Botanical collecting effort in Amazonia

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Introduction

A comprehensive list of the world's plants is the goal of several international initiatives, such as the Global Strategy for Plant Conservation under the Convention on Biological Diversity (www.cbd.int/programmes/cross-cutting/plant); Species 2000 (www.sp2000.org); and Encyclopedia of Life (www.eol.org). However, it is clear that a list of known plant species is not equivalent to a list of all plant species, since considerable areas of the planet remain poorly studied. Here we provide information on the state of floristic knowledge of one such area, the Amazonian rainforest biome.

Amazonia is one of the last true wilderness areas on earth. Even though the forests were more densely populated in pre-Columbian times, than previously believed, and human activity may have altered biodiversity patterns (Heckenberger et al. 2007), the overall diversity has not been impoverished to the extent witnessed in densely populated northern hemisphere regions. Deforestation and land conversion in recent decades has nibbled on the peripheral parts of the forest biome but millions of square kilometres of pristine forest remain.

The Amazonian rainforest is generally regarded as one of the floristically richest environments on earth. However, it has also been pointed out that this perception is based on rather shallow exploration. The most telling testimony of this to date is a study by Nelson et al. (1990) in which they plotted on the map the collecting localities of c. 2,300 herbarium specimens of the genus *Inga* (Fabaceae). They were able to show severe bias in the geographical distribution of the collecting: almost all extant specimens originated from the vicinity of a handful of centres of research (Figure 1).

The interior of Amazonia is largely inaccessible due to sparse human populations and, thereby, lack of roads and airports. The region is traversed by numerous navigable rivers, but between these lie extensive continuous blocks of forest. Even so, one could imagine that the coverage of collecting has improved in the last two decades. We took a fresh look at the situation using the data currently available to test this view.

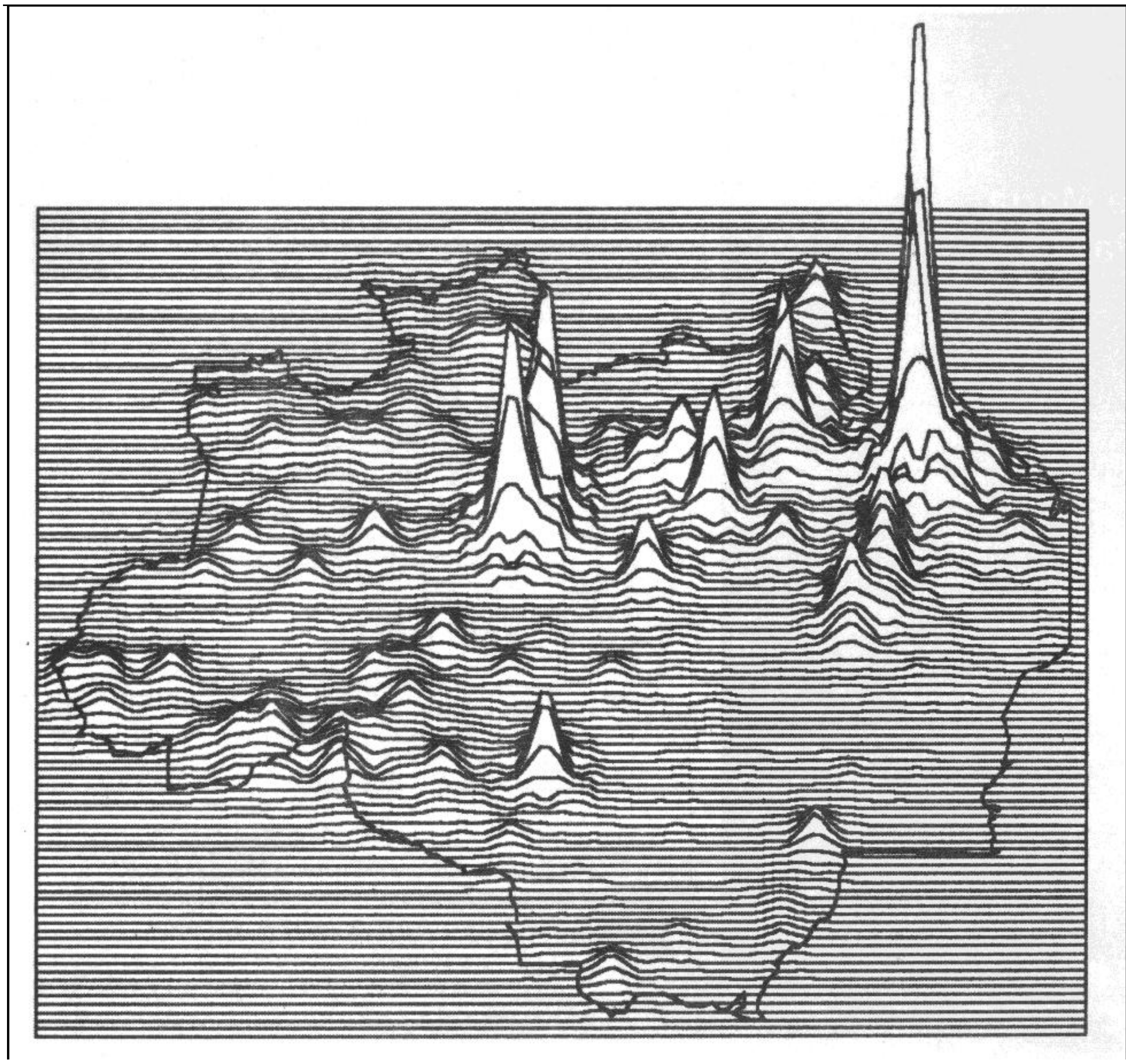

Figure 1. Biased botanical collecting effort discovered by Nelson et al. (1990) as presented in Val, A.L., Figlioulo, R., Feldberg, E. (orgs.) 1991: Bases científicas para estrátegias de preservação e desenvolvimento na Amazônia: fatos e perspectivas, INPA, Manaus.

Material and Methods

Amazonia was defined as the Amazonian rainforest biome, i.e., most of the watershed of the Amazon to c. 1,000 m above sea level (a.s.l.) plus the Guyanas and the lower Orinoco, following e.g. Fittkau (1971), Daly & Prance (1989), and corresponding with Amazonia *sensu latissimo* of Eva & Huber (2005). The exact delimitation of Amazonia was obtained from the ecoregion boundaries of Olson et al. (2001). The size of Amazonia delimited in this way is c. 6.9 million km2.

Using a GIS we plotted on the map the collecting localities of herbarium specimens from the study area contained in the database of the New York Botanical Garden (NY; herbarium acronyms after Holmgren et al., 1990), and the VAST (VAScular Tropicos) nomenclatural database of Missouri Botanical Garden (MO; available at http://mobot.mobot.org/W3T/Search/vast.html). They were queried in 2002 and 2006, respectively. In total, 377,371 collections were located in Amazonia (duplicates of the two databases were not identified). These were collected in 16,058 different localities (Table 1).

For the illustration of spatial variation in collecting activity, we made three different map products: one grid map with a 1-degree grid and another with a 0.5-degree grid, and a network of Thiessen polygons (polygons whose boundaries define the area that is closest to a certain data point relative to all other data points) based on the collecting localities. We used the GIS to calculate the number of empty cells in the grid maps, and the number of collecting localities in all other cells; this was done separately for each Amazonian country and for Amazonia as a whole.

	NY	MO	Total
No. of collections in terrestrial Neotropics	62,464	1,001,066	1,063,530
No. of collections in Amazonia	34,418	342,953	377,371
No. of collecting localities in terrestrial Neotropics	7,464	55,782	63,246
No. of collecting localities in Amazonia	2,731	13,327	16,058

Table 1 Point data of georeferenced herbarium collections from the database of New York Botanical Garden (NY) and the TROPICOS database of Missouri Botanical Garden (MO) available for this study. NB: NY and MO data may include duplicates of the same collection.

Results

The total number of grid cells in Amazonia was 552 or 2211 (1°- or 0.5°-grid, respectively). Of these, 83 or 940 were void of collections (15.0 % or 42.5 %, respectively). In the half-degree grid, the paucity of data translates into an area of 2.9 million km2 with no collections. Poorly-collected area (= less than one collecting locality per 1000 km2) covered 27.7% (1.9 million km2) of the Amazonian area. In all, more than 70% of Amazonia is covered by a collecting locality network with a density below one per 1,000 km2. This means, on average, that the knowledge of the flora of a square larger than 30 km by 30 km is acquired through plant-collecting at a single point. Comparatively well-collected areas (with more than 20 localities per 1000 km2, i.e., one locality representing a square of c. 7 km by 7 km or smaller) was limited to 1.9% (130,000 km2) of the Amazonian area.

There were considerable differences between Amazonian countries in the distribution of collections. Ecuador had no empty cells even on the half-degree grid, whereas in Colombia > 40% and in Brazil > 50% of the half-degree cells lacked collections (Table 2).

	Amazonian cells		
	N	N_{empty}	$\%_{empty}$
Bolivia	120	19	15.8
Brazil	1342	766	57.1
Colombia	151	67	44.4
Ecuador	46	0	0.0
French Guiana	26	1	3.8
Guyana	67	9	13.4
Peru	275	66	24.0
Surinam	48	10	20.8
Venezuela	136	2	1.5
TOTAL	2211	940	42.5

Table 2 Number of grid cells (N), and number and proportion of cells lacking collections (N empty, % empty) in the nine Amazonian countries. All numbers calculated for the half-degree grid only.

The choice of grid cell size had a considerable effect on the overall picture of the distribution of collecting effort (Figure 2). The coarser grid gave an impression of a more even distribution with fewer gaps (Figure 2a), although it should be noted that even the majority of those areas shown in shades of green in Figure 2 contain only very few collecting localities. The finer grid (Figure 2b) revealed vast areas lacking collections. Both resolutions, however, showed certain trends:

- Western, northern, and southern Amazonia have clearly higher and more evenly distributed collecting effort than central and eastern Amazonia.
- Brazil has considerably lower overall collecting intensity and many more empty cells than other Amazonian countries.
- Colombia, Peru, and particularly Brazil have considerable parts of their Amazonian territory void of collections or nearly so, whereas the Ecuadorean and the Guayanan Amazonia are more evenly covered

The network of Thiessen polygons based on collecting localities conveys a visualisation of the extent of land covered by a single collecting locality (Fig 3). Compared with the grid presentation, it provides a scale-independent presentation of collecting effort: a big polygon indicates regionally low collecting activity, whereas a small polygon tells the opposite, and the size of the polygons varies without threshold values. The polygons show that the knowledge of the flora of interior Amazonia is based on collections from a handful of widely scattered localities. The area of the largest polygons is more than 10 000 km^2, indicating that such an area is covered by a single collecting locality. There were 83 of these large polygons (>10 000 km^2) in Amazonia.

Discussion and Conclusions

Our results show that Amazonia remains poorly explored botanically. Collecting effort also continues to be very unevenly distributed. The best-collected areas are generally found around larger cities (e.g., Manaus, São Gabriel de Cachoeira, Iquitos, Saül, and Cayenne), and relatively high collecting activity is also found along the main routes of access (e.g., the Amazon river and Rio Negro, Rio Tocantins, and Rio Madeira, and the roads BR163 and BR364). We must, however, ask how well the observed pattern reflects the real spatial distribution of collecting effort because we mapped registers of only two herbaria.

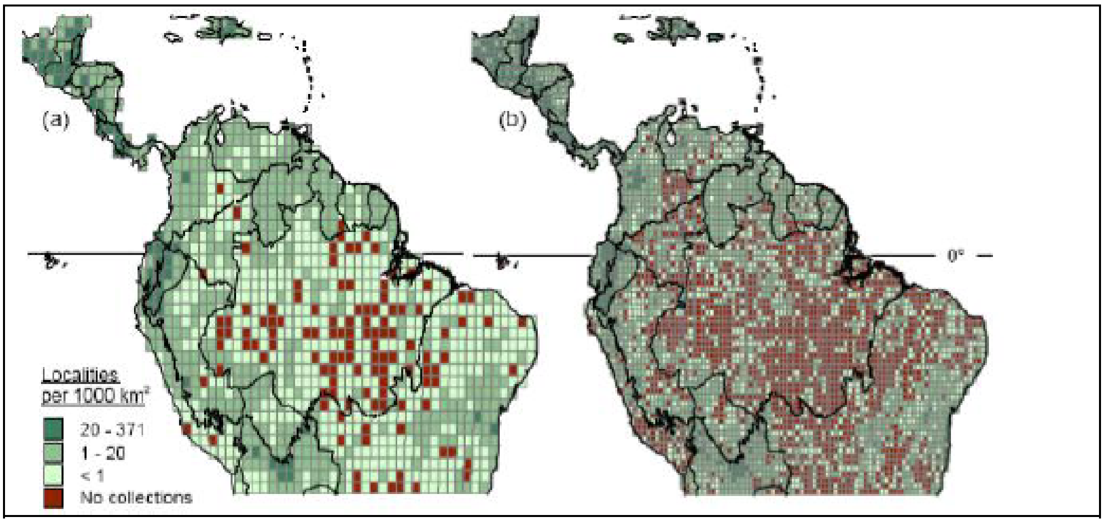

Figure 2. Collecting activity as the number of collecting localities per 1,000 km2 presented per grid cell for (a) a one-degree grid and (b) a half-degree grid. Cells lacking collections are highlighted in red. Cells with at least one collecting locality are divided into four categories, which denote poorly collected, fairly collected, and relatively well-collected areas. Also shown is the delimitation of Amazonia employed, and national borders.

The herbaria of MO and NY have very large Neotropical collections, and collectors all over the world send duplicates to one or both of these major centres of investigation. Nevertheless, at least Brazilian herbaria apparently contain plenty of collections not duplicated in Northern Hemisphere herbaria (especially IAN, MG, INPA, and RB; D. Daly, pers. comm.; M. Hopkins, pers. comm.). Hence our maps may be weak for Brazil. Furthermore, the majority of our data came from MO, which has been particularly active in the Spanish-speaking Neotropics. On the other hand, the pattern of geographical bias in our map is very similar to that found by Nelson et al. (1990), even if they used a quite distinct dataset – their sample came from seven Brazilian and two North American herbaria (NY and US, but not MO), and consisted of collections of a single plant genus. Ours was 160+ times larger and not taxonomically restrained. That the distribution patterns of collecting effort were so similar in both studies despite the methodological differences strengthens the credibility of the results. Therefore, we believe that the pattern in our maps is probably a rather good representation of the true collecting activity distribution. We discuss necessary technical considerations in the mapping of collecting activity elsewhere (Schulman et al. 2007a).

Given the global importance of Amazonia as a centre of biodiversity, it is discouraging to see that many of the gaps in our knowledge of the diversity and distribution patterns within the basin have remained largely unaltered for the last two decades. This study analysed botanical activity but, since the same logistical and financial restrictions apply, the zoological picture is similar (Kress et al., 1998). If uncorrected for collecting gaps and bias, current biological knowledge regarding species ranges in Amazonia may be misleading. For biology to play a meaningful role in land-use planning, e.g., in the selection of conservation areas (cf. Schulman et al., 2007b), corrective models are needed (see Schulman et al. 2007a).

In the long run, the best way to get rid of the deficiencies is, of course, to collect more information. We hope that future expeditions will focus on the white areas revealed by our analyses. Concerted action should be taken to explore the unique Amazonian biome more evenly.

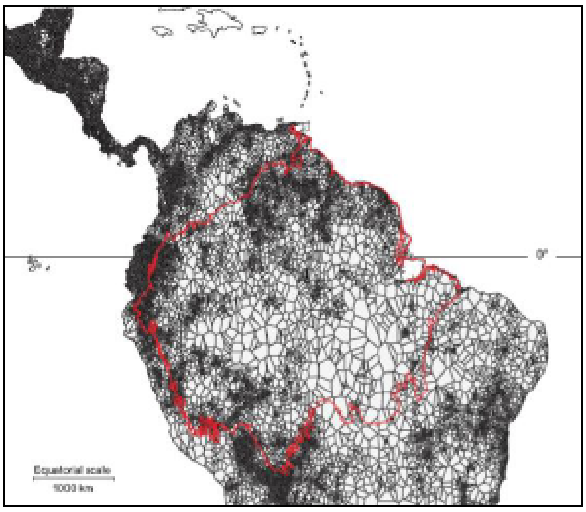

Figure 3. Collecting activity as the area covered by each single collecting locality (=Thiessen polygons); each polygon shows the area closest to the collecting locality that is situated in the centre of the polygon. The smaller the polygons the higher the density of collecting localities. Also shown is the delimitation of Amazonia employed.

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