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TEMPORAL VARIATION IN THE ABUNDANCE AND NUMBER OF SPECIES OF FROGS IN 10,000 HA OF A FOREST IN CENTRAL AMAZONIA, BRAZIL

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ABSTRACT. In this study we sampled diurnal and nocturnal anuran assemblages in 10,000 ha of tropical forest. We provide data on composition and variation in the occurrence and abundance of these species during two rainy seasons. Our study took place at Reserva Florestal Adolpho Ducke, Manaus, Amazonas state, Brazil. We analysed the anuran assemblage for three diurnal samples and five nocturnal samples from November/2002 to May/2004. Data were collected in 72 plots systematically distributed over a 64 km^2 grid. Diurnal anuran assemblage surveys were conducted by visual encounter. We sampled the nocturnal anuran assemblage using standardized methods – simultaneous visual encounter surveys and auditory sampling. We detected 30 species of anurans, belonging to seven families using all methods and periods. A total of 6,030 individuals belonging to eight species and four families were recorded in diurnal samples and 25 species (16,050 individuals), belonging to six families were recorded in nocturnal samples. The number of nocturnal species varied from 18 in the beginning of the second rainy season to 22 in the middle of the rainy season. Fourteen species were found in the five sampling periods. The species with high abundance that were widely distributed in the study area were those with reproductive specializations such as direct development, development in terrestrial nests, or development in bromeliads with parental care. This study showed the viability of the system of surveys and the methods used for sampling anuran assemblages in a tropical forest. They were also adequate for estimating the richness and abundance of species. However, systematically distributed plots, such as those used in this study, mostly reveal terrestrially breeding frogs. The aquatic-breeding frogs were found mainly in riparian zones and were rare in zones distant from water bodies. There were a low number of plots around water bodies (25%) which, consequently, reduced the record of aquatic-breeding individuals.

KEYWORDS. Abundance, Anura, Richness, Auditory Sampling, Visual Surveys.

INTRODUCTION

Tropical forests house a great number of anuran species (Duellman, 1999) and, consequently, a high diversity of reproductive modes (Hödl, 1990; Duellman and Trueb, 1994; Haddad and Prado, 2005). These reproductive modes can vary from aquatic clutches and tadpoles, until modes with terrestrial clutches and direct development in the eggs. This fact promotes a differential distribution of species in the habitat, where terrestrial-breeding species are widely distributed (Menin *et al.,* 2007a).

Studies on distribution and diversity of anuran assemblages in tropical forests have been conducted mainly with leaf-litter assemblages (e.g. Inger, 1980; Scott, 1982; Lieberman, 1986; Allmon, 1991; Rodriguez, 1992; Giaretta *et al.,* 1997; Rocha *et al.,* 2000, 2001, 2007; Van Sluys, 2007) or around habitats used for reproduction (Crump, 1971, 1974). The majority of leaf-litter studies used square plots, which varied from 25 to 232 m^2 (e.g. Rodriguez, 1992; Inger, 1980, respectively) and generally showed variation along altitudinal gradients or in species capture between rainy and dry seasons (e.g. Giaretta *et al.,* 1999). Other studies were developed using rectangular transects and combined different standardized methods (visual and auditory methods) for anuran sampling (Veith *et al.,* 2004; Rödel and Ernst, 2004). In western Amazonia, Duellman (1995) conducted diurnal and nocturnal samples using visual encounter surveys in trials and square plots of 20 x 20 m. These samples were conducted in different rainy and dry periods. However, the trials and plots were distributed in a random way in the study area. Nevertheless, the use of square plots for amphibian surveys are expensive, and the sampling resources such as time and personnel are frequently limited. Since anurans show a great diversity of habits with the species being terrestrial, arboreal, semi-arboreal, aquatic and fossorial, it is necessary to use different methods in order to form a general picture of local diversity.

In the tropical forest of Central Amazonia, Brazil, there is a great diversity of anuran species (Zimmerman and Rodrigues, 1990; Hero, 1990). Some areas in this region have been studied throughout the past 25 years. The Reserva Florestal Adolpho Ducke (RFAD), Manaus, Brazil, is one of these areas, and has 50 frog species (Lima *et al.,* 2006), 12 of which are found in borders and open areas. The 38 remaining species are found in forested areas, and the majority of them re-

produce during the rainy season (Lima *et al.,* 2006). Only two species, *Osteocephalus buckleyi* (Hero, 1990) and *Hypsiboas boans* (= *Hyla boans,* Magnusson *et al.,* 1999) reproduce during the dry season in streams. In RFAD, some species are terrestrial-breeding frogs (e.g., *Leptodactylus (Lithodytes) andreae, L. pentadactylus, L. stenodema, Pristimantis* spp., *Synapturanus* spp., *Anomaloglossus stepheni),* while others use aquatic habitats to deposit their eggs (e.g., *Rhinella, Hypsiboas, Leptodactylus*) or only for tadpole development (e.g., *Phyllomedusa* spp., *Allobates* spp.) (Lima *et al.,* 2006). The studies conducted in this area vary from the elaboration of a tadpole identification key (Hero, 1990) to population ecology studies of diurnal and nocturnal species (e.g., Moreira and Lima, 1991; Galatti, 1992; Magnusson *et al.,* 1999; Hero *et al.,* 1998, 2001; Rodrigues, 2006). However, these studies were developed in a small area in the northwestern corner of the RFAD. In the last few years, a system of biological surveys was established in the RFAD, with 72 permanent plots systematically distributed over a 64 km^2 grid in the area (Magnusson *et al.,* 2005). However, this system differs from those used in other studies by adopting 250 m long plots positioned to follow altitudinal contour lines (Magnusson *et al.,* 2005). This system permitted the development of studies about the distribution of diurnal anuran species in a mesoscale (Guimarães, 2004) and recorded species that had not been found previously (Menin, unpubl. data).

In this study, we sampled diurnal and nocturnal anuran assemblages in the RFAD in 72 permanent plots distributed throughout the reserve, using different sampling methods and low material and personal costs. We provide data on composition and variation in the occurrence and abundance of these species during two rainy seasons.

Material and Methods

Study area

Our study took place at Reserva Florestal Adolpho Ducke (RFAD, 02°55' and 03°01'S, 59°53' and 59°59'W), adjacent to the city of Manaus, Amazonas state, Brazil. The reserve covers 10,000 ha of *terra firme* (non-flooded) rainforest, a well-drained forest not subject to seasonal inundation. The forest is characterized by a 30-37 m tall closed canopy, with emergents growing to 40-45 m (Ribeiro *et al.,* 1999). The understorey contains abundant sessile palms (*Astrocaryum* spp. and *Attalea* spp.; Ribeiro *et al.,* 1999). The climate is characterized by a rainy season from November to May and a dry season during the rest of the year (Marques Filho *et al.,* 1981). Mean annual temperature is approximately 26°C (Marques Filho *et al.,* 1981) and mean annual rainfall was 2489 mm between 1985 and 2004. RFAD is split evenly between two major watersheds; a ridge running through the middle of the reserve separates the eastern from the western watershed.

Data collection

We sampled the anuran assemblage during three diurnal samples (November-December 2002, February-April 2003 and January-February 2004) and five nocturnal samples (November-December 2002, March-May 2003, November-December 2003, January-March 2004 and April-May 2004). Data were collected in 72 plots systematically distributed over a 64 km^2 grid formed by 8 km long trails (Fig. 1; more information is available from http://ppbio.inpa.gov.br). Each plot was at least 1 km distant from any other. Plots were 250 m long and positioned to follow altitudinal contour lines, and thus minimized altitudinal and soil variation within each plot (Magnusson *et al.,* 2005). All plots were at least 1 km from the edge of the reserve. Surveys occurred only during the rainy season (November to May). Diurnal surveys required a mean of 46 days to cover all plots within the reserve, and nocturnal surveys required a mean of 49 days to survey all 72 plots.

Diurnal anuran assemblage surveys lasted about 2 hours per plot and were conducted between 08:00 and 16:00 h by two people walking along a 250 x 1 m (0.025 ha) plot. Observers visually scanned and gently turned over the leaf-litter, detecting individuals by visual encounter. The two first surveys were conducted by the same person (second author and field assistant), but in the third survey, a member was changed (two field assistants with high field experience).

We sampled the nocturnal anuran assemblage using standardized methods – simultaneous visual encounter surveys and auditory sampling (Crump and Scott, 1994; Zimmerman, 1994; Rödel and Ernst, 2004). These methods are complementary and adequate for surveying the distribution and abundance of anurans in long- and short-term studies (Doan, 2003; Rödel and Ernst, 2004). We sampled each plot for about one hour between 18:30 and 22:00 h. Every 5 m, the two observers stopped and recorded the

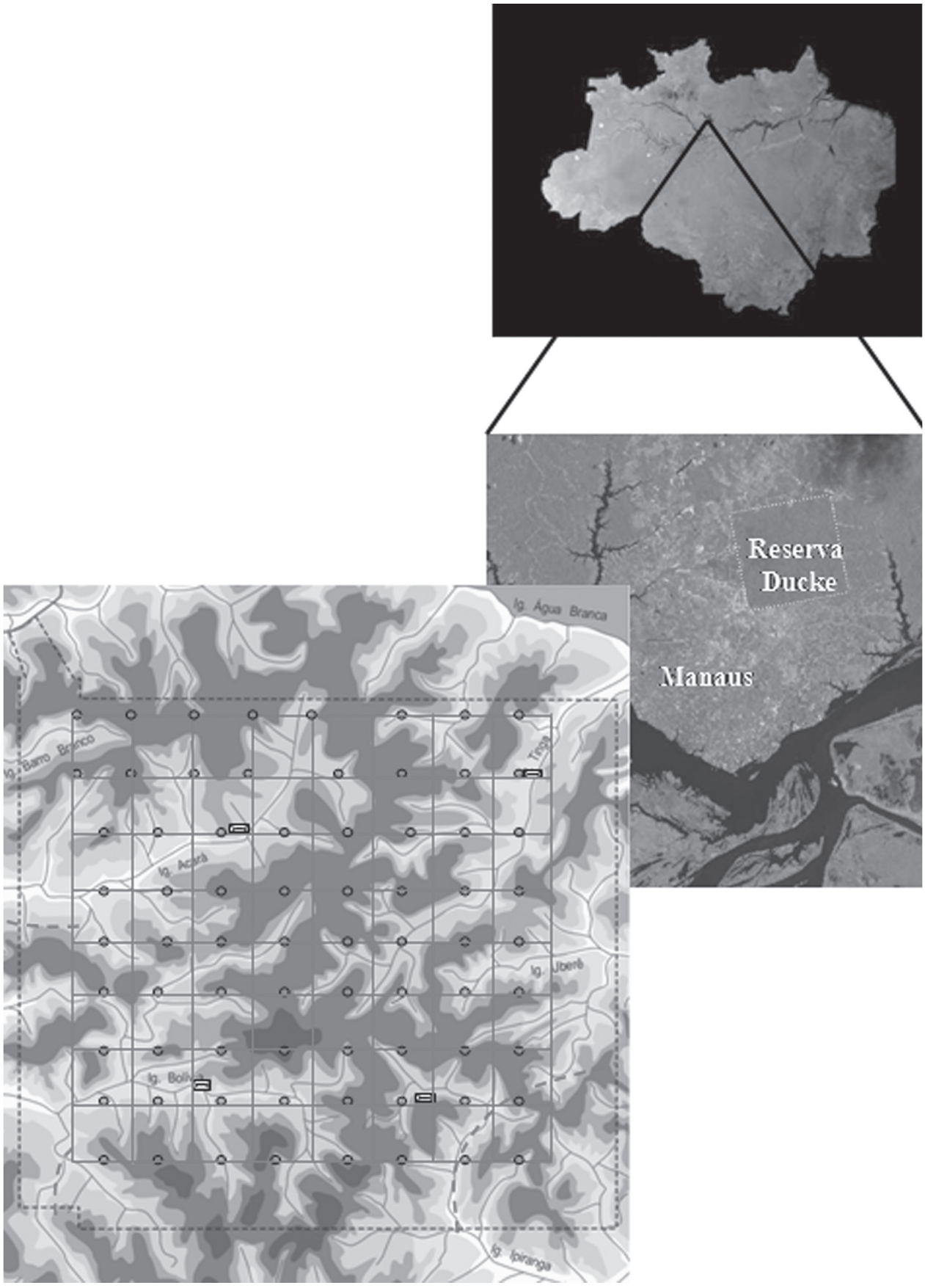

FIGURE 1. Localization of the Reserva Florestal Adolpho Ducke, adjacent to the city of Manaus, Brazil, and the grid system inside the reserve. Gray dots on the trail system indicate de location of plots.

number of calling individuals of each species and searched the litter and vegetation for anurans. All individuals located visually or by their call within 20 m of the center line of the plot were recorded, so that approximately 1 ha was searched per plot. All surveys were conducted by the same two people (senior author and field assistant).

Each individual found and captured was identified to species level and classified as adult or juvenile. Voucher specimens were deposited in the Amphibians and Reptiles Collection of the Instituto Nacional de Pesquisas da Amazônia (INPA-H) in Manaus, Amazonas, Brazil. The nomenclature in this study is in accordance with Amphibian Species of the World (Frost, 2007).

Data analysis

We made sample- and individual-based rarefaction curves (*sensu* Gotelli and Colwell, 2001), using EstimateS 7, *Sobs Mao Tau* index (Colwell *et al.,* 2004; Colwell, 2005) for both diurnal and nocturnal samplings. The rarefaction methods are adequate to estimate species richness and comparisons among data sets with different numbers of individuals (Gotelli and Colwell, 2001). These curves permitted the evaluation of the number of plots and individuals necessary to reach the highest number of species in each sample.

Results

Species composition

We detected 30 species of anurans, belonging to seven families (Table 1) using all methods and periods. Only two species *(Rhinella marina* and *Hypsiboas lanciformis)* reproduce in open areas and were found occasionally in the forest, and only one individual of *Leptodactylus riveroi,* a nocturnal species, was found in a diurnal sampling.

A total of 6,030 individuals belonging to eight species and four families (Table 2) were recorded in diurnal samples. Three of the eight species were also in nocturnal activity: the vocal activity of *Leptodactylus (Lithodytes)* aff. *andreae* began near sunset and finished in the first hours of the night. Juveniles of *Pristimantis fenestratus* are diurnal (the adults are nocturnal). The adults of *Rhinella proboscidea* were found in nocturnal activity only during the reproductive period. *Leptodactylus (Li.)* aff. *andreae, Anomaloglossus stepheni* and *P. fenestratus* occurred in 70 to 72 plots and the number of individuals of these species increased from the first to the second sampling (Table 2). The comparisons with data of the third sampling were ignored because this sample was conducted by different people. *Leptodactylus (Li.)* aff. *andreae* was the most abundant species, representing 65.6% of all reported individuals, followed by *An. stepheni* (22.4%), *P. fenestratus* (7.6%), *Dendrophryniscus minutus* (2.2%), *R. proboscidea* (1.0%), *Allobates* sp. (0.7%), *Atelopus spumarius* (0.3%), and *Al. femoralis* (< 0.1%).

We recorded 25 species (16,050 individuals) in nocturnal samples belonging to six families (Table 3). However, the adults and juveniles of *R. proboscidea* and *At. spumarius* and juveniles of *P. fenestratus* were found during the night resting on seedlings or small shrubs. With the exception of *At. spumarius,* a diurnal species, the nocturnal anuran assemblage was composed of 24 species (Table 3). Some species *(H. lanciformis, H. geographicus, L. mystaceus, Phyllomedusa bicolor, Ph. tarsius,* and *Ph. tomopterna)* were found in few plots (Table 3). In visual surveys, *R. proboscidea* was the most abundant species, representing 28.0% of the all recorded individuals, followed by *P. fenestratus* (25.3%), *Osteocephalus oophagus* (19.3%) and *L. (Li.)* aff. *andreae* (9.9%). *Rhinella marina, R. proboscidea, H. geographicus, Ph. tarsius, L. mystaceus,* and *L. (Li.) lineatus* were found exclusively in visual surveys (Table 3). In auditory surveys, six species represented 95.9% of the total. *Pristimantis fenestratus* was the most abundant species (43.1%) followed by *O. oophagus* (20.1%), *P. zimmermanae* (11.4%), *S. mirandaribeiroi* (9.9%), *S.* cf. *salseri* (6.7%) e *L. (Li.)* aff. *andreae* (4.7%). *Hypsiboas cinerascens, Trachycephalus resinifictrix, Ph. bicolor, S. mirandaribeiroi* and *S.* cf. *salseri* were found exclusively by auditory samples. Considering both visual and auditory surveys in the five samplings periods, the same six species were abundant, representing 92.7% of the total of recorded individuals. Five species (with the exception to *S. mirandaribeiroi*) occurred in all 72 plots. The number of individuals recorded was higher in auditory surveys. However, the number of species was higher in visual surveys (Table 3).

Considering simultaneous diurnal and nocturnal samplings, three species occurred only in one watershed: *At. spumarius* was found only in the eastern watershed, while *L. rhodomystax* and *Allobates* sp. were found only in the western watershed.

Temporal variation in composition and abundance

Seven species were recorded regularly in the three diurnal samplings (Table 2). The number of species in each plot varied from one to five (mean = 3.3 ± 0.9, n = 216). The number of individuals increased in each sample, and was higher in the second and third samples, in the middle of the rainy seasons (Table 2). About 87.5% of diurnal species were sampled with approximately 20 plots (Fig. 2A). However, the number of individuals necessary to sample the same percentage of species varied among periods from approximately 250 to 1,000 individuals (Fig. 2B).

Rhinella proboscidea and *D. minutus* were found mainly in the beginning of the rainy season, but

Table 1. Families, species, habit, activity period and reproductive site of 30 anuran species found in Reserva Florestal Adolpho Ducke, Manaus, Brazil. * = nocturnal activity only during reproductive period.

Family/Species	Habit and activity period	Reproductive site
Aromobatidae		
Anomaloglossus stepheni (Martins, 1989)	terrestrial, diurnal	Leaf-litter
Allobates sp.	terrestrial, diurnal	Terrestrial clutches, tadpoles in temporary ponds
Allobates femoralis (Boulenger, 1884)	terrestrial, diurnal	Terrestrial clutches, tadpoles in temporary ponds
Brachycephalidae		
Pristimantis fenestratus (Steidachner, 1864)	arboreal/terrestrial, diurnal (juveniles)/nocturnal (adults)	Leaf-litter
Pristimantis ockendeni (Boulenger, 1912)	arboreal, nocturnal	Leaf-litter
Pristimantis zimmermanae (Heyer and Hardy, 1991)	arboreal, nocturnal	Leaf-litter
Bufonidae		
Atelopus spumarius Cope, 1871	terrestrial, diurnal	Streams
Dendrophryniscus minutus (Melin, 1941)	terrestrial, diurnal	Streams and temporary ponds
Rhinella marina (linnaeus, 1758)	terrestrial, nocturnal	Ponds in open areas
Rhinella proboscidea (Spix, 1824)	terrestrial, diurnal/nocturnal*	Temporary ponds on stream edges
Centrolenidae		
Cochranella oyampiensis (Lescure, 1975)	arboreal, nocturnal	Clutches on leaves above streams; tadpoles in streams
Hylidae		
Hypsiboas geographicus (Spix, 1824)	arboreal, nocturnal	Ponds on stream edges
Hypsiboas cinerascens (Spix, 1824)	arboreal, nocturnal	Wetland near streams
Hypsiboas lanciformis Cope, 1871	arboreal, nocturnal	Ponds in open areas
Osteocephalus oophagus Jungfer and Schiesari, 1995	arboreal, nocturnal	Small water bodies in epiphytes, bromeliads and holes in trees
Osteocephalus taurinus Steindachner, 1862	arboreal, nocturnal	Temporary ponds
Phyllomedusa bicolor (Boddaert, 1772)	arboreal, nocturnal	Leaves over ponds
Phyllomedusa tarsius (Cope, 1868)	arboreal, nocturnal	Leaves over ponds
Phyllomedusa tomopterna (Cope, 1868)	arboreal, nocturnal	Leaves over ponds
Trachycephalus resinifictrix (Goeldi, 1907)	arboreal, nocturnal	Small water bodies in tree holes
Leptodactylidae		
Leptodactylus (Lithodytes) aff. *andreae* Müller, 1923	terrestrial, diurnal/nocturnal	Escavated burrows in the soil
Leptodactylus (Lithodytes) lineatus (Schneider, 1799)	terrestrial, nocturnal	Temporary ponds or subterranean tunnels in ant nests
Leptodactylus knudseni Heyer, 1972	terrestrial, nocturnal	Temporary ponds
Leptodactylus mystaceus (Spix, 1824)	terrestrial, nocturnal	Excavated basin near temporary ponds
Leptodactylus pentadactylus (Laurenti, 1768)	terrestrial, nocturnal	Excavated burrows in the soil
Leptodactylus rhodomystax Boulenger, 1884	terrestrial, nocturnal	Temporary ponds
Leptodactylus riveroi Heyer and Pyburn, 1983	terrestrial, nocturnal	Temporary ponds
Leptodactylus stenodema Jiménez de la Espada, 1875	terrestrial, nocturnal	Burrows in the soil ?
Microhylidae		
Synapturanus mirandaribeiroi Nelson and Lescure, 1975	fossorial, nocturnal	Subterranean burrows excavated in the soil
Synapturanus cf. *salseri* Pyburn, 1975	fossorial, nocturnal	Subterranean burrows excavated in the soil

TABLE 2. Number of plots in which each anuran species was reported and number of individuals in each diurnal sample, Reserva Florestal Adolpho Ducke, Manaus, Brazil. The total corresponds to the sum of the three samples.

Family/Species	Number of plots	November-December 2002	February-April 2003	January-February 2004	Total
Aromobatidae					
Anomaloglossus stepheni	72	387	432	534	1,353
Allobates sp.	15	13	16	14	43
Allobates femoralis	2	1	1	-	2
Brachycephalidae					
Pristimantis fenestratus	70	35	127	298	460
Bufonidae					
Atelopus spumarius	10	5	10	6	21
Dendrophryniscus minutus	24	60	23	49	132
Rhinella proboscidea	34	33	12	17	62
Leptodactylidae					
Leptododactylus (Li.) aff. *andreae*	72	391	1,326	2,240	3,957
Number of species		8	8	7	8
Number of individuals		925	1,947	3,158	6,030

L. (Li.) aff. *andreae, P. fenestratus* and *At. spumarius* were more abundant in the middle of the rainy seasons (January/February/March). *Allobates* sp. showed small variation along the sampling periods, and *Al. femoralis* was found occasionally (Table 2).

The number of nocturnal species varied from 18 in the beginning of the second rainy season to 22 in the middle of the rainy season (Table 3). Fourteen species were found in the five sampling periods (Table 3). The number of species in each plot varied from one to 11 (mean = 5.25 ± 1.9, n = 360) and was higher in the middle of the rainy season (21 species – February-March/2004), while the lower number was found in the beginning of the rainy seasons (18 and 17 species, respectively). There are differences in the number of plots necessary to reach the same number of species in the same rainy season and amongst years. The number of plots necessary to reach the minimum number of species (17 species) varied among samples. Seventy two plots were necessary to reach this number in the beginning of the rainy season and approximately 16 plots in the middle of the rainy season (Fig. 3A).

The higher number of individuals (4,059 and 5,288) was found in the beginning of the rainy seasons, and the lower number (1,795 and 1,921) was found at the end of the rainy seasons (Fig. 3B). The number of individuals necessary to reach the minimum number of species (17 species) was higher (approximately 3,000 individuals) in the beginning than in the middle of the rainy season (approximately 750 individuals) (Fig. 3B).

In four nocturnal samples, the number of adults was higher than juveniles. However, at the end of the second rainy season, the number of juveniles was higher (April-May/2004 – Table 3).

The majority of terrestrial-breeding species showed great abundance in the beginning of the rainy seasons *(An. stepheni, L. (Li.) aff. andreae, P. fenestratus, P. ockendeni, P. zimmermanae, S. mirandaribeiroi,* and *S.* cf. *salseri); L. stenodema* showed an inverse pattern, while *L. pentadactylus* showed small variation in abundance during the rainy seasons. However, the aquatic-breeding species showed small abundance (exception *R. proboscidea* and *O. taurinus*) and the occurrence of individuals was variable during the rainy seasons.

DISCUSSION

Currently, 50 species of anurans have been found in the RFAD (Lima *et al.,* 2006). Twelve species are found predominantly in open areas, and two of these species were found in the plots of this study *(Rhinella marina* and *Hypsiboas lanciformis). Hypsiboas lanciformis* (two individuals) was found by chance but *R. marina* (16 individuals) was found moving in the forest. Twenty eight species (74% of the 38 species exclusive to forest habitat) were found in this study. Among the 22 species that inhabit the leaf-litter in RFAD, 17 (77%) were found in this study. The species with high abundance and wide distribution in the study area were those with reproductive specializations such as direct development (*Pristimantis* spp.), development in terrestrial nests *(L. (Li.)* aff. *andreae, Synapturanus* spp. and *An. stepheni),* or development

TABLE 3. Number of plots and number of individuals per species of anurans found by two sampling methods conducted in nocturnal periods, Reserva Florestal Adolpho Ducke, Manaus, Brazil. (V = visual survey; number of juveniles/number of adults; A = auditory survey). * = diurnal species.

Family/Species	Number of plots	November-December/2002		March-May/2003		November-December/2003		February-March/2004		April-May/2004	
		V	A	V	A	V	A	V	A	V	A
Brachycephalidae											
P. fenestratus	72	14/0	1,005	15/1	604	24/2	2,406	21/24	1,416	65/168	937
P. ockendeni	41	1/0	44	0	1	3/0	49	1/2	9	0	0
P. zimmermanae	72	2/0	765	0	138	2/0	544	4/1	205	0/1	30
Bufonidae											
*A. spumarius**	12	1/1	0	2/0	0	2/0	0	5	0	6/4	0
R. marina	12	2/0	0	5/0	0	3/1	0	2/0	0	2/1	0
R. proboscidea	52	4/11	0	31/4	0	27/21	0	23/26	0	61/161	0
Centrolenidae											
C. oyampiensis	13	0	0	0	41	0	30	1/0	32	0	40
Hylidae											
H. geographicus	5	0	0	1/0	0	3/0	0	2/0	0	0	0
H. cinerascens	20	0	12	0	47	0	17	0	34	0	26
H. lanciformis	2	1/0	0	0	0	0	0	0	0	0	1
O. oophagus	72	62/0	958	40/12	615	59/4	650	44/1	499	28/5	245
O. taurinus	42	13/1	6	17/3	2	12/2	4	10/1	12	3/1	7
P. bicolor	2	0	0	0	0	0	0	0	1	0	1
P. tarsius	1	0	0	1/0	0	0	0	0	0	0	0
P. tomopterna	3	0	0	0	0	0	0	1/0	2	0	1
T. resinifictrix	20	0	11	0	5	0	6	0	5	0	3
Leptodactylidae											
L. (Li.) aff. *andreae*	70	34/3	202	3/3	64	39/3	286	17/5	144	7/18	6
L. (Li.) lineatus	1	0	0	0	0	0	0	2/0	0	0	0
L. knudseni	50	4/0	28	3/1	19	0	11	1/2	15	0	7
L. mystaceus	3	4/0	0	0	0	0	0	0	0	0	0
L. pentadactylus	28	5/2	4	8/1	6	8/7	2	9/1	0	8/2	0
L. rhodomystax	12	1/1	1	1/0	3	2/0	2	1/0	2	1/0	0
L. stenodema	21	0/2	0	1/2	10	0	0	2/4	3	0	11
Microhylidae											
S. mirandaribeiroi	45	0	485	0	53	0	661	0	200	0	60
S. cf. *salseri*	48	0	369	0	32	0	396	0	195	0	4
Number of species		15	13	13	15	12	14	17	16	10	15
Total number of species		19		20		18		22		20	
Number of individuals		4,059		1,795		5,288		2,987		1,921	

in bromeliads with parental care *(O. oophagus)*. Species with reproductive specializations were also the most abundant in another forest in the Neotropical region and in Central Amazonia with studies on leaf-litter frogs (Heatwole and Sexton, 1966; Scott, 1976; Lieberman, 1986; Fauth *et al.,* 1989; Allmon, 1991; Heinen, 1992; Giaretta *et al.,* 1997, 1999; Rocha *et al.,* 2001; Watling and Donnelly, 2002; Van Sluys *et al.,* 2007). In the Neotropical region, many species have terrestrial reproductive modes with tadpole or egg development out of water (Hödl, 1990; Haddad and Prado, 2005).

Different to many studies conducted in tropical forests, this study used systematically-distributed plots of 250 m over an area of 64 km^2. Studies on leaf-litter herpetofauna conducted in tropical forests usually use square plots varying from 25 to 232 m^2 (p. ex. Inger and Colwell, 1977; Scott, 1982; Lieberman, 1986; Giaretta *et al.,* 1999; but see Rocha *et al.,* 2001 and Van Sluys *et al.,* 2007 for smaller plots). Another study with visual and auditory samplings in forest transects in Central Amazonia was conducted by Zimmerman and Simberloff (1996), but transects were not systematically distributed in the study area to the north of Manaus (Biological Dynamic Fragment Forest Project – BDFFP), and the distance between them varied as did the lengths. Allmon (1991) found 16 species in samplings of leaf-litter frogs in

BDFFP, using 498 plots of 25 m². The most abundant species in Allmon's study (*L. (Li.)* aff. *andreae, An. stepheni, R. proboscidea, Pristimantis* spp. and *Allobates* sp., representing 93.4% of the total) were also the most abundant species in the diurnal samples of the present study, indicating a high similarity in species composition in these areas. Nevertheless, some species found by the author were rare in our study (three individuals of *Chiasmocleis shudikarensis,* two of *Ctenophryne geayi* and *Ph. bicolor,* one of *Allobates femoralis, D. minutus* and *R. marina*). The method used by the author probably underestimates the species *D. minutus,* which has diurnal habits and was recorded in 33% of the plots in the present study, but the differences can be related to specific characteristics of each area. All diurnal forest species known

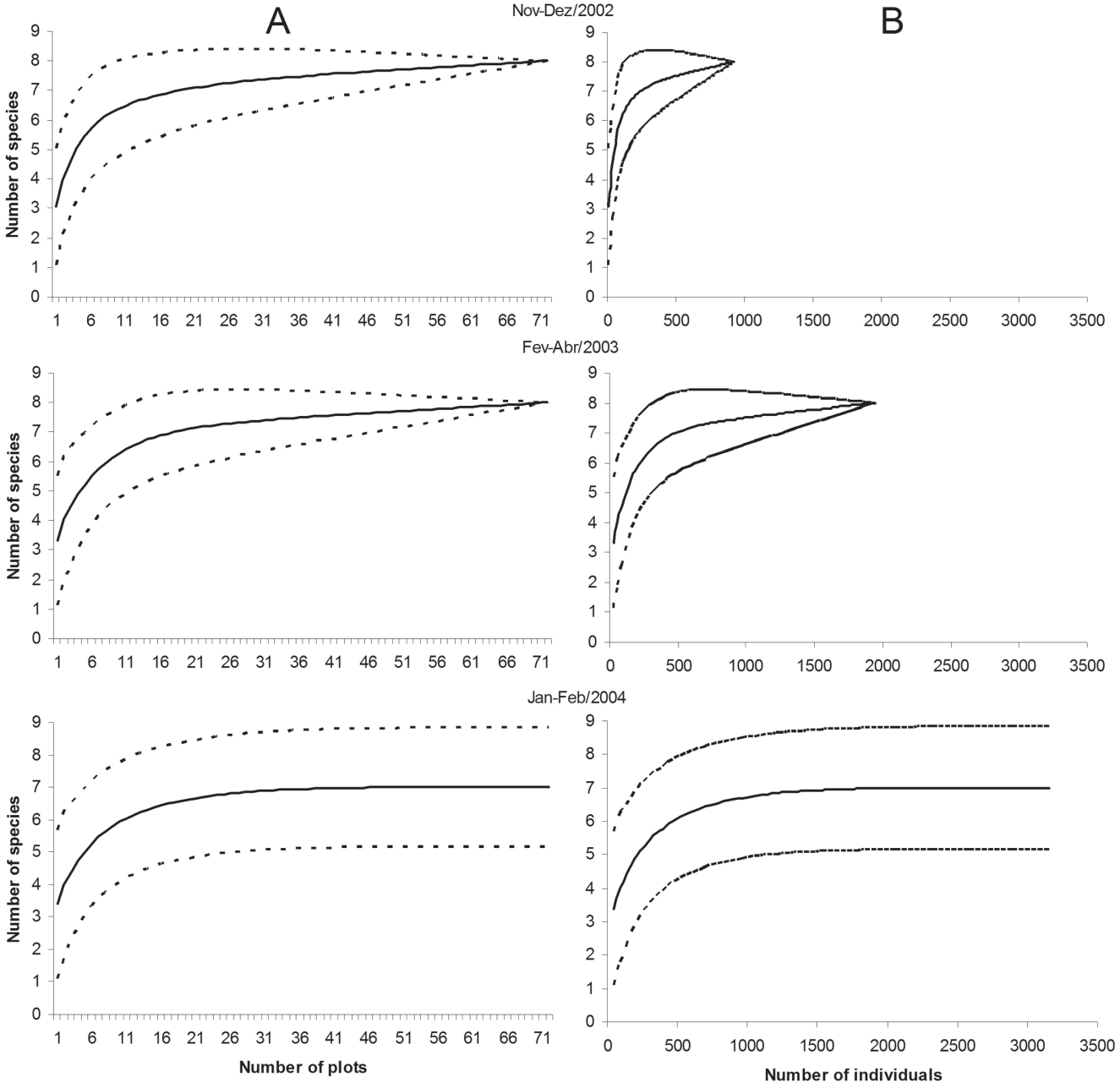

FIGURE 2. Rarefaction curves based on number of plots (A) and number of individuals of anurans (B) for each diurnal sampling without nocturnal species occasionally sampled, in Reserva Florestal Adolpho Ducke, Manaus, Brazil. The sampling conducted in November-December/2002 corresponds to the beginning of the rainy season, while the period of February-April/2003 and January-February/2004 corresponds to the middle of the rainy seasons. The continuous line is the average calculated with 1,000 randomizations and the dashed lines above and below are the 95% confidence intervals.

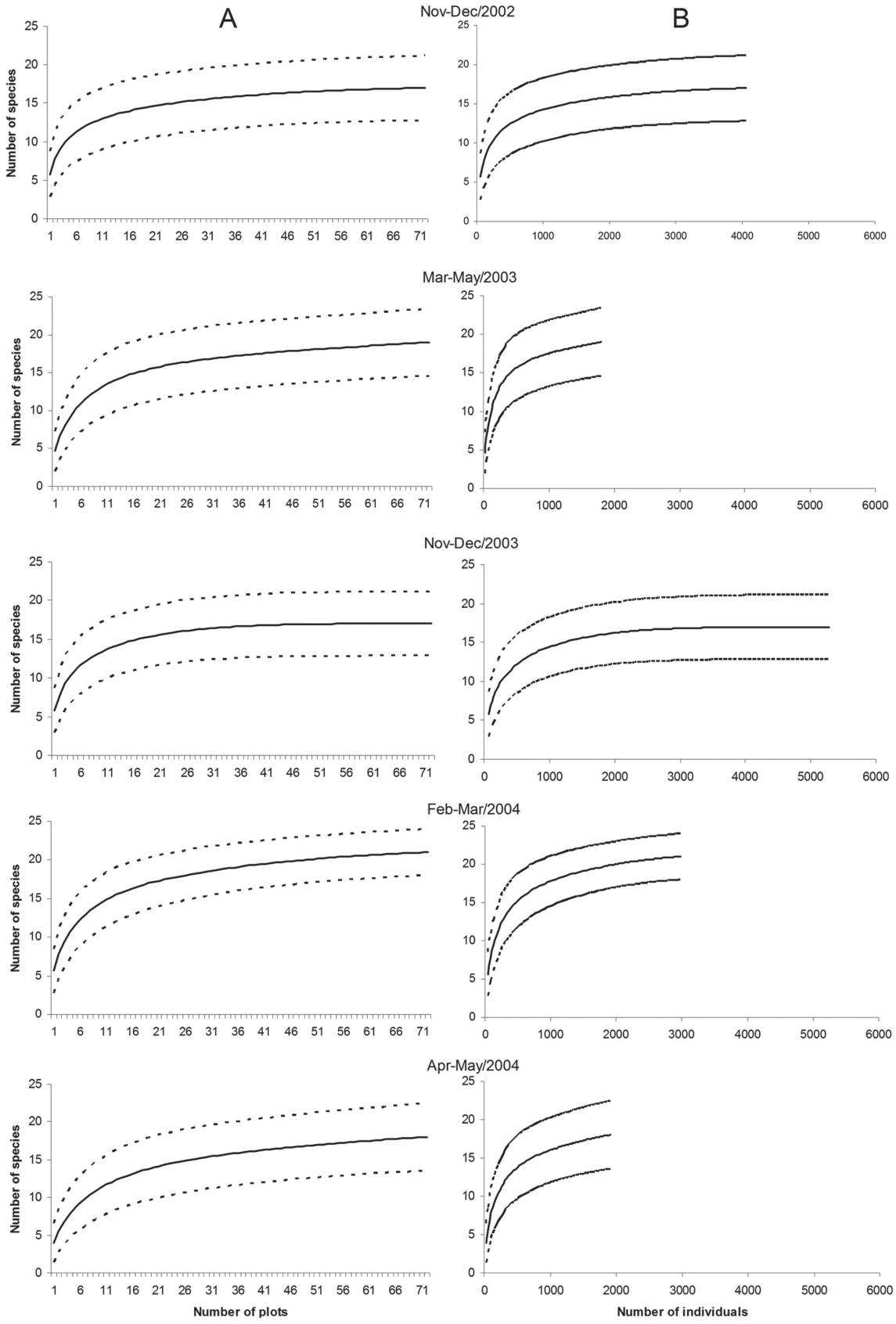

FIGURE 3. Rarefaction curves based on number of plots (A) and number of individuals of anurans (B) for each nocturnal sampling conducted in Reserva Florestal Adolpho Ducke, Manaus, Brazil. The samplings in November-December/2002 and 2003 correspond to the beginning; March-May/2003 to the middle/end; February-March/2004 to the middle; April-May/2004 to the end of the rainy seasons. The continuous line is the average calculated with 1,000 randomizations and the dashed lines above and below are the 95% confidence intervals.

for the Manaus region were recorded, indicating that the method used (visual survey with leaf-litter turn over) was efficient.

The 24 species with nocturnal habits recorded in this study represented 72% of the total number of nocturnal species in the RFAD. Six species were rare in the samples and were recorded from one to five plots *(H. geographicus, Ph. bicolor, Ph. tarsius, Ph. tomopterna, L. mystaceus* and *L. (Li.) lineatus)*. However, individuals of *H. geographicus* are commonly found on margins of streams and the small number recorded may be related to the fact that the advertisement calls of this species can only be heard within a few meters of the frogs (Zimmerman and Bogart, 1984). The three species of *Phyllomedusa* recorded in this study reproduce mainly in temporary ponds isolated from streams, found in clayed areas (Zimmerman and Simberloff, 1996). These habitats are rare in RFAD (Rodrigues, 2006). *Leptodactylus mystaceus* are common in borders and in disturbed areas in the forest (Duellman, 1978) and *L. (Li.) lineatus* are associated with ant nests (genus *Atta*) (Lamar and Wild, 1995), and their calling activity occurs in November and December in RFAD (A.P.Lima, pers. obs.). Therefore, the low abundance of these species could be explained by the following possibilities: 1) these species are rare due to habitat specificity, 2) the methods of survey employed are not adequate for locating these species, or 3) the number of plots around water bodies is low. In this study, only 25% (18 plots) were located around water bodies (streams or ponds). In this way, the presence of these species with low abundance is restricted to reproductive sites (such as riparian zones) and the low abundance may be reflecting a differential detection of the species in the environment (Gaston, 1994).

On the other hand, the methods used permitted an efficient estimate of the abundance of many species as well as the record of secretive, arboreal and semi-arboreal species not available for plots in leaf-litter, as detected by Rödel and Ernst (2004). The two nocturnal species that were most abundant in visual and auditory surveys *(P. fenestratus* and *O. oophagus)* were also the more common species found in auditory surveys by Zimmerman and Simbelorff (1996) in the BDFFP areas (*O. oophagus* was erroneously identified as *O. buckleyi* by Zimmerman and Simberloff, 1996). However, some species recorded in the present study were found exclusively in one type of survey (e.g., auditory surveys: *Synapturanus* spp.; visual surveys: *R. proboscidea*). Some species were found exclusively in auditory surveys but were inaccessible in visual surveys, such as the fossorial species *Synapturanus* spp. (Pyburn, 1975; Nelson and Lescure, 1975; Menin *et al.,* 2007b) and *Trachycephalus resinifictrix* which is arboreal and breed exclusively in large, water-filled treeholes (Schiesari *et al.,* 2003). The combination of the two methods (nocturnal visual and auditory surveys) permitted the detection of a higher number of species.

Variation in the abundance of leaf-litter anurans is known to occur in different forests. There is seasonality in the reproduction of many species, and a higher number of individuals were found in the wetter months (Crump, 1971, 1974; Aichinger, 1987; Allmon, 1991; Duellman, 1995; Giaretta *et al.,* 1997, 1999; Vonesh, 2001). In a tropical forest in Peru, 93% of reproductive individuals were found during the rainy season, 85% of juveniles during the dry period and the abundance of males in calling activity was higher in the beginning of the rainy season in temporary ponds (Aichinger, 1987). In another area, some species were found in higher abundance during dryer periods (Toft, 1980; Watling and Donnelly, 2002); other species can reproduce throughout the year in areas without pronounced seasonality (Duellman, 1978). For juveniles, there is an inverse pattern: the majority of individuals were found at the end of the rainy season and beginning of the dry season (Aichinger, 1987; Watling and Donnelly, 2002).

In the present study, the rarefaction curves based on samples and individuals showed that the higher number of exclusively diurnal anuran species was found in the beginning and middle of the rainy season. The difference in the number of species among the three periods of sampling was caused by one species *(Al. femoralis)* found in the first two samples. This species is common in clearings and forest borders (A.P.Lima, pers. obs.). The species *Allobates* sp. showed small variation between the studied periods. However, the abundance of three species *(An. stepheni, L. (Li.)* aff. *andreae* and *P. fenestratus)* increased in each sample. This increase can be related to juvenile recruitment from the middle to the end of the rainy season (Allmon, 1991; Moreira and Lima, 1991). For leaf-litter anuran assemblages in Costa Rica and Panama, which are formed mainly by species of *Craugastor, Pristimantis* and *Colostethus,* the abundance of species was higher in the dry season (Toft, 1980; Watling and Donnelly, 2002). In these areas, the dry season is shorter (between three to four months) and more humid than areas in the Amazon basin and the higher number of species in the dry sea-

son occurred due to an increase in the number of juveniles (Watling and Donnelly, 2002).

A higher number of nocturnal species was found in the middle of the rainy season. This fact was also reported in tropical forests of Peru (Duellman, 1995). Rocha *et al.* (2000) showed that approximately 70% of the activity of the leaf litter fauna in a brazilian forest is nocturnal. The rarefaction curves between the beginning of the different rainy seasons were similar, indicating small variation in the occurrence and record of species in these periods. The rarefaction curves in the middle and end of the rainy season did not stabilize, indicating variation, and the total number of species in these periods was not reached. These differences are related to the record of rare species in some samples *(Ph. bicolor, Ph. tarsius, Ph. tomopterna* and *L. (Li.) lineatus),* which agrees with the data found by Duellman (1995) in Cuzco Amazónico Reserve (Peru). The author stressed that the record of rare species was related to the availability of adequate habitats for reproduction which appeared with the increase in rain volume. A similar tendency was found for tadpole assemblages in aquatic habitats in Central Amazonia (Gascon, 1991), suggesting that few common species compose the base of species in an area and that more rare species reproduce at specific sites or have explosive reproduction, reducing the probability of finding them. Among the 25 species found in nocturnal samples, 15 species (60%) were found in all sample periods. According to Duellman (1995), of a total of 61 species found in Peru, only 27 (44%) were found in six sample periods (three rainy seasons and one dry season).

There was a great variation in the abundance of nocturnal aquatic-breeding anurans. The terrestrial-breeding frogs and species that reproduce in arboreal microhabitats were found mainly at the beginning of the rainy seasons and were found throughout the reserve (Menin *et al.,* 2007a), explaining the great number of individuals recorded in the same periods. The variation in the abundance of species during rainy seasons is related, mainly, to a reduction of calling activity. Duellman (1995) also found a high abundance of arboreal and leaf-litter frogs from the beginning to the middle of the rainy season in Peru. Nevertheless, Gottsberger and Gruber (2004), studying an anuran assemblage in French Guyana, found continuous activity in terrestrial-breeding frogs throughout the rainy season, with a higher number of individuals at the beginning. The authors also showed that activities of some species are correlated with rainfall occurring in the previous 24 h and in the next 24 h.

In summary, this study showed the viability of the system of surveys and methods used for sampling anuran assemblages in a tropical forest which can be used in other areas of the Amazon or other tropical forests. They were adequate for estimating the richness and abundance of species. Systematically distributed plots, such as those used in this study, mostly reveal terrestrially breeding frogs. The aquatic-breeding frogs were found mainly in riparian zones and were rare in zones distant from water bodies. In our study area, the systematic distribution of plots with standardized distances caused the low number of plots around water bodies (25%) and, consequently, the reduced record of aquatic-breeding individuals. We suggest the installation of plots along stream margins in order to sample species with a distribution limited to water bodies, which were underestimated in this study.

Resumo

No presente estudo nós amostramos as comunidades diurna e noturna de anuros na Reserva Florestal Adolpho Ducke, Manaus, Amazonas, Brazil, uma área com 10.000 ha de floresta de terra firme. Fornecemos dados sobre a composição e a variação na ocorrência e abundância das espécies em duas estações chuvosas. Realizamos três amostragens diurnas e cinco amostragens noturnas no período de Novembro/2002 a Maio/2004 em 72 parcelas sistematicamente distribuídas sobre uma grade de 64 km^2. A comunidade diurna foi amostrada por procura visual e a comunidade noturna foi amostrada por procura visual e auditiva simultaneamente. Nós registramos 30 espécies de anuros pertencentes a sete famílias, considerando todos os métodos e períodos de amostragem. Um total de 6.030 indivíduos pertencentes a oito espécies e quatro famílias foram registrados nas amostragens diurnas e 25 espécies (16.050 indivíduos), pertencentes a seis famílias, foram registrados nas amostragens noturnas. O número de espécies noturnas registradas variou de 18 no início da segunda estação chuvosa a 22, no meio da estação chuvosa. Quatorze espécies foram encontradas nos cinco períodos de amostragem. As espécies com alta abundância e grande distribuição na área de estudo foram aquelas com especializações reprodutivas, tais como desenvolvimento direto, desenvolvimento em ninhos terrestres ou desenvolvimento em bromélias com cuidado parental. Neste estudo demonstramos a viabilidade do sistema de amostragem e dos métodos usa-

dos para amostragem de comunidades de anuros em uma floresta tropical. Esses métodos também foram adequados para estimar a riqueza e a abundância das espécies. No entanto, parcelas distribuídas sistematicamente, tais como as usadas neste estudo, permitem principalmente o registro de espécies com reprodução terrestre. Espécies com reprodução aquática foram registradas principalmente nas áreas ripárias e foram raras em áreas distantes dos corpos d'água. Houve um pequeno número de parcelas (25%) próximas aos corpos d'água, o que, conseqüentemente, levou ao número reduzido de registros de indivíduos com reprodução aquática.

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