ELSEVIER

Biological Conservation 103 (2002) 103–111

BIOLOGICAL CONSERVATION

www.elsevier.com/locate/biocon

Patterns of amphibian diversity in Brazilian Amazonia: conservation implications

Claudia Azevedo-Ramos[a,*], Ulisses Galatti[b]

[a]*DPE/Centro de Filosofia e Ciências Humanas, Universidade Federal do Pará, 66070-100 Belém, PA, Brazil*
[b]*Departamento de Zoologia, Museu Paraense Emílio Goeldi, 66017-970 Belém, PA, Brazil*

Received 6 June 2000; received in revised form 13 February 2001; accepted 15 May 2001

Abstract

A literature survey was conducted to determine the amphibian diversity and distribution in Brazilian Amazonia. Patterns of endemisms and similarity of fauna between localities were also addressed. Twenty-eight inventories were found for the region, the majority localized in areas with easier access by road or river. A minimum of 163 amphibian species was recorded for Brazilian Amazonia. Although many species are endemic to the Amazonian lowlands as an entity, the patterns of species uniqueness among sites suggested low endemic distribution within the lowlands of the Amazon Basin. The mean similarity between localities varied from low to intermediate (mean = 0.40), indicating that the Brazilian Amazonia is characterized by distinctive assemblages of amphibians throughout its extension. Localities further apart had lower similarity. No threatened species were recorded. These results contribute to determine priority areas for new inventories and establishment of conservation units. We suggest that areas next to the Amazon deforestation frontier should be prioritized for new studies due to the high rate of alteration and potential loss of species. Additionally, studies on amphibian population dynamics are few in Brazilian Amazonia and more of them should be emphasized to help to draw a better picture of the status of amphibians in this region.

Keywords: Amphibia; Amazonia; Brazil; Geographical distribution; Species diversity

1. Introduction

Amphibian populations are declining in many parts of the world (Blaustein and Wake, 1990; Pechmann and Wilbur, 1994), increasing concerns about the future of this animal group. In Brazilian Amazonia, despite environmental pressures caused by land use and ecosystem conversion, there is a lack of information on the current status of Amphibian populations.

Recent estimates of deforestation in Brazilian Amazonia reach the level of 20,000 km^2 year^{-1} (INPE, 1998). However, present estimates capture less than half of the forest area that is impoverished each year (Nepstad et al., 1999). Logging damages 10,000–15,000 km^2 of forest every year, and in 1998 an estimated 270,000 km^2 of forest became vulnerable to fire (Nepstad et al., 1999). These figures indicate that forest impoverishment may affect important ecosystem functions (e.g. carbon sink) and Amazonian genetic patrimony (e.g. biodiversity).

One of the challenges for decision-makers is to plan conservation or land-use strategies in the absence of complete information, which is usually what happens for most biological groups in Amazonia. For instance, the biodiversity database for Brazilian Amazonia is far from complete and still fragmented. The lack of basic information about species diversity and distribution, endemisms, and population dynamics, combined with incipient knowledge of ecosystem function, obviously make development of reasonable plans for local development difficult. The success in determining areas either for conservation or sustained use in Brazilian Amazonia would be greatly improved if the diversity and distribution of different animal and plant species were well known.

Until now, it has been difficult to access basic information on Brazilian Amazonian amphibia, such as

* Corresponding author at present address: Núcleo de Altos Estudos Amazônicos, Universidade Federal do Pará, 66070-100 Belém, PA, Brazil. Tel.: +55-91-2493593; fax: +55-91-2493593.

E-mail addresses: cramos@amazon.com.br (C. Azevedo-Ramos), ulisses@museu-goeldi.br (U. Galatti).

0006-3207/01/$ - see front matter
PII: S0006-3207(01)00129-X

species richness, assemblage composition and biogeographic distribution, due to dispersed and unpublished information. This paper addresses the results of a survey on amphibia diversity and distribution in the lowlands of Amazonia. Our aim is to present a realistic picture of the current knowledge of amphibian diversity throughout Brazilian Amazonia, addressing the question of species richness, endemisms, and similarity of fauna among sites. These data may contribute to a better understanding of Amazonian amphibian communities, and help in determining priority areas for new inventories and conservation units.

2. Methods

As information on population densities is lacking for most amphibians in Brazilian Amazonia, we based our estimates of diversity on species richness. We did a survey of amphibian inventories undertaken in Brazilian Amazonia, using different kinds of data sources (e.g. scientific papers, electronic data sets, technical reports). We did not use records of museum collections or papers on species descriptions. The sources of data used here are listed in Table 1. The sites were not sampled equally. Therefore, inventories were classified based on their

Table 1
Twenty-eight localities in Brazilian Amazonia with amphibian inventories and their respective sources of data[a]

State	Locality	Effort (~months)	Type of Inventory	Source
Acre	PortoWalter	2.3	1	J.P.Caldwell (not publ.) 1996
Amapá	Champion	1.7	2	G.Coli (not publ.) 1998
Amapá	Serra do Navio	0.7	2	M.S.Hoogmoed and T.C. Avila-Pires (not publ.) 1988
Amazonas	Upper river Juruá	4.0	1	C.Gascon (not publ.) 1991/92 Gascon (1996)
Amazonas	Upper river Purus	0.5	2	Heyer (1977)
Amazonas	Lower river Juruá	4.0	1	C.Gascon (not publ.) 1991/1992 Gascon (1996)
Amazonas	Lower river Purus	0.5	2	Heyer (1977)
Amazonas	Ituxi	2.3	1	J.P. Caldwell (not publ.) l997
Amazonas	Intermediary/ lower river Madeira	0.8	2	Heyer (1977)
Amazonas	Mamirauá	1.3	2	M.S.Hoogmoed and T.C. Avila-Pires (not publ.) 1994
Amazonas	Manaus	12.0	1	Zimmerman and Rodrigues (1990) Hero (1990)
Amazonas	Intermediary river Juruá	4.0	1	C.Gascon (not publ.) 1991/1992 Gascon (1996)
Amazonas	Intermediary river Purus	0.5	2	Heyer (1977)
Amazonas	Taraquá	0.3	3	M.Henzl and U.Galatti (not publ.) 1996
Amazonas	Urucú	0.9	2	Gascon and Pereira (1993) M.S.Hoogmoed and T.C. Avila-Pires (not publ.) 1989
Pará	Alter do Chão	9.5	1	J.P. Caldwell (not publ.) l997 Azevedo-Ramos et al. (1999)
Pará	Belém	9.5	1	Crump (1971) Estupiñán and Galatti (1999)
Pará	Carajás	1.0	2	U. Galatti (not publ.) 1997/98
Pará	Caxiuanã	6.8	1	Avila-Pires and Hoogmoed (1997) Bernardi et al. (1999)
Pará	Paragominas	2.3	1	C. Azevedo-Ramos (not publ.) 1998/1999
Pará	Santarém	2.3	1	J.P. Caldwell (not publ.) l995
Pará	Trombentas/Nhamundá	0.5	2	M.S.Hoogmoed and T.C. Avila-Pires (not publ.) 1988
Rondônia	Upper river Madeira	0.8	2	Heyer (1977) Moreira et al. (1997)
Rondônia	Road Br364	7.4	1	Vanzolini (1986) Moreira et al. (1997)
Rondônia	Costa Marques	0.6	2	Moreira et al. (1997)
Rondônia	Extrema	0.6	2	Moreira et al. (1997)
Rondônia	Guajará-Mirim	3.8	1	Moreira et al. (1997) J.P. Caldwell (not publ.) l998 Galatti (1999)
Roraima	Ajanari/Maracá	9.0	1	Martins (1998) J.P. Caldwell (not publ.) l993

[a] "Type of Inventory" means: 1 (effort $\geqslant$2 months); 2 (effort $<$2 months); 3 (incomplete inventories). The dates of unpublished data indicate the year of the inventory.

sampling effort to differentiate among those on which we would use statistical analyses. Heyer (1988) suggested a minimum of 30 days of amphibian sampling for a given area. Conservatively, we classified the inventories as 1 (effort $\geqslant 2$ months); 2 (effort < 2 months); 3 (incomplete inventories: only a few days or with emphases in some Families). We also arbitrarily divided some large-scale inventories (e.g. inventories along main tributaries of the Amazon river) into smaller areas, or combined close areas at one site (e.g. Maraca island and Ajanari region, in Roraima state) to better represent the fauna of a given region.

Synonymies among species were checked and updated based on Duellman (1993) and an updated electronic version of Frost (1985). Undetermined species (identified only to genus level) were used to estimate the total number of species in a given locality. However, they were not used in similarity analyses between sites or to estimate the total number of species for Brazilian Amazonia due to the impossibility of determining whether they represented the same undetermined species observed at another locality. Additionally, taxonomic problems led us to treat a potential group of species as one species. That is what occurred, for instance, with *Bufo* "*typhonius*" and *Scinax* "*ruber*", both part of species complexes.

We estimated the similarity of fauna for each pair of localities using the "coefficient of geographical resemblance" (Hoogmoed and Gorzula, 1979; Duellman, 1990; Duellman and Thomas, 1996). This coefficient is expressed by the formula $2C/(A+B)$, where C is the number of species in common between two localities; A is the total number of species in site A; and B is the total number of species in site B.

Rainfall has been proposed as the main determinant of species richness among Amazonian anuran assemblages (Duellman, 1978, 1988). To evaluate the relationship between rainfall and species richness throughout the Amazon Basin, we used the rain data obtained in each

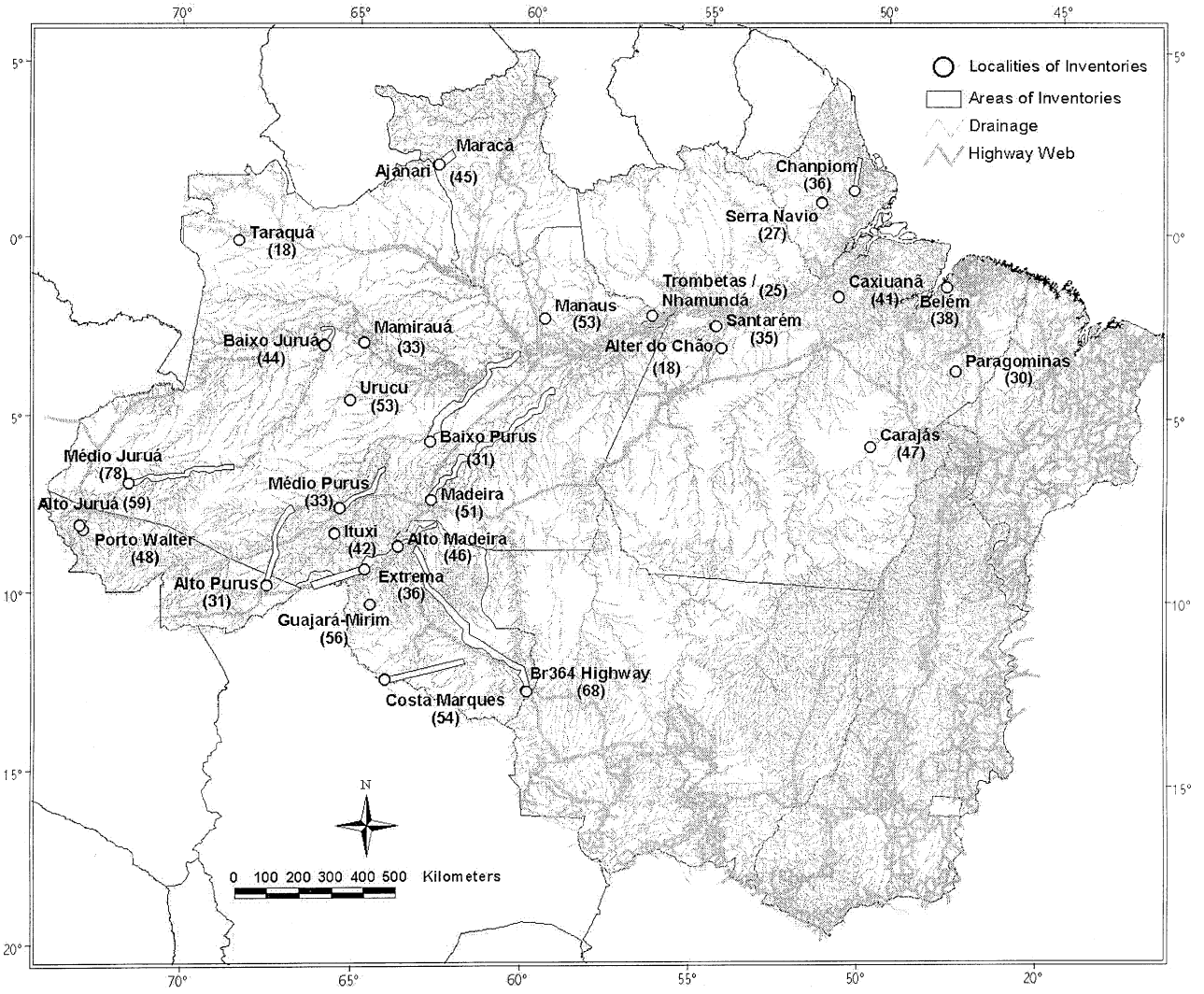

Fig. 1. Localities where Amphibian inventories were carried out in Brazilian Amazonia, showing their relationship to the access by river and road. The numbers represent the total number of species of each locality.

article when available, or we estimated the mean local rainfall based on rain data from 1961 to 1990 provided by CPTEC/INPE (Centro de Previsão de Tempo e Estudos Climáticos—Instituto Nacional de Pesquisas Espaciais).

3. Results

We found 28 localities that have been inventoried for amphibia fauna in the Brazilian Amazon. Of those, 13 (46%) localities had inventories classified as 1 (Table 1). All inventories were done in forest areas, except for Alter do Chão, next to Santarém, in Pará state, which is characterized by savanna vegetation. The location of each site and the number of species found in each locality is shown in Fig. 1. Most of the inventories were done along the main tributaries of the Amazon river and in areas with access by roads, leaving extensive areas with difficult access still to be surveyed. Among the 13 localities with better inventories, the localities with the highest number of species were the intermediate and upper Juruá river (Amazonas), Guajará-Mirim (Rondônia), Manaus (Amazonas), and along the Br364 Highway (Rondônia). Alter do Chão (Pará) and Paragominas (Pará) had the lowest diversity. Overall, it seems that western Amazonia has higher diversity than eastern Amazonia (Fig. 1). However, differences in species richness may also reflect differences in sampling intensity (Table 1) or sampling area (Fig. 1).

A total of 163 amphibian species were recorded for Brazilian Amazonia. However, this number represents the minimum possible number of species due to underestimation related to taxonomic problems and by the fact that undetermined species and isolated descriptions of species were not included here. Also, this number is based mainly on the Anura fauna (frogs and toads) since data for Gymnophiona (caecilians) and Caudata (salamanders) were rare. The relative importance of undetermined species for local estimates of total number of species was variable (2–39%) but usually high for most localities (Table 2). Most of the undetermined species belong to Gymnophiona, Microhylidae, and the genera *Osteocephalus*, *Colostethus* and *Eleutherodactylus*. This may indicate a number of new species still to be described and/or the difficulty researchers have in taxonomically identifying species in these groups. The consequence is a high degree of uncertainty in the estimates of amphibian diversity in the region.

Few species had wide distributions. *Bufo marinus*, *B.* "*typhonius*" (Bufonidae), *Scinax* "*ruber*" (Hylidae) and *Adenomera andreae* (Leptodactylidae) were the only species occurring in more than 80% of the localities. *B. marinus* was the only species that occurred in all localities.

As few articles mentioned the degree of endemism of species, we analyzed the fraction of species unique to each site (Table 2). A total of 38 species occurred in only one locality. However, most of them are known from other sites in Brazil and in the Amazon Basin (Frost, 1985; Duellman, 1993), indicating that their distribution is wider than present inventories show. This suggests gaps in inventories in Brazilian Amazonia. The comparison of these species distributions with those described in Frost (1985) and Duellman (1993), indicated that only 13 species (8% of the total species in Brazilian Amazonia) may be endemic (Table 2).

Despite the unequal sampling effort, we included all localities in a similarity matrix to give a better overview of shared species among sites, with no detrimental effect on the comparison of the 13 best-sampled localities (Table 3). Few areas showed very high or very low values of similarity indices. Most of the localities had mean values of similarity varying between low and intermediate (mean of 0.40; range 0.30–0.67) with other areas. Few localities could be identified as having very similar fauna (Fig. 2), suggesting that Brazilian Amazonia has unique amphibian assemblages throughout its extension. This means that in conserving the locality with the highest value of mean similarity, only a small fraction of the diversity of Amazonian amphibians would be preserved. For conservation purposes, areas with high biodiversity are important. However, areas with complementary fauna must be also taken into account. For instance, the only open area analyzed (savanna vegetation of Alter do Chão, in Santarém, Pará) showed lower diversity in relation to adjacent forest areas (e.g. Santarém; Table 3), but had a distinctive fauna composition (Fig. 2). Therefore, a local fauna would be better represented if different kinds of habitats were included in conservation units. Also important to political strategies for conservation areas in Amazonia is the fact that the greater the distance between localities, the lower the similarity of fauna ($F_{76,1} = 11.7$; $P = 0.001$; Fig. 3).

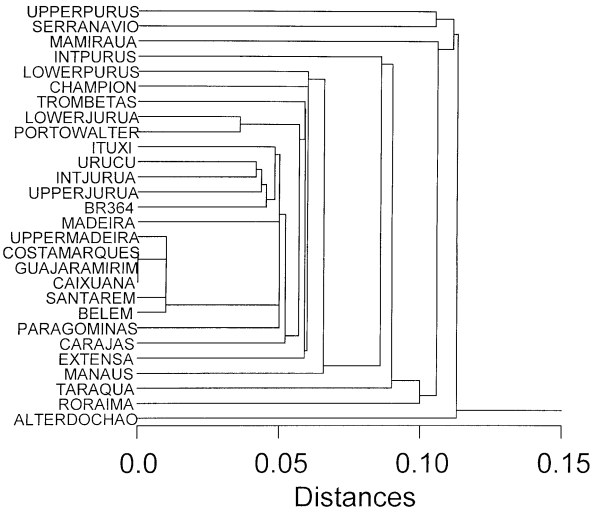

Fig. 2. Dendrogram of the localities based on a matrix of similarity using Euclidean distances.

Table 2
Relative importance of the number of undetermined species in relation to total species, and comparison between species with unique occurrence on the inventories and those endemics according to Frost (1985) and Duellman (1993)[a]

Locality (abbreviation)	No. undetermined species/total number (%)	No. unique species on the inventories	Endemic species after Frost (1985) and Duellman (1993)
Intermediary-Juruá (IJU)	19/78 (24.4)	1 *Leptodactylus diedrus*	1 *Leptodactylus dantasi*[b]
BR364 (BR)	12/68 (17.6)	1 *Leptodactylus podicipinus*	0
Upper-Juruá (UJU)	13/59 (22.0)	0	0
Guajará-mirim (GM)	11/56 (19.6)	0	
Costa Marques (CM)	04/54 (7.4)	0	0
Manaus (MA)	01/53 (1.9)	9 *Bufo dapsilis* *Cochranella oyampiensis* *Colostethus stepheni* *Eleutherodactylus okendeni* *Leptodactylus riveroi* *Chiasmocleis hudsoni* *Synapturanus salseri* *Typhlonectes cunhai* *Pipa arrabali*	2 *Colostethus stepheni*[c] *Typhlonectes cunhai*
Urucu (URU)	13/51 (25.5)	0	0
Intermediary/ lower-Madeira (MAD)	03/51 (5.8)	0	0
PortoWalter (PW)	10/48 (20.8)	4 *Hemiphractus scutatus* *Phyllomedusa atelopoide* *Scinax funereus* *Eleutherodactylus sulcatus*	
Carajás (CJ)	02/47 (4.2)	1 *Epipedobates flavopictus*	0
Upper-Madeira (UMA)	03/46 (6.5)	0	0
Ajanari-Maracá (RR)	05/45 (11.1)	6 *Allophryne ruthveni* *Dendrobates leucomelas* *Hyla crepitans* *Scinax exiguus* *Pleurodema brachyops* *Pseudopaludicula boliviana*	0
Lower-Juruá (LJU)	07/44 (15.9)	0	0
Ituxi (ITU)	09/42 (21.4)	0	0
Caxiuanã (CAX)	01/41 (2.4)	0	0
Belém (BE)	02/38 (5.3)	2 *Hyla bokermani* *Scinax baumgardneri*	0
Champion (CH)	05/36 (13.9)	2 *Eleutherodactylus conspicillatus* *Lysapsus laevis*	0
Extrema (EXT)	07/36 (19.4)	0	0
Santarém (STM)	05/35 (14.3)	2 *Bufo glaberrimus* *Dendrobates castaneoticus*	2 *Dendrobates castaneoticus* *Hyla inframaculata*
Mamirauá (MAM)	13/33 (39.4)	0	0
Intermediary-Purus (IPU)	02/33 (6.6)	0	0
Upper-Purus (UPU)	02/31 (6.4)	1 *Hyla pauiniensis*	2 *Hyla pauiniensis* *Hyla xapuriensis*[d]

(*continued on next page*)

Table 2 (*continued*)

Locality (abbreviation)	No. undetermined species/total number (%)	No. unique species on the inventories	Endemic species after Frost (1985) and Duellman (1993)
Lower-Purus (LPU)	00/31 (0)	0	1 *Hyla imitator*[e]
Paragominas (PA)	01/30 (3.3)	0	0
Serra do Navio (SN)	02/27 (7.4)	5 *Epipedobates pulchripectus* *Adelophryne gutturosa* *Eleutherodactylus chiastonotus* *Eleutherodactylus gutturalis* *Eleutherodactylus zeuctotylus*	2 *Hyla dentei* *Epipedobates pulchripectus*
Trombetas/Nhamundá (TRO)	06/25 (24.0)	0	0
Taraquá (AR)	05/18 (27.77)	0	2 *Hyla tintinnabulumf*[f] *Scinax lindsayi*[g]
Alter do Chão (ACH)	02/18 (11.11)	0	0

[a] Type localities are indicated below when different from localities used in this study.
[b] Feijó, Acre.
[c] Presidente Figueiredo, Amazonas.
[d] Xapuri, Acre.
[e] Lago Codajás, Amazonas.
[f] Rio Uaupés, Amazonas.
[g] Rio Uaupés, 3 km Yapima (Colombia), Amazonas.

There was no statistically significant relationship between species richness and rainfall for the 13 best sampled localities ($F_{13,1} = 3{,}280$; $P = 0.098$). However, there was a positive trend in the data, due almost entirely to low species richness at Alter do Chão. (Fig. 4). The addition of new areas, especially with low rainfall, may clarify this relationship.

As most decisions about the establishment of conservation units require actions within states, we separated the localities ($n = 28$) into groups by Brazilian Amazonian states to determine the number of species within macroregions and evaluate the frequency with which each species occurred in localities in each state (Table 4). This analysis showed that the anuran fauna was very different among localities within a given state. The majority of species occurred in only one or two localities. The fauna of a sub-region may be more similar to the fauna of the neighboring state than to the fauna of other

Table 3
Number of total species (bold), number of shared species between two localities (upper side of the table) and the coefficient of geographical resemblage between two localities (lower side of the table) for 13 sities in Brazilian Amazonia[a]

	STM	MA	RR	ITU	PW	BE	CAX	IJU	UJU	LJU	BR	GUA	ACh
STM	**30**	16	13	16	15	14	17	18	16	14	21	18	8
MA	0.39	**52**	15	18	18	17	20	25	20	19	25	24	10
RR	0.37	0.32	**40**	11	10	17	13	11	11	7	23	18	13
ITU	0.50	0.42	0.30	**33**	22	13	17	24	24	16	24	24	4
PW	0.44	0.40	0.25	0.62	**38**	15	15	27	25	20	20	19	4
BE	0.42	0.39	0.45	0.38	0.40	**36**	19	19	15	13	18	13	9
CAX	0.49	0.43	0.32	0.47	0.38	0.50	**40**	20	18	18	23	17	10
IJU	0.40	0.45	0.22	0.52	0.56	0.40	0.40	**59**	42	35	32	27	8
UJU	0.42	0.41	0.26	0.61	0.59	0.36	0.42	0.80	**46**	29	27	25	6
LJU	0.42	0.43	0.18	0.46	0.53	0.36	0.47	0.73	0.70	**37**	21	17	6
BR	0.49	0.46	0.48	0.54	0.42	0.39	0.48	0.56	0.53	0.45	**56**	30	11
GUA	0.48	0.49	0.42	0.61	0.46	0.32	0.36	0.52	0.55	0.41	0.59	**45**	11
ACh	0.35	0.29	0.46	0.16	0.15	0.35	0.36	0.21	0.26	0.23	0.31	0.36	**16**
mean	0.42	0.39	0.35	0.44	0.40	0.39	0.43	0.45	0.43	0.40	0.48	0.43	0.30

[a] Mean similarity values by locality are indicated at the end of the table. Abbreviations of the localities are as in Table 2.

Table 4
Distribution of amphibian species among states in Brazilian Amazonia in accordance with the number of localities they were found[a]

No. localities with the occurrence of a given species	States in Brazilian Amazonia					
	Amazonas	Pará	Rondônia	Amapá	Acre	Roraima
1	43 (43)	22 (27)	27 (30)	38 (81)	38 (100)	45 (100)
2	18 (18)	16 (20)	20 (22)	9 (19)		
3	12 (12)	13 (16)	24 (27)			
4	15 (15)	13 (16)	6 (7)			
5	3 (3)	8 (10)	12 (13)			
6	5 (5)	5 (6)				
7	2 (2)	3 (4)				
8	2 (2)	1(1)				
Total number of species	100	81	89	47	38	45

[a] In parentheses, relative frequence (%) of number of species/total of species.

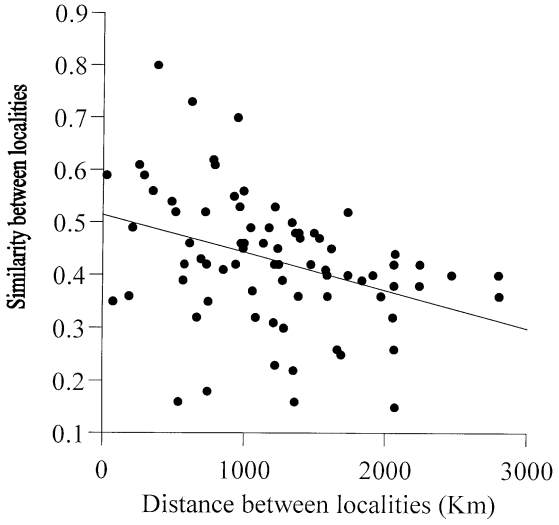

Fig. 3. Relationship between the coefficient of geographical resemblance and the distance of 13 localities in Brazilian Amazonia.

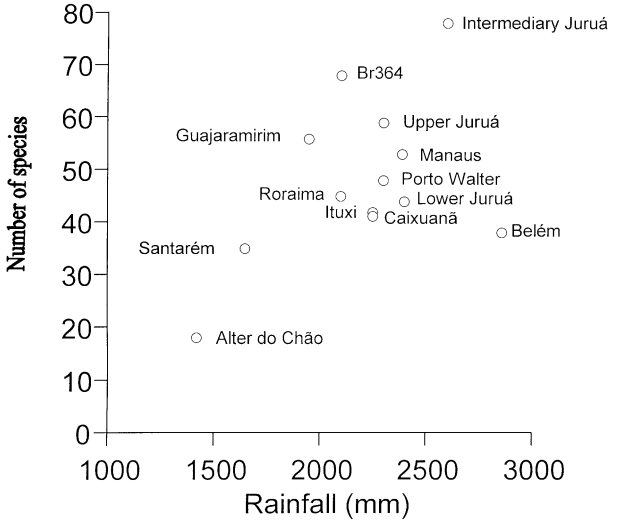

Fig. 4. Relationship between local number of Amphibia species and rainfall for 13 localities in Brazilian Amazonia.

sub-regions within the same state, depending on the distance between them. This may have political implications when determining the limits of a conservation unit.

4. Discussion

The information on amphibian diversity in Brazilian Amazonia is fragmented and not much of it is available in the scientific literature. The lack of information is especially problematic for caecilians and salamanders. Additionally, the taxonomic uncertainty (Caldwell, 1996) and few long-term inventories prevent more accurate estimates of amphibian diversity in the region, leading to the present estimate ($n = 163$ species) as a minimum registered.

The analysis of faunal similarity between localities showed that the Amazon region has distinctive assemblages of amphibian fauna, and these assemblages do not necessarily represent a subset of richer areas. The consequence for conservation strategies is that the preservation of a particular locality would allow the protection of less than half (mean similarity index = 0.40) of the amphibian diversity in Brazilian Amazonia. Since the greater the distance between localities, the lower the similarity of their fauna, conservation units should be established in different regions along south–north and east–west axes, comprising different kinds of habitats. Because localities within Amazonian states in Brazil differ in richness and composition of amphibian assemblages, depending on the size or the number of conservation units established in a state, only a small parcel of the diversity of that region may be preserved. For an effective conservation of species or ecosystems, the interest must transcend state boundaries.

Localities in the western Brazilian Amazonia seem to have higher amphibian diversity than localities in eastern Amazonia. Despite the fact that sampling effort and

extension might have an effect on the pattern found, and as rainfall showed no clear effect on species richness, the higher diversity found in lowlands of western Brazilian Amazonia may also be an effect of the proximity to the western Amazonian highlands and their patterns of higher endemisms and species richness (Duellman, 1978, 1982, 1988). Future studies with standardized efforts may clarify the pattern found. Patterns of endemisms and threatened species are generally used to determine geographic distribution of reserves (Gaston and Williams, 1996; Vane-Wright, 1996). The Amazon region as a whole has many endemic amphibian species (Lynch, 1979), especially in upper Amazonia, where the Andes probably played an important role as a Pleistocene refuge (Duellman, 1982; Heyer and Maxson, 1982). However, our results showed that the degree of uniqueness among sites in lowlands of Brazilian Amazonia is low. This is in accordance with what has been found for other taxa in the same region (Kress et al., 1988). Also, there is no mention of threatened amphibian species in this region. As population dynamics are unknown for most of the species, it would be very difficult to distinguish natural fluctuations from declining populations. Therefore, it seems that patterns of endemism and threatened species are not good indicators for the establishment of conservation areas for Amazonian amphibians in Brazil. Additionally, the current uncertainty about species richness estimates and the extent of areas still to be surveyed also restrict conservation strategies based solely on these two parameters. Instead, or associated with them, patterns of regional development and habitat conversion, as well as the presence/absence of conservation units around a given locality, could be useful to determine priorities for new inventories and conservation areas. Records of museum collections can also be an useful tool for assessing conservation priorities in Amazonia (Kress et al., 1998; Heyer et al., 1999). As natural flutuations are common in amphibian populations (Pechmann and Wilbur, 1994), larger conservation units would be prefered than small ones wherever it is possible.

The 28 localities surveyed for amphibians showed that the majority of inventories have been made along the main tributaries of the Amazon river or in the few regions with better access by roads. Information about amphibian diversity is still missing in extensive areas throughout the Amazon basin (e.g. areas between the main tributaries of the Amazon river). Because of the large Amazonian extension still to be surveyed, we suggest that studies near the deforestation frontier in southern and eastern Amazonia should be prioritized due to the rapid conversion of forests into other ecosystems and the consequent loss of species. Also, study sites that include the complexity of habitats of a given region will best contribute to the evaluation of a local diversity. Studies should give more emphasis to population dynamics so that threatened species could be identified in advance.

A series of recommendations has been proposed to monitor amphibian diversity and populations in Brazil (Azevedo-Ramos, 1998). As the rates of deforestation and logging in Brazilian Amazonia indicate the urgency of creating an accessible biological database for the region, compilation of available data and effective training of human resources to augment field studies in the region seem to be critical. Additionally, as inventories made along the east–west axis identified a distinctive fauna in each locality and not a sub-sample of richer areas, it is recommended that future sampling designs include areas along this axis to better characterize the amphibian diversity of Amazonian fauna.

Acknowledgements

We thank all authors who have surveyed Brazilian Amazonia in recent years and kindly made their unpublished data available for this study. Laurie Vitt and Jan Caldwell facilitated access to the species lists from their inventories in the Amazon Basin by making them available on the web. A draft of this paper was presented during the conference for "Evaluation and Identification of Priority Actions for Conservation, Sustainable Use and Repartitioning of the Benefits of the Brazilian Amazon Biodiversity" and received valuable suggestions from participants in the Amphibia-Reptile study group. Veronica Regina Oliveira and Renan Bernardi helped with literature search and Ellen White corrected the English. Luis Barbosa made Fig. 1. Conservation International in Brazil made the initial suggestion for this paper and gave partial financial support.

References

Avila-Pires, T.C.S., Hoogmoed, M.S., 1997. The herpetofauna. In: Lisboa, P. (Ed.), Caxiuanã. Museu Paraense Emílio Goeldi, Belém, Pará, pp. 389–401.

Azevedo-Ramos, C., 1998. Monitoring amphibian diversity and population: what should be emphasized in brazilian studies. Bulletin of the Ecological Society of America 79, 128–129.

Azevedo-Ramos, C., Magnusson, W.E., Bayliss, P., 1999. Predation as the key factor structuring tadpole assemblages in a savanna area in central Amazonia. Copeia1999, 22–33.

Bernardi, J.A.R., Estupiñán-T, R.A., Galatti, U., 1999. New anuran records from the Floresta Nacional de Caxiuanã, eastern Amazon, Brazil. Herp. Review 30, 176–177.

Blaustein, A.R., Wake, D.B., 1990. Declining amphibian populations: a global phenomenon? Trends in Ecology and Evolution 5, 203–204.

Caldwell, J.P., 1996. Diversity of Amazonian anurans. The role of systematics and phylogeny in identifying macroecological and evolutionary patterns. In: Gibson, A.C. (Ed.), Neotropical Biodiversity and Conservation. Occasional Publ. Mildred E. Mathias Bot. Garden 1, University of California, Los Angeles, pp. 73–88.

Crump, M.L., 1971. Quantitative analysis of the ecological distribution of a tropical herpetofauna. Occas. Pap. Mus. Nat. Hist. Univ. Kansas 3, 1–62.

Duellman, W.E., 1978. The biology of an equatorial herpetofauna in Amazonian Ecuador. Misc. Publ. Mus. Nat. Hist. Kansas 65, 1–352.

Duellman, W.E., 1982. Quaternary climatic-ecological fluctuations in the lowland tropics: frogs and forests. In: Prance, G.T. (Ed.), Biological Diversification in the Tropics. Columbia Univ. Press, New York, pp. 389–402.

Duellman, W.E., 1988. Patterns of species diversity in anuran amphibians in the American tropics. Ann. Missouri. Bot. Gard. 75, 79–104.

Duellman, W.E., 1990. Herpetofaunas in neotropical rainforests: comparative composition, history, and resources use. In: Gentry, A.H. (Ed.), Four Neotropical Rainforests. Yale Univ. Press, New Haven, pp. 455–505.

Duellman, W.E., 1993. Amphibian species of the world: additions and corrections. Univ. Kansas Mus. Nat. Hist. Spec. Publ. 21, 1–372.

Duellman, W.E., Thomas, R., 1996. Anuran amphibians from a seasonally dry forest in southeastern Peru and comparisons of the anuras among sites in the upper Amazon basin. Occ. Pap. Mus. Nat. Hist. Univ. Kansas 180, 1–34.

Estupiñán, R.A., Galatti, U., 1999. La Fauna Anura en Areas com Diferentes Grados de Intervencion Antropica de la Amazonia Oriental Brasileñ. Rev. Acad. Colombiana Ciências Exatas, Físicas y Naturales 23, 181–193.

Frost, D.R., 1985. Amphibian Species of the World. Allen Press, Lawrence, Kansas. (Updated electronic version available from http://research.amnh.org; Copyright 1998–1999 by the American Mus. Nat. Hist.).

Galatti, U. 1999. Avaliação ecológica rápida da Reserva Biológica Estadual Rio Ouro Preto, Guajará-Mirim, Rondônia. Inventário da herpetofauna da Res. Biol. Rio Ouro Preto. Relatório final. Programa das Nações Unidas para o Desenvolvimento/Plano Agropecuário e Florestal de Rondônia. PNUD/Planafloro, pp 1–11. Porto Velho.

Gascon, C., 1996. Amphibian litter fauna as river barrier in flooded and non flooded Amazonian rainforest. Biotropica 28, 136–140.

Gascon, c., Pereira, O.S., 1993. Preliminary checklist of the herpetofauna of the upper rio Urucu, Amazonas, Brazil. Ver. Brasil. Zool. 10, 179–183.

Gaston, K., Williams, P.H., 1996. Spatial patterns in taxonomic diversity. In: Gaston, K.J. (Ed.), Biodiversity—A Biology of Numbers, Difference. Blackwell Science Ltd. University Press, Cambridge, pp. 202–229.

Hero, J-M., 1990. An illustrated key to tadpoles occurring in the central Amazon rainforest, Manaus, Amazonas, Brasil. Amazoniana 11, 201–262.

Heyer, W.R., 1977. Taxonomic notes on frogs from the Madeira and Purus rivers, Brazil. Papéis Avulsos de Zoologia 31, 141–162.

Heyer, W.R., 1988. On frog distribution patterns East of the Andes. In: Vanzolini, P.E., Heyer, W.R. (Eds.), Proceedings of a Workshop Neotropical Distribution Patterns. Academia Brasileira de Ciência, Rio de Janeiro, pp. 145–273.

Heyer, W.R., Maxson, L.R., 1982. Distributions, relationships, and zoogeography of Lowland frogs: the *Leptodactylus* complex in South America, with special reference to Amazonia. In: Prance, G.T. (Ed.), Biological Diversification in the Tropics. Columbia University Press, New York, pp. 375–402.

Heyer, W.R., Coddington, J., Kress, W.J., Acevedo, P., Cole, D., Erwin, T.W., Meggers, B.J., Pogue, M.G., Thorington, R.W., Vari, R.P., Weitzman, M.J., Weitzman, S.H., 1999. Amazonian biotic data and conservation decisions. Ciência e Cultura. Journal of the Brazilian Association for the Advancement of Science 51, 372–385.

Hoogmoed, M.S., Gorzula, S.J., 1979. Checklist of the savanna inhabiting frogs of the El Manteco region with notes on their ecology and description of a new species of treefrog (Hylidae, Anura). Zool. Mededelingen 54, 183–216.

INPE (Instituto Nacional de Pesquisas Espaciais). 1999. Monitoring of the Brazilian Amazonian Forest by satellite (1997–1998). INPE report. Ministério da Ciência e Tecnologia. São Paulo.

Kress, W.J., Heyer, W.R., Acevedo, P., Coddington, J., Cole, D., Erwin, T.W., Meggers, B.J., Pogue, M., Thorington, R.W., Vari, R.P., Weitzman, M.J., Weitzman, S.H., 1998. Amazonian diversity: assessing conservation priorities with taxonomic data. Biodiversity and Conservation 7, 1577–1587.

Lynch, J.D., 1979. The amphibians of the lowland tropical forests. In: Duellman, W.E. (Ed.), The South American Herpetofauna: Its Origin, Evolution, and Dispersal. Monography of the Museum of Natural History. The University of Kansas Kansas, Laurence, pp. 189–215.

Martins, M., 1998. The frogs of the Ilha de Maracá. In: Milliken, W., Ratter, J.A. (Eds.), Maracá: Biodiversity and Environment of an Amazonian Rainforest. John Wiley and Sons, New York, pp. 285–306.

Moreira, G.R., Gordo, M., Martins, M., Galatti, U., Oda, W.Y. 1997. Relatório Final da Área Temática Herpetofauna. Macrozoneamento Sócio-Econômico-Ecológico do Estado de Rondônia. Planafloro, pp 1–57. Porto Velho.

Nepstad, D.C., Verissímo, A., Alencar, A., Nobre, C., Lima, E., Lefebvre, P., Schlesinger, P., Potter, P., Moutinho, P., Mendonza, E., Cochrane, M., Brooks, V., 1999. Large-scale impoverishment of Amazonian forests by logging and fire. Nature 398, 505–508.

Pechmann, J.H.K., Wilbur, H.M., 1994. Putting declining amphibian populations into perspective: natural fluctuations and human impacts. Herpetologica 50, 65–84.

Vane-Wright, R.I., 1996. Identifying priorities for the conservation of biodiversity: systematic biological criteria within a socio-political framework. In: Gaston, K.J. (Ed.), Biodiversity—A Biology of Numbers and Difference. Blackwell Science Ltd, University Press, Cambridge, pp. 309–344.

Vanzolini, P. E. 1986. Levantamento Herpetológico da Área do estado de Rondônia sob influência da rodovia BR 364. Programa Polonoroeste, Subprograma Ecologia Animal. Relatório de Pesquisa No. 1, Ministério de Ciência e Tecnologia/CNPq. Brasilia.

Zimmerman, B.L., Rodrigues, M.T., 1990. Frogs, snakes, and lizards of INPA-WWF Reserves near Manaus, Brasil. In: Gentry, A.H. (Ed.), Four Neotropical Rainforest. Yale University Press, New Haven, pp. 426–454.