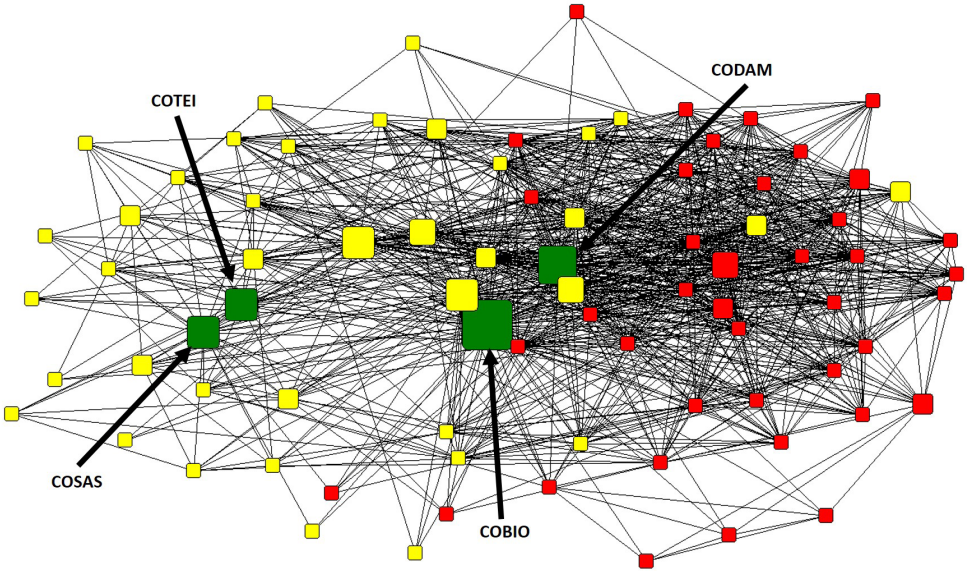

Figure 6. Scientific collaboration network for INPA based on researchers belonging to the permanent staff with articles published between 2004 and 2014. Each square represents one institution with at least 5 articles and the lines represent collaborations. Membership of INPA was divided between the four research departments (COBIO, Biodiversity; CODAM, Environmental Dynamics; COSAS, Society, Environment & Health; COTEI, Technology & Innovation) and is marked with green squares. Brazilian institutions are marked with yellow squares, and foreign institutions with red squares. Square size is based on the number of publications. The network resulted in a single component consisting of 82 institutions and 2,102 connections. This figure is in color in the electronic version.

DISCUSSION

Much of the science produced in developing countries, including Brazil, is published in national scientific journals that are only partially indexed in the WoS database (Leta and Chaimovich 2002; Glänzel *et al.* 2006; Penteado-Filho and Avila 2010). Therefore, the results did not represent the totality of the science published at INPA, but only the research that had been indexed in that database. It should be noted that this survey may also have underestimated the number of articles authored or co-authored exclusively by researchers from foreign institutions as the search was performed using an INPA affiliation criterion; therefore, articles resulting from cooperative agreements with INPA may indicate this relationship with INPA only in the acknowledgments section. There was an overall increasing trend from 2004 to 2014 in the number of INPA articles per year and in international visibility (average number of citations per article). This increase in INPA productivity was paralleled by a general increase in Brazilian scientific production, which could be attributed to an increase in the coverage of Brazilian journals indexed in different bibliographic databases or to an actual growth in scientific production (Mugnaini *et al.* 2004).

Brazilian scientific production recorded in WoS has increased more than 18 times over the last three decades (UNESCO 2010; Helene and Ribeiro 2011) with an annual growth between 7% and 28% in 2006–2009 (Ponomariov and Toivanen 2014). The growth in INPA's publications in WoS was generally below the national average except in 2008 and 2011, when there were increases of 40% and 44%, respectively. In 2007, INPA raised funds from the Brazilian Ministry of Planning, Budget and Management (MPOG) of around USD 20 million, more than double the annual budget of the institution, through the project "Expansion and Modernization of INPA Infrastructure for the Study of Biodiversity and Sustainability of Amazon Ecosystems in light of Global Climate Change" (INPA 2009). In 2009, four large research programs from the National Council for the Development of Science and Technology (CNPq), called National Science and Technology Institutes (INCT), were awarded to INPA, with a total budget of around USD 6 million (INPA 2010). Although these funded programs do not specifically correlate with the observed increase in scientific production indexed in WoS, it has been generally established that the expansion in research funding was a major factor in the increase in Brazilian scientific production (Helene and Ribeiro 2011).

Although it has been shown that one of the advantages of international cooperation is an increase in scientific productivity (Van Raan 1998), the results clearly indicate that the increase in INPA's scientific productivity in the international arena was not related to increased international cooperation but to a sharp increase in national cooperation.

This trend may be related not only to the expansion in research funding but also to an increase in the development of Brazilian scientific expertise, suggesting that domestic capacities are fueling scientific production (Ponomariov and Toivanen 2014). Another reason for the growth in INPA's scientific productivity is the presence of consolidated graduate programs that promote the contribution of and interactions with a greater number of students and post-doctoral fellows. Several studies have shown that there is a linear relationship between the number of graduate students and the number of scientific publications in Brazil (Guimarães 2004; De Meis *et al.* 2007; Coutinho *et al.* 2012). In fact, during the period studied, graduate students have been the main source of INPA first authorship in publications co-authored by permanent INPA staff researchers acting as thesis advisors. Despite the consistent growth in INPA's scientific production, the asymmetry observed in articles originating from international cooperation and published in higher impact factor journals indicates that quality remains a challenge, especially when considering the decreasing trend in articles led by INPA's permanent staff researchers. The persistence of asymmetry in international collaborations was also reflected in the number of publications without any participation from INPA's permanent staff researchers, indicating that the role of INPA in many interactions with foreign institutions remains as an access and logistics provider for the development of Amazonian research, as was pointed out in Velho and Velho (1996) in the 1990s.

As Brazil's scientific cooperation with other Latin American countries was found to have consistently increased (Glänzel *et al.* 2006), it is surprising that INPA's international cooperation with other Latin American countries did not follow the same trend and has been almost entirely mediated through cooperative programs or networks with developed countries. In this framework, INPA researchers only participate with researchers from other Amazonian countries in synthesis articles on Amazonian topics that were largely led by American and European researchers. INPA needs to examine why direct research networks with institutions from other Amazonian countries have not developed and why its graduate programs are not focused more on building the capacity of young Amazonian scientists.

Although the internal and the external environments have been favorable to scientific productivity, INPA's productivity has remained concentrated on "islands of competence." Only 52 of the 210 permanent staff researchers at INPA have authored five or more articles in WoS, indicating that 53% of INPA's research groups had four or less articles published in WoS during the eleven-year study period; a reduction in international visibility.

The results of the knowledge area and research network analyses point to the need for the development of institutional strategies for scientific cooperation, which have more often emphasized "islands of competence" and minimized the potential growth of the non-consolidated research groups important for regional social contexts. Therefore, efforts to reduce the fragmentation and peripheral position of COSAS and COTEI in INPA's research network are key to improving research visibility with a science connected with social demands. This strengthening process should involve a wide range of actions such as increased financial support, the encouragement of international scientific cooperation, and the creation or strengthening of graduate programs associated with COSAS and COTEI research areas. Specifically, regarding COTEI, we recommend approaching the business sector, which is at present absent from the INPA research network, as innovation is very much a business agenda.

CONCLUSIONS

From 2004 to 2014, international cooperation remained highly asymmetrical even though there was a reduction in the dependence on international cooperation to finance INPA's research. For the future, the primary challenge is to increase INPA's overall output in WoS publications and to establish more symmetrical international scientific cooperation to increase both productivity and the impact of the science produced by the institution. Scientific productivity with international visibility and international scientific networking are highly skewed in INPA's research departments, with the major concentration being in only two departments (Biodiversity and Environmental Dynamics). Although significant cooperation occurred with developed countries over the study period, cooperation with other Amazonian nations is still incipient and requires further development.

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SUPPLEMENTARY MATERIAL

(only available in the electronic version)

HENRIQUES et al. A critical assessment of INPA's scientific cooperation based on publications from 2004 to 2014.

Table S1. Centrality measures for researchers in a collaboration network based in 604 articles with at least one researcher belonging to INPA's permanent research staff. The nodes represent authors with at least five articles published from 2004 to 2014. The ten highest values of the of degree centrality and betweenness centrality and the ten lowest values of closeness centrality are marked in bold (This table is available in electronic edition only).

Table S2. Centrality measures for the partner institutions of INPA in a collaboration network based in 595 articles with at least one researcher belonging to INPA's permanent research staff. The nodes represent institutions with at least five articles published from 2004 to 2014. The ten highest values of the of degree centrality and betweenness centrality and the ten lowest values of closeness centrality are marked in bold.

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Author/Country	Research Group	Degree Centrality	Betweenness Centrality	Closeness Centrality	Number of Articles
Deputy leader COBIO	Conservation and Management of Amazonian biota: Ecological Basis for Rational Development	85	1151	361	38
Deputy leader COBIO	Integrated Systematics of Aquatic Insects, with an emphasis on Simuliidae (Diptera) in South America	19	393	463	34
Leader COBIO	Ecophysiology and Molecular Evolution	35	0	598	27
Leader COBIO	Entomology in the Amazon: Insect Diversity	10	325	610	26
Partner/Australia		124	145	377	25
Deputy leader COBIO	Freshwater Fish Ecology and Conservation	14	954	398	24
Researcher COBIO		13	273	409	23
Deputy leader CODAM	Human Carrying Capacity and Deforestation Impacts	45	18	439	20
Deputy leader COBIO	Ecology, Systematic and Natural History of the Amazon Mastofauna	17	335	407	19
Leader COBIO	Conservation and Management of Amazonian biota: Ecological Basis for Rational Development	23	320	428	19
Partner/Brazil		107	129	378	18
Leader CODAM	Forest management	26	18	435	17
Partner/Australia		101	117	380	17
Researcher COBIO		58	44	415	17
Leader COSAS	Malaria and Dengue in the Amazon	9	164	584	17
Researcher COBIO		2	83	691	16
Deputy leader COBIO	Ecophysiology and Molecular Evolution	49	158	519	16
Researcher COBIO		20	4	437	13
Leader CODAM	Biosphere-Atmosphere Interactions and Biogeochemical Cycles in the Amazon	9	41	432	13
Leader CODAM	Amazon Meteorological Modeling	5	0	462	13
Researcher CODAM		23	11	421	13
Leader COTEI	Laboratory of Principles Assets of the Amazon - LAPAM	6	0	666	13
Researcher COBIO		49	105	380	12
Leader COBIO	Freshwater Fish Ecology and Conservation	3	0	481	11
Leader CODAM	RHANIA - Water Resources in Natural and Anthropic Environments in the Amazon	4	0	472	11
Deputy leader COBIO	Animal Genetics	3	0	758	10
Deputy leader CODAM	Ecology, Monitoring and Sustainable Use of Wetlands - MAUA	37	246	372	10
Partner/Brazil		49	87	381	9
Leader CODAM	FISIOGEN	2	0	676	9
Deputy leader COBIO	Ecology and Genetics of Tropical Tree Populations	23	100	389	9
Partner/Germany		18	83	434	9
Leader CODAM	Ecology, Monitoring and Sustainable Use of Wetlands - MAUA	34	224	373	9
Partner/Brazil		9	243	505	9
Partner/Scotland		28	0	598	9
Partner/USA		28	0	598	9
Deputy leader COTEI	Research Group in Pupunha	4	0	459	8

Table S1. Continuation.

Author/Country	Research Group	Degree Centrality	Betweenness Centrality	Closeness Centrality	Number of Articles
Partner/Brazil		49	82	382	8
Partner/Brazil		18	926	452	8
Deputy leader COBIO	Amazon Seeds: Diversity, Ecology and Dispersion	2	0	528	8
Leader COBIO	Ecology and Genetics of Tropical Tree Populations	4	0	472	8
Researcher COBIO		28	64	439	8
Partner/England		51	92	385	8
Partner/England		57	48	384	8
Partner/Brazil		51	105	380	8
Partner/Brazil		21	359	518	8
Leader COBIO	Ecology and Conservation of Amazon Turtles	0	0	1248	8
Deputy leader COBIO	Ecology and Amazon Plant Evolution	27	63	384	8
Leader COBIO	Zoology in the Amazon: Diversity, Biogeography and Collections	7	585	418	7
Partner/Brazil		16	0	441	7
Partner/Brazil		18	0	452	7
Researcher COBIO		22	158	519	7
Researcher CODAM		33	17	396	7
Partner/Brazil		10	0	545	7
Deputy leader COBIO	Palynology in the Amazon	0	0	1248	6
Partner/England		54	48	384	6
Partner/Brazil		6	0	693	6
Partner/Brazil		24	84	445	6
Partner/Brazil		17	39	522	6
Partnar/Colombia		56	103	381	6
Partner/Brazil		11	0	1224	6
Leader COBIO	Integrated Systematics of Aquatic Insects, with an emphasis on Simuliidae (Diptera) in South America.	4	395	535	6
Partner/Brazil		13	0	441	6
Partner/USA		5	0	495	6
Leader CODAM	Ecophysiology and Plant Health	0	0	1248	6
Partner/Brazil		11	0	443	6
Partner/England		22	336	372	6
Leader COBIO	Animal Genetics	5	83	675	6
Deputy leader COBIO	Entomology in the Amazon: Insect Diversity	1	0	774	6
Deputy leader COTEI	Biodegradation and Wood Preservation in the Amazon	11	0	1224	6
Partner/Canada		25	0	598	6
Partner/Germany		32	224	373	6
Leader COTEI	Aquaculture in the Western Amazon	0	0	1248	5
Partner/Brazil		20	16	429	5
Researcher COBIO		3	243	595	5
Partner/Brazil		5	0	481	5
Leader COBIO	Research Group in Bees	4	0	600	5
Partner/USA		28	0	450	5

Table S1. Continuation.

Author/Country	Research Group	Degree Centrality	Betweenness Centrality	Closeness Centrality	Number of Articles
Partner/Brazil		9	0	545	5
Partner/Brazil		28	0	451	5
Deputy leader COSAS	Integrated research on Leishmaniosis and Chagas Disease in the Amazon region	2	0	1213	5
Partner/USA		9	3	465	5
Partner/Brazil		9	113	457	5
Partnar/Brazil		10	0	443	5
Partner/USA		32	4	443	5
Researcher COBIO		1	0	693	5
Partner/Brazil		10	0	1224	5
Partner/Brazil		6	222	466	5
Deputy leader COTEI	Society-Nature: Bioprospecting, Biotechnology and Economic and Social Dynamics	4	0	666	5
Leader COSAS	Amazon Mycobacteria and Fungi	6	1	1212	5
Partner/Brazil		0	0	1248	5
Researcher COBIO		30	2	445	5
Partner/Brazil		6	1	1212	5
Partner/USA		10	6	443	5
Researcher COBIO		2	0	517	5
Deputy leader COSAS	Amazon Mycobacteria and Fungi	2	0	1213	5
Partner/USA		46	5	389	5
Partner/Brazil		10	16	430	5

Table S2. Centrality measures for the partner institutions of INPA in a collaboration network based in 595 articles with at least one researcher belonging to INPA's permanent research staff. The nodes represent institutions with at least five articles published from 2004 to 2014. The ten highest values of the of degree centrality and betweenness centrality and the ten lowest values of closeness centrality are marked in bold.

Institutions/Country	Degree Centrality	Betweenness Centrality	Closeness Centrality	Number of Articles
Univ Fed. Amazonas UFAM/Brazil	167	152.98	117	83
Univ São Paulo USP/Brazil	190	178.32	103	57
Smithsonian Trop Res Inst STRI/Panama	158	49.44	115	35
Univ Est Campinas UNICAMP/Brazil	101	80.86	115	29
Museu Paraense Emilio Goeldi MPEG/Brazil	150	98.19	109	23
Univ Est Amazonas UEA/ Brazil	51	24.45	137	19
Univ Est Paulista UNESP/ Brazil	35	9.7	147	19
Univ Fed Rio de Janeiro UFRJ/Brazil	47	30.67	136	16
Univ Fed Para UFPA/Brazil	89	92.72	112	16
Natl Inst Space Res INPE/ Brazil	71	3.74	139	16
Univ Fed Parana UFPR/ Brazil	21	2.54	152	13
EMBRAPA Amazonia Oriental/Brazil	113	48.69	114	13
Wildlife Conservat Soc WCS/Brazil	137	11.91	133	12
Univ Nilton Lins/Brazil	28	5.87	148	12
Univ Leeds/England	136	29.11	116	12
EMBRAPA Roraima/Brazil	79	14.92	125	11
McMaster Univ/Canada	51	15.09	146	11
Univ Fed Sao Carlos UFSCar/Brazil	21	4.55	149	10
Univ Oxford/England	134	39.29	113	10
Univ British Columbia/ Canada	32	10.67	149	10

Table S2. Continuation.

Institutions/Country	Degree Centrality	Betweenness Centrality	Closeness Centrality	Number of Articles
Max Planck Inst Chem/ Germany	48	13.85	131	10
Duke Univ/USA	102	13.6	124	10
Univ Nacl Colombia/ Colombia	74	28.57	122	9
Univ Fed Uberlandia/Brazil	33	3.37	141	9
Univ Fed Pernambuco/ Brazil	33	13.76	141	9
EMBRAPA Amazonia Ocidental/Brazil	28	3.77	149	9
Univ Amsterdam/ Netherlands	69	10.24	126	8
Univ Fed Goias/Brazil	34	1.99	142	8
Univ Fed Espirito Santo UFES/Brazil	11	0	161	8
Univ Fed Rio Grande Norte UFRN/Brazil	25	14.53	147	8
Louisiana State Univ/USA	35	2.56	142	8
James Cook Univ/ Australia	85	15.22	122	8
Cornell Univ/USA	14	0.7	155	8
Univ E Anglia/England	60	21.45	122	7
Wageningen Univ/ Netherlands	50	13.53	129	7
Univ Calif Berkeley/USA	36	12.47	134	7
Univ Brasilia UnB/Brazil	17	1.33	152	7
Univ Nacl Autonoma Mexico/Mexico	51	10.77	134	7
Univ Est Maranhao UEMA/ Brazil	8	0.12	160	7
Univ Plymouth/England	21	0.3	159	7
Univ Est Mato Grosso UNEMAT/Brazil	53	10.2	129	7
Univ Texas Austin/USA	88	24.98	118	7
Univ Florida/USA	49	17.79	127	7
Harvard Univ/USA	54	3.91	139	7
EMBRAPA Pantanal/Brazil	11	0	160	7
Univ Colorado/USA	68	12.44	127	6
Univ Fed Acre UFAC/Brazil	70	12.11	129	6
Univ Fed Ceara UFC/Brazil	12	0.65	175	6
Univ Los Andes/Colombia	88	2.68	134	6
Univ Fed Mato Grosso UFMT/Brazil	23	4.75	144	6

Table S2. Continuation.

Institutions/Country	Degree Centrality	Betweenness Centrality	Closeness Centrality	Number of Articles
Univ Miami/USA	23	0.3	159	6
Univ Arizona/USA	51	4.1	139	6
Univ Fed Rio Grande Sul UFRGS/Brazil	14	1.47	154	6
Univ Fed Lavras UFLA/ Brazil	24	2.55	143	6
Univ Gottingen/Germany	45	17.98	133	6
Max Planck Inst Limnol/ Germany	9	0.53	156	6
Inst Des Sustentavel Mamiraua IDSM/Brazil	10	0.94	157	6
Forestry & Forest Prod Res Inst FFPRI/Japan	17	0	151	6
Oregon State Univ/USA	65	60.86	119	6
Univ Fed Santa Catarina UFSC/Brazil	9	0.12	156	5
Univ Fed Mato Grosso Sul UFMS/Brazil	25	25.24	141	5
Univ Toulouse 3/France	71	8.47	126	5
Univ Calif Santa Barbara/ USA	8	0.08	166	5
Univ Queensland/Australia	27	7.71	141	5
Univ Nacl San Antonio Abad Cusco/Peru	60	2.68	134	5
Univ Exeter/England	50	9.38	130	5
State Univ New York SUNY/USA	40	10.93	132	5
Univ West Scotland/ Scotland	13	0	161	5
Pontificia Univ Catolica Rio Grande Do Sul PUCRS/Brazil	13	4.03	154	5
Univ Fed Vicosa UFV/ Brazil	43	7.88	136	5
Univ Kansas/USA	29	5.55	141	5
Univ Fed Oeste Para UFOPA/Brazil	21	0.17	147	5
Colorado State Univ/USA	53	10.37	134	5
Missouri Bot Garden/USA	88	7.59	127	5
Fundacao Med Trop Dr Heitor Vieira Dourado FMTAM/Brazil	20	0.48	164	5
Ctr Protect & Res Aquat Mammals CPPMA/Brazil	9	0	159	5
Conservat Int/USA	55	1.89	138	5
Ctr Pesquisa Leonidas & Maria Deane FIOCRUZ AM/Brazil	8	0.22	156	5