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Anurans of the sandy coastal plains of the Lagamar Paulista, State of São Paulo, Brazil

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Abstract: Insular habitats are considered ideal for biogeographic studies, as they represent almost closed habitats with known formation timelines. Although São Paulo state in Brazil has a large number of continental and oceanic islands, few studies have examined the composition of the fauna in each locality. These studies are crucial to determine the community structure and to make biogeographic and phylogenetic inferences. From February 2007 to January 2009, we surveyed the anuran community of sandy coastal plains in four municipalities of the Lagamar Paulista: Cananéia, Ilha Comprida, Iguape and Pariquera-Açu, in the state of São Paulo, Brazil. This region is located in the Cananéia-Iguape estuary complex, comprising three continental islands: Ilha de Cananéia, Ilha Comprida, and Ilha do Cardoso, and the continental portions adjacent to these islands in the municipalities of Iguape and Pariquera-Açu. Through the use of pitfall traps and active search, we registered a total of 32 anuran species: 17 in Ilha Comprida, 21 in Ilha de Cananéia, 26 in Ilha do Cardoso, 27 in Iguape, and 23 in Pariquera-Açu. The analysis of the richness indices of the study sites revealed higher values in continental areas. This result is very common in comparative studies between islands and continents. This may be caused by an island effect and may reveal the historical process of island formation in the Lagamar. Our findings provide important information for identifying patterns of amphibian distribution in insular areas of the São Paulo coast, and for examining how events of marine transgression and regression have affected the local amphibian communities.
Keywords: *amphibia, anuran community, continental islands, lagamar, Atlantic Rainforest.*

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Resumo: Ambientes insulares são considerados ideais para estudos biogeográficos, já que representam ambientes quase fechados cujo tempo de formação é conhecido. Embora o estado de São Paulo possua um grande número de ilhas continentais e oceânicas, faltam estudos de base que determinem a composição faunística de cada localidade. Tais estudos são cruciais para se determinar a estrutura de comunidades e fazer inferências biogeográficas e filogenéticas que a expliquem. Durante os meses de fevereiro de 2007 a janeiro de 2009 inventariamos a comunidade de anuros de ambientes de restinga em quatro municípios do Lagamar Paulista: Cananéia, Ilha Comprida, Iguape e Pariquera-Açu, estado de São Paulo. Inserida no complexo estuarino Cananéia-Iguape, esta região caracteriza-se pela presença de três ilhas continentais: Ilha de Cananéia, Ilha Comprida e Ilha do Cardoso e porções continentais adjacentes a estas ilhas nos municípios de Iguape e Pariquera-Açu. Através da metodologia de procura ativa e armadilhas de interceptação e queda foi registrado um total de 32 espécies de anuros em todas as localidades: 17 espécies na Ilha Comprida, 21 na Ilha de Cananéia, 26 na Ilha do Cardoso, 27 em Iguape e 23 em Pariquera-Açu. A análise dos índices de riqueza revelou valores mais altos nas áreas continentais, resultado comumente observado em comparações entre ilhas e continente. Este resultado pode ser um reflexo de um efeito de isolamento promovido pelo evento de formação das ilhas, ou pode ser resultado de origem e tempo distintos em que as ilhas foram formadas. Os resultados aqui apresentados são de fundamental importância, pois fornecem subsídios tanto para estudos de padrões de distribuição de anfíbios em formações insulares do litoral paulista como para o entendimento de como eventos de transgressão e regressão marinha atuaram sobre as comunidades de anfíbios locais.
Palavras-chave: *amphibia, comunidade de anuros, ilhas continentais, lagamar, Mata Atlântica.*

Introduction

Sandy coastal plain areas are among the most threatened habitats in the Atlantic forest (Rocha et al. 2007). Main threats to these habitats include deforestation for urban development, the construction of entertainment resorts, pollution by industrial and/or domestic effluents, among others (Rocha et al. 2003, Dias & Rocha 2005, Rocha et al. 2007). Although coastal sandy plains are not included among the richest habitats in the Atlantic forest, they harbor many endemic species (Dias et al. 2002, Rocha et al. 2003, Rocha et al. 2005). Thus, the knowledge of species composition is crucial to subsidize conservation actions, given the vulnerability of these coastal habitats.

The number of studies on the anuran fauna of the coastal Atlantic rainforest has increased in recent years (e.g., Rocha et al. 2008, Narvaes et al. 2009, Silva-Soares et al. 2010). However, given the great diversity of anuran species in this domain, these numbers are still low. The use of new approaches (e.g. molecular data, call descriptions), as well as the increase of studies conducted in remote areas (Brasileiro et al. 2007a, b, c), have increased the number of species description in the coastal Atlantic rainforest (Pombal Junior & Bastos 2003, Fitzpatrick et al. 2009). This is even more evident for insular habitats, from which several species have been recently described (e.g., Brasileiro et al. 2007a, b, c, Silva & Alves-Silva 2008). Moreover, insular habitats are ideal for examining theories of community structure, as they are almost closed habitats with a known timeline (Diamond 1975a, b, Leibold & Mikkelson 2002, Gillespie et al. 2005). Thus, the first step to elaborate ecological theories is the knowledge of the faunal composition of these habitats.

The aim of the present study was to survey the anuran species from sandy coastal plains in three continental islands (Ilha do Cardoso, Ilha de Cananéia, and Ilha Comprida) and from two adjacent mainland sites in south São Paulo state. Furthermore, we compared our results with those of other coastal areas of northern São Paulo and Rio de Janeiro states and southern São Paulo and Paraná states. Studies such as the present one may help raise hypotheses on the factors involved in the structure of insular anuran communities.

Material and Methods

1. Study sites

The present study was conducted in four municipalities of the Lagamar Paulista: Cananéia, Iguape, Pariquera-Açu, and Ilha Comprida, southern coast of São Paulo state, southeastern Brazil (Figure 1). Lagamar Paulista is the common name of the coastal and continental region near the Iguape-Cananéia estuary (Magalhães 2003). This complex encompasses three continental and barrier islands (Ilha de Cananéia, Ilha Comprida, and Ilha do Cardoso), according to Suguio (1992), as they are geologically associated with the mainland and were formed by fluctuations of the sea level or by the accumulation of sediments on the coast (barrier islands) (Martin & Suguio 1978, Watanabe et al. 1997, Suguio et al. 2003).

The typical vegetation of the complex, usually xerophytic shrubs, is the same as that found in sandy coastal plains, characterized by species tolerant to high temperatures and insulation, little water availability, high salinity, and sandy soils (Zaluar & Scarano 2000, Scarano 2002). A common characteristic of all sandy coastal plains of Brazil is the presence of species of the family Bromeliaceae (Freitas et al. 2000, Cogliatti-Carvalho et al. 2001). In these habitats, bromeliads play a fundamental role in the establishment of other species (Zaluar & Scarano 2000), particularly by providing resources to several animal species (see examples in Osses et al. 2008).

Each study site is further described below.

1.1. Municipality of Cananéia

It comprises two continental islands (Ilha de Cananéia and Ilha do Cardoso) and a continental portion adjacent to these islands.

Ilha de Cananéia: area of approximately 125 km^2. As a result of historical factors during colonization, only small patches of well-preserved Atlantic rainforest and sandy coastal plains remain. It is separated from the mainland by the Mar de Cubatão, and from Ilha Comprida by the Mar de Cananéia. It is characterized by the presence of Pleistocene (Cananéia Formation) and Holocene deposits and is considered a barrier island based on its origin: the deposition of sediment during sea transgression and regression during the Quaternary (see definition in Suguio 1992). The study was conducted in an area of preserved sandy coastal plain in the central portion of the island (24° 55’ 59.80’’ S and 47° 53’ 16.49’’ W; elevation = 0-137 m above sea level) (Figure 1). The distance between Ilha de Cananéia and the adjacent continental portion varies between 300 m and 1 km, similar to the distances between Ilha de Cananéia and Ilha Comprida. The distance to Ilha do Cardoso is 2 to 3 km.

Ilha do Cardoso: area of approximately 136 km^2. It is considered one of the most preserved areas of the complex (Magalhães 2003). The Mar de Itapitangui (São Paulo state) separates the island from the continent to the north and the Mar de Ararapira (Paraná State) to the south. It is characterized by Pleistocene (Cananéia Formation) and Holocene deposits, and most of the island consists of a mountain range formed by Precambrian rocks (Pariquera-Açu Formation) (Suguio & Tessler 1992). The present study was conducted in the northern region of the area where the state park Parque Estadual da Ilha do Cardoso is located (PEIC) (Perequê Unit) (25° 03’ 05’’ S and 48° 05’ 42’’ W; elevation = 0-900 m a.s.l.) (Figure 1). The distance from the island to the continent (Cananéia-SP and Guaraqueçaba-PR) varies from 200 m to 1 km. The distance between Ilha do Cardoso and Ilha Comprida is approximately 1.5 km.

1.2. Municipality of Ilha Comprida

It comprises a total area of 189 km^2. Most of the sandy coastal plains have been cleared for urbanization. It is separated from the continent by the estuarine channel known as Mar Pequeno (Magalhães 2003) and from Ilha de Cananéia, by the Mar de Cananéia. It is a typical barrier island, formed by Pleistocene (Cananéia Formation) and Holocene deposits (Suguio et al. 2003). The present study was conducted in an area located in the central-south region of the island (25° 00’ 19’’ S and 47° 52’ 18.7’’ W; elevation = 0-10 m a.s.l.) (Figure 1). The distance between Ilha Comprida and the mainland (Cananéia and Iguape) varies from 400 m to1 km.

1.3. Municipality of Pariquera-Açu

The study site was located in the state park Parque Estadual da Campina do Encantado (PECE) (24° 38’ 44.8’’ S and 47° 48’ 39.9’’ W; elevation = 18 m a.s.l.) (Figure 1). The park has an area of 23.59 km^2, with remnants of well-preserved sandy coastal plains (Magalhães 2003). The forests of the PECE consist of different physiognomies with a varied structure, mainly related with the type of soil and water availability. Unlike its surroundings, the forests are still well preserved, especially due to regular floods, making settlements and agricultural activities unfeasible (São Paulo 2008). The PECE is currently one of the largest well-preserved continuous lowland forests subject to flooding on the coast of southeast Brazil. The presence of sambaquis (paleo-indian constructions consisting of shells and marine animals) inside the park (São Paulo 2008) suggests that the shoreline was closer to the municipality than its current

level (Martin & Suguio 1989). The municipality of Pariquera-Açu is equally distant from the Ilha de Cananéia and Ilha Comprida by approximately 21 km.

1.4. Municipality of Iguape

The study site was located in the Engenheiro Narciso de Medeiros Agricultural School (24° 41' 14'' S and 47° 31' 52'' W; elevation = 3-50 m a.s.l.) (Figure 1), which encompasses an area of 1.28 km^2. It is located in the Área de Proteção Ambiental of Cananéia/Iguape and is one of the last remnants of original forest in this municipality (Magalhães 2003). Although the municipality of Iguape is currently isolated (by the estuarine channel, Ribeira do Iguape river, and Valo Grande) in this study, it was considered a continental portion due to the recent history of isolation of the area (approximately 180 year).

The climate of the Lagamar region is humid mesothermic (Cfa according to Köppen), with an average temperature in the hottest months above 22 °C and high levels of annual rainfall (between 1,600 and 2,000 mm). There is no dry season, only a decrease in rainfall in the winter (Lamparelli 1999). The Cananéia area differs from the central and northern regions of the coast of São Paulo state, as the average temperatures are slightly lower during the winter (Lamparelli 1999).

2. Data collection

From February 2007 to January 2009, we surveyed the anuran species of the study sites using two complementary methods: active night search and pitfall traps with drift fences. The traps consisted of a line with six 60 L buckets placed 15 m from one another and a drift fence 50 cm high in relation to the ground. Three lines of traps were set up with a distance of 500 m from one another at each study site, totaling 15 lines of traps. The traps were inspected before the sunset, during three consecutive days, at each site, totaling a sampling effort of 1728 hours-bucket, during the entire period of the study.

Simultaneously to the pitfall traps with drift fences, we conducted active visual and acoustic searches at night during three or four consecutive days each month (Heyer et al. 1994).

Data collection started after sunset and ended when the reproductive activity of the frogs decreased or stopped. The trails surveyed during the active search included pre-established paths near the sites where the traps were set up and near previously chosen water bodies (permanent, semi-permanent, and temporary). Each transect at the study sites (one in each studied area) were approximately 2 km long. Bromeliads located along the trails were also inspected for adults, tadpoles or eggs.

Individuals collected were anesthetized with xylocaine, fixed with 10% formalin, preserved in 70% ethanol, and deposited in the collection of amphibians Célio F. B. Haddad (CFBH), Department of Zoology, I.B., Universidade Estadual Paulista, Rio Claro, São Paulo, Brazil.

3. Data analyses

To evaluate the sampling effort, we constructed an accumulation species curve (Colwell 2005). We used data of presence and absence of species per month and per site. The samples were arranged randomly by the method Mao Tau (1000 iterations). The confidence interval of Chao II richness estimator was compared among the study sites (Zar 1996, Santos 2003).

The similarity level regarding the composition of species among study sites and areas nearby or to the north or south of the coast of São Paulo state, south of Rio de Janeiro State and north of Paraná state (Table 1) was calculated with the Sorensen similarity index, which minimizes the effect of sub-sampling, emphasizing the co-occurrence of species (Wolda 1981). The clustering procedure used for the construction of the dendrogram was the UPGMA (group mean). Species with dubious identification were considered as exclusive of each site to avoid incorrect similarity in species composition among sites.

Results

We recorded a total of 32 species of anurans including all study areas; 27 species in Iguape, 23 in Pariquera-Açu, 21 in Ilha de Cananéia, 17 in Ilha Comprida and 18 in Ilha do Cardoso (Table 2). In all study sites, Hylidae was the richest family (approximately 63% in Iguape, 61% in Pariquera-Açu, 65% in Ilha Comprida, 57% in Ilha de Cananéia, and 61% in Ilha do Cardoso). Some species observed in the study sites are shown in Figure 2.

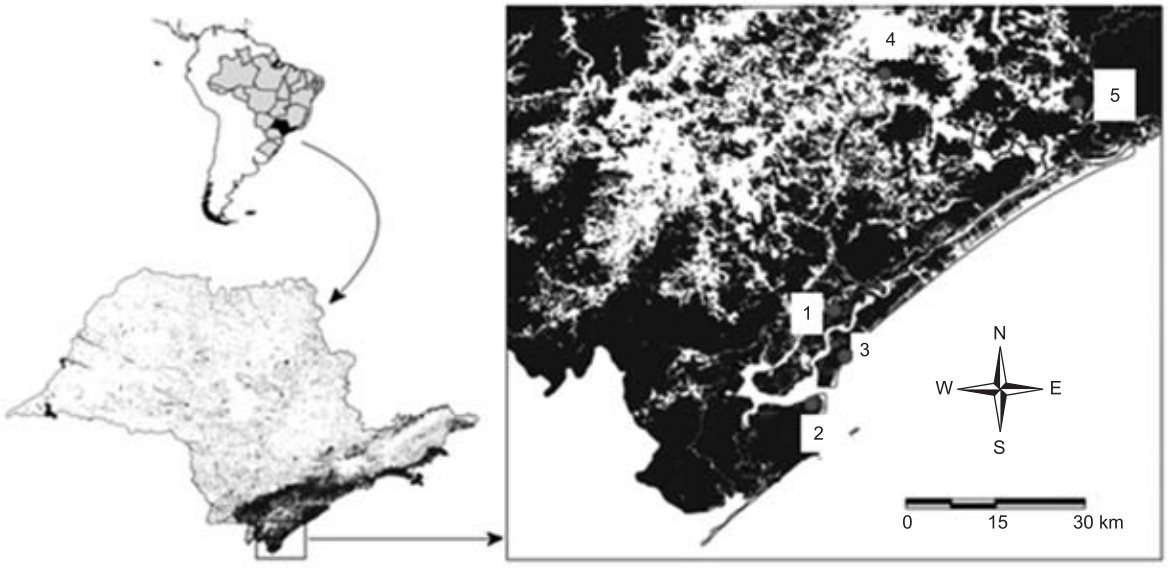

Figure 1. Geographic location of the study areas on the southern coast of São Paulo state, Brazil, being 1) Ilha de Cananéia, 2) Ilha do Cardoso, 3) Ilha Comprida, 4) Pariquera-Açu and 5) Iguape. Dark gray, Atlantic forest remnants of the region.

Figura 1. Localização geográfica das áreas estudadas no litoral sul do estado de São Paulo, Brasil, sendo 1) Ilha de Cananéia, 2) Ilha do Cardoso, 3) Ilha Comprida, 4) Pariquera-Açu e 5) Iguape. Em cinza escuro estão representados os remanescentes de Mata Atlântica da região.

Table 1. Localities whose anuran communities were compared to those examined by this study, geographic coordinates and literature sources. EE = Estação Ecológica, PESM = Parque Estadual da Serra do Mar.
Tabela 1. Localidades cuja anurofauna foi comparada com as estudadas no presente trabalho, suas coordenadas geográficas e referências. EE = Estação Ecológica, PESM = Parque Estadual da Serra do Mar.

Site	Municipality	State	Coordinates	Source
EE Boracéia	Salesópolis	SP	23° 37' S and 45° 52' W	Heyer et al. (1990)
ESEC Juréia-Itatins	Juréia-Itatins	SP	24° 31' S and 47° 16' W	Narvaes et al. (2009)
Ilha de São Sebastião	Ilha Bela	SP	23° 45'-23° 55' S and 45° 17'-45° 24' W	Centeno (2008)
PESM Picinguaba	Ubatuba	SP	23° 21' S and 44° 49' W	Hartmann (2004)
PESM Santa Virgínia	São Luís do Paraitinga	SP	23° 19' S and 45° 08' W	Giasson (2008)
Municipality	Rio de Janeiro	RJ	22° 52'-23° 04' S and 43° 10'-43° 46' W	Izecksohn & Carvalho-e-Silva (2001)
Reserva do Rio das Pedras	Mangaratiba	RJ	22° 59' S and 44° 06' W	Carvalho-e-Silva et al. (2008)
Fazenda Dellamana	Guaraqueçaba	PR	25° 15'-25° 16' S and 48° 17'-48° 19' W	Castanho (2000)

Table 2. Presence and absence of anuran species in the surveyed sites in the Lagamar Paulista, São Paulo State, Brazil. In parentheses the recording method: ○ = active search; + = pitfall traps with drift fences. The "X" indicates presence of the species.
Tabela 2. Lista de espécies de anuros das cinco áreas estudadas no Lagamar paulista, estado de São Paulo, Brazil. Entre parenteses o modo de registro: ○ = procura ativa; + = armadilhas de interceptação e queda. "X" indica o registro das espécies.

Species	Iguape	Pariquera Açu	Ilha Comprida	Ilha de Cananéia	Ilha do Cardoso
Ischnocnema guentheri (Steindachner, 1864)	X(○)			X (○)	
Rhinella ornata (Spix, 1824)	X(○,+)	X(○,+)	X(○,+)	X(○,+)	X(○,+)
Rhinella icterica (Spix, 1824)	X(○)	X(○,+)			
Dendrophryniscus leucomystax Izecksohn, 1968	X(○,+)	X(○,+)	X(+)	X(○,+)	X(○,+)
Haddadus binotatus (Spix, 1824)	X(○,+)	X(○,+)	X(○,+)	X(○)	X(○,+)
Aparasphenodon bokermanni Pombal, 1993		X(○)			X(○)
Dendropsophus berthalutzae (Bokermann, 1962)	X(○)	X(○)			X(○)
Dendropsophus decipiens (Lutz, 1925)					X(○)
Dendropsophus elegans (Wied-Neuwied, 1824)	X(○)	X(○)			
Dendropsophus microps (Peters, 1872)	X(○)	X(○)			
Dendropsophus werneri (Cochran, 1952)	X(○)	X(○)	X(○)	X(○)	
Hypsiboas albomarginatus (Spix, 1824)	X(○)	X(○)	X(○)	X(○)	X(○)
Hypsiboas faber (Wied-Neuwied, 1821)	X(○)	X(○)	X(○)	X(○)	X(○)
Hypsiboas raniceps Cope, 1862	X(○)	X(○)			
Hypsiboas semilineatus (Spix, 1824)	X(○)	X(○)	X(○)	X(○)	
Itapotihyla langsdorffii (Duméril and Bibron, 1841)			X(○)	X(○)	X(○)
Scinax argyreornatus (Miranda-Ribeiro, 1926)	X(○)		X(○)	X(○)	X(○)
Scinax fuscovarius (Lutz, 1925)	X(○)	X(○)	X(○)	X(○)	
Scinax hayii (Barbour, 1909)	X(○)				
Scinax littoralis (Pombal and Gordo, 1991)	X(○,+)			X(+)	X(○)
Scinax sp. (gr. *catharinae*)	X(○)	X(○)	X(○)	X(○)	
Scinax sp.1 (aff. *alter*)	X(○)	X(○)	X(○)	X(○,+)	X(○)
Scinax sp.2 (aff. *alter*)	X(○)	X(○)	X(○)	X(○)	
Scinax sp. (aff. *perpusillus)*				X(○)	X(○)
Phyllomedusa distincta Lutz, 1950	X(○)	X(○)	X(○)		
Trachycephalus mesophaeus (Hensel, 1867)	X(○)				X(○)
Crossodactylus caramaschii Bastos and Pombal, 1995	X(○)				
Physalaemus spiniger Haddad and Pombal, 1998	X(○,+)	X(○,+)	X(○,+)	X(○,+)	X(○,+)
Leptodactylus sp.(gr. *marmoratus*)	X(+)	X(○)		X(○)	
Leptodactylus bokermanni Heyer, 1973	X(○,+)	X(○,+)	X(○)	X(○,+)	X(○,+)
Leptodactylus latrans (Steffen, 1815)	X(○,+)	X(○,+)	X(○,+)	X(○,+)	X(○,+)
Chiasmocleis leucosticta (Boulenger, 1888)		X(+)		X(+)	X(○,+)
Total	27	23	17	21	18

Figure 2. Anuran species registered in the Lagamar Paulista, São Paulo State, Brazil, a) *Dendrophryniscus leucomytax*, b) *Rhinella icterica*, c) *Rhinella ornata*, d) *Haddadus binotatus*, e) *Aparasphenodon bokermanni*, f) *Dendropsophus berthalutzae*, g) *D. elegans*, h) *D. werneri*, i) *Hypsiboas albomarginatus*, j) *H. raniceps*, l) *H. faber*, m) *Itapotihyla langsdorffii*, n) *Scinax argyreornatus*, o) *Scinax litorallis*, p) *Scinax* sp. 1 (aff. *alter*), q) *Scinax* sp. 2 (aff. *alter*), r) *Scinax* sp. (aff. berthae), s) *Scinax* sp. (aff. *perpusillus*), t) *Phyllomedusa distincta*, u) *Trachycephalus mesophaeus*, v) *Physalaemus spiniger*, w) *Leptodactylus bokermanni*, x) *Leptodactylus* sp. (gr. *marmoratus*), and y) *Chiasmocleis leucosticta*.

Figura 2. Espécies de anuros registradas no Lagamar paulista, estado de São Paulo, Brasil, a) *Dendrophryniscus leucomytax*, b) *Rhinella icterica*, c) *Rhinella ornata*, d) *Haddadus binotatus*, e) *Aparasphenodon bokermanni*, f) *Dendropsophus berthalutzae*, g) *D. elegans*, h) *D. werneri*, i) *Hypsiboas albomarginatus*, j) *H. raniceps*, l) *H. faber*, m) *Itapotihyla langsdorffii*, n) *Scinax argyreornatus*, o) *Scinax litorallis*, p) *Scinax* sp. 1 (aff. *alter*), q) *Scinax* sp. 2 (aff. *alter*), r) *Scinax* sp. (aff. berthae), s) *Scinax* sp. (aff. *perpusillus*), t) *Phyllomedusa distincta*, u) *Trachycephalus mesophaeus*, v) *Physalaemus spiniger*, w) *Leptodactylus bokermanni*, x) *Leptodactylus* sp. (gr. *marmoratus*) e y) *Chiasmocleis leucosticta*.

Only 11 species were captured with pitfall traps with drift fences (Table 2) representing approximately 34% of the total diversity of species recorded in all sites sampled. Some species were recorded in some study sites only with this method: *Chiasmocleis leucostica* (Pariquera-Açu and Ilha de Cananéia), *Dendrophryniscus leucomystax* (Ilha Comprida), *Leptodactylus* sp. (gr. *marmoratus*) (Iguape) and *Scinax littoralis* (Ilha de Cananéia).

The analysis of the accumulated species curve indicated an asymptote only for Ilha Comprida, which was confirmed by the values obtained for Chao II (Figure 3). Based on the graphic analysis of

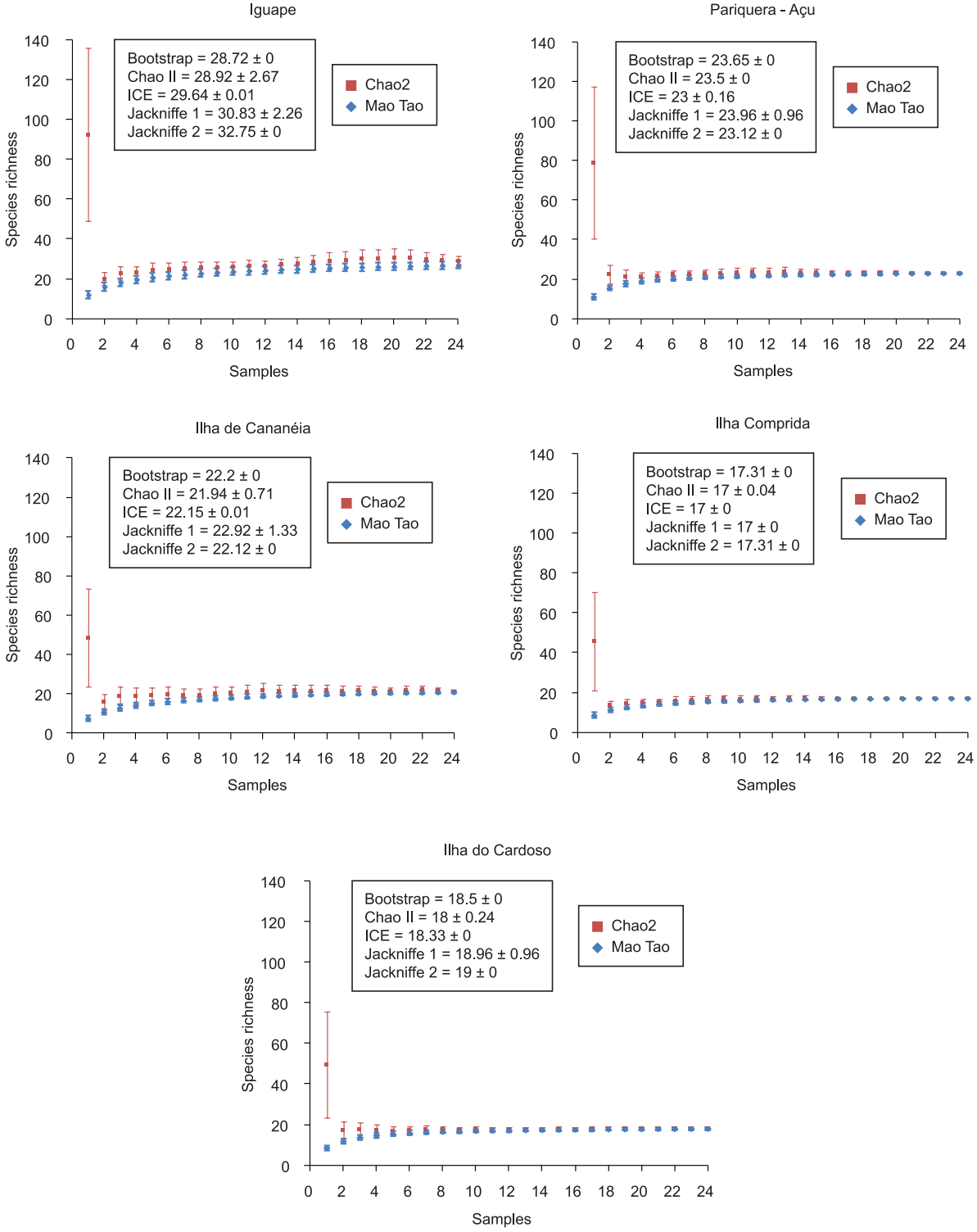

Figure 3. Species accumulation curve (Mao Tau) of each studied areas and corresponding richness values estimated by Chao II. Vertical bars correspond to standard deviations of observed species richness. Next to each figure final richness values estimated by Jackknife I, Jackknife II, Bootstrap, and Chao II and their corresponding standard deviations values.

Figura 3. Curva de acumulação de espécies (Mao Tau) obtida para as áreas estudadas e os valores estimados por Chao II. Barras verticais correspondem aos valores de desvio-padrão obtidos. Ao lado de cada gráfico os valores finais e seus respectivos desvios-padrões estimados por Jackknife I, Jackniffe II, Bootstrap e Chao II.

Chao II average values and their corresponding confidence intervals, a significant difference was observed among study sites regarding species richness, except for Ilha de Cananéia and Pariquera-Açu (Figure 4).

Eight species (25%) occurred in all study sites (Table 2). Other species were recorded only in the study sites on the mainland or only on the islands. The species recorded exclusively on the mainland were: *Rhinella icterica, Dendropsophus elegans, D. microps, Hypsiboas raniceps, Scinax hayii,* and *Crossodactylus caramaschii*. The two latter were found only in the municipality of Iguape (Table 2). The species recorded only on the islands were: *Dendropsophus decipiens* (Ilha do Cardoso), *Itapotihyla langsdorffii* (Ilha do Cardoso, Ilha de Cananéia, and Ilha Comprida) and *Scinax* sp. (aff. *perpusillus*) (Ilha do Cardoso and Ilha de Cananéia) (Table 2).

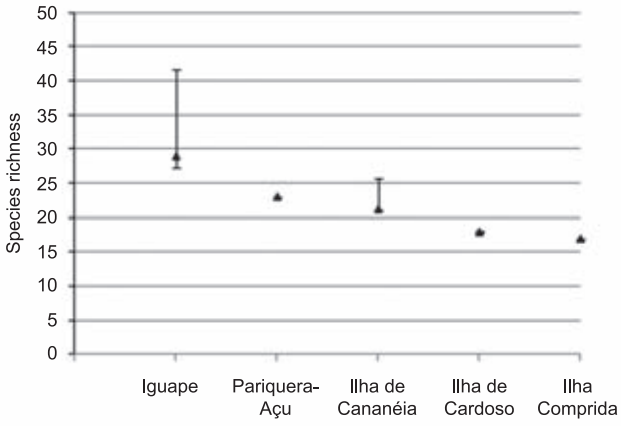

Figure 4. Richness obtained through Chao II estimator and their corresponding confidence intervals (95%) obtained for each locality during the study.

Figura 4. Riqueza obtida por meio do estimador Chao II e seu respectivo intervalo de confiança (95%) para cada localidade estudada do Lagamar paulista.

Compared to other areas, the cluster analysis revealed two distinct groups, one consisting of the study sites and other southern São Paulo coastal areas, and another composed of nearby municipalities and the coast of northern São Paulo and Rio de Janeiro. In the group composed of the study areas, two groups are observed, one comprising the Ilha do Cardoso, with a composition of anurans more similar to that of Guaraqueçaba, in the adjacent Paraná state, and another consisting of the islands of Cananéia-Comprida and Iguape-Pariquera-Açu. A division regarding the composition of anuran species was observed between the insular and continental habitats examined. The similarity between these two sites and the anuran fauna of the ecological reserve Juréia-Itatins, (approximately 100 km away) was higher than the similarity of these sites with the Ilha do Cardoso (Figure 5) (approximately 130 km away from the ecological reserve Juréia-Itatins).

Discussion

Hylidae was the richest family in all studied sites surveyed in the present study. This was expected, since this pattern has also been found in most studies on Brazilian anuran communities (e.g., Bertoluci & Rodrigues 2002, Prado et al. 2005, Brasileiro et al. 2005, Zina et al. 2007), as well as throughout the Neotropics (Doan & Arriaga 2002, Álvarez et al. 2009, Laurencio 2009, Ortega-Andrade et al. 2010). Hylidae is one of the most species-rich families of amphibians, with approximately 900 species currently recognized (Wiens et al. 2010, Frost, 2011). Hylids occur in most continents, but most species and genera are found in the Neotropics

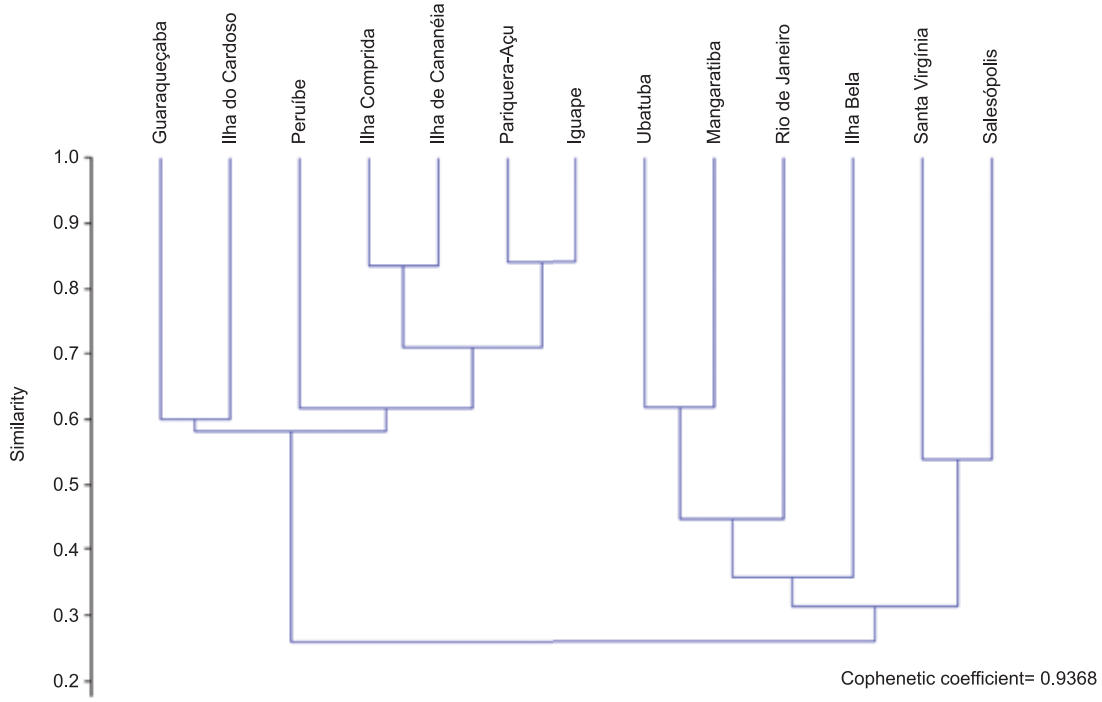

Figure 5. Dendrogram constructed based on the Sorensen Similarity Index for the study sites in the Lagamar Paulista, São Paulo state, and compared areas on the southeastern coast of Brazil (UPGMA).

Figura 5. Dendrograma resultante da análise de agrupamento (método de ligação UPGMA) baseado no índice de similiaridade de Sorensen entre as áreas estudadas e comunidade de anuros de áreas costeira do sudeste brasileiro.

(Wiens et al. 2010, Frost, 2011). The New World hylids are very diverse morphologically and ecologically (Wells, 2007) and exhibit a great diversity of reproductive modes (Haddad & Prado, 2005). These traits, combined with their arboreal habits, allow them to occupy many different habitats, which might explain the dominance of this family in number of species in several communities in the Neotropics.

The low species richness obtained using pitfall traps with drift fences was expected, given the limitations imposed by this method (Cechin & Martins 2000), such as its inefficiency to capture arboreal species. According to Rocha et al. (2004), only a small fraction of anurans in open sandy coastal plains seems to move on the ground, as a result the pitfall traps method seems to be inefficient to survey anuran species in these environments. However, our records of some terrestrial species and those with explosive reproduction (e.g., *Chiasmocleis leucosticta* - see Haddad & Hödl 1997, and *Dendrophryniscus leucomystax* - see Zina 2010) support the importance of pitfall traps as a secondary method associated with active search at the reproductive sites (Cechin & Martins 2000).

The record of species with explosive reproduction may be favored by the formation of temporary or semi-permanent water bodies for a short period of time (after rains), which drain very fast due to the sandy soil. The absence of some of these species (e.g., *C. leucosticta* and *Trachycephalus mesophaeus*) in Ilha Comprida may explain the fact that the total richness was only obtained for this site. Additionally, some differences concerning to water bodies characteristics (drainage speed, for instance) among the studied sites may explain this results. To test these hypotheses, it would be necessary to evaluate habitat availability and habitat use for each species, issues that are beyond the scope of this study.

Species accumulation curves have been widely used to make inferences and evaluate the sampling effort in studies of anuran communities (Silva et al. 2008, Santos et al. 2009, Armstrong & Conte 2010), even in experimental studies where the sampling effort is standardized. The use of this analysis is especially important when the anuran community is the study object, since the capture rates of unrecorded species are strongly influenced by abiotic factors (Bertoluci 1998, Bertoluci & Rodrigues 2002, Zina et al. 2007). This in turn reinforces the need of long-term studies to achieve the total richness of anuran species.

The richness indices observed for the study sites revealed higher values in continental areas. This result is very common in studies comparing islands and continents (MacArthur & Wilson 1967, Centeno et al. 2008, Silva et al. 2008) and agrees with the theory of island biogeography proposed by MacArthur & Wilson (1967). These differences in species richness may result from the way the islands were formed and the habitats that are available for the establishment and/or maintenance of a given population. To test these hypotheses, it would be necessary to evaluate habitat availability and habitat use for each species, as well as species' migration capacity, issues that are beyond the scope of this study.

Among the species that occurred exclusively on the islands, *Scinax* cf. *perpusillus* inhabits bromeliads and is a member of a group of three out of nine species that are endemic to insular habitats: *Scinax alcatraz*, *S. peixotoi*, and *S. faivovichi* (Brasileiro et al. 2007a,b). The dependence on bromeliads, vegetation typical of sandy coastal plains, during their entire life cycle might have been the factor responsible for the isolation of populations in flooded habitats during processes of marine transgression and island formation. The study of island endemic species of the *Scinax perpusillus* group using molecular markers is essential to understand the processes and selective pressures that led to the isolation and later speciation of their members.

The analysis of the similarity index revealed a clear distinction between anuran communities of the coastal regions of north and south of São Paulo state. Geological and climatic processes and their distinct results along the coast of São Paulo state might be responsible for this dichotomy. According to Fitzpatrick et al. (2009), more recent vicariant events, to which the southern region of São Paulo state was subjected, could be responsible for the formation of two well-defined clades (north and south) of frog species in the genus *Thoropa*. According to these authors, these results support the fact that the Atlantic rainforest has had very different landscape dynamics along the southeast coast due to climatic and geologic events from the Pleistocene to the present.

The formation of another interesting cluster, consisting of two distinct groups: continental (Pariquera-Açu and Iguape) and insular (Ilha de Cananéia and Ilha Comprida), might be due to the way these two islands were formed.

Five geologic events formed the coastal region of Cananéia and Iguape (Suguio & Martin 1978). Approximately 120,000 years ago, the sea rose 8 m above the current level during the Cananéia Transgression (Pleistocene Transgression). This event isolated the islands of the Lagamar estuarine complex. The second stage is represented by a regressive phase (Pleistocene Regression), when sediments began to be deposited as beach ridges. During this phase, the Ilha Comprida and Ilha de Cananéia grew and were defined as barrier islands, especially the former one. In the third stage (approximately 17,000 years ago), the sea level was 110 m below the current one. At this time, Ilha de Cananéia and Ilha Comprida gradually became connected, possibly through the Lage do Argolão, a surface of continuous rock, currently submersed. The Ilha de Cananéia, however, remained isolated from the mainland due to erosion of deposits of the Cananéia Formation by rivers. In the fourth stage, the sea level rose again (3.5 m - Santos Transgression), isolating the islands. In the fifth stage, the sea level stabilized at its current level. Thus, it is very likely that during the entire process in which the complex was formed, exchanges of individuals between populations of anuran species occurred between Ilha Comprida and Ilha de Cananéia. It is also possible that one given species present only on one of the islands colonized the other one via Lage do Argolão. Such events could explain the similarity in species composition between the Ilha de Cananéia and Ilha Comprida and the formation of an isolated group of island communities. Again, studies using molecular markers and estimations of time divergence between lineages would be useful to test such hypotheses.

Ilha do Cardoso has the highest elevations among the three islands examined in the study. Most of this island consists of Pre-Cambrian rocks (Suguio & Tesser 1992). The effects of marine regression and transgression on the anuran community of this island might have been differentiated. It is possible that during regressive processes, bridges between the Ilha do Cardoso and coastal areas of Paraná state enabled the contact between the anuran fauna of sandy coastal plains of these two areas, which could explain their similarity, as opposed to the similarity observed between Ilha do Cardoso and other areas of the Lagamar complex.

Seven species registered during this study are restricted or partially restricted to coastal areas in south and southeast Brazil [*Aparasphenodon bokermanni*, *Dendrophryniscus leucomystax*, *Dendropsophus berthalutzae*, *Scinax argyreornatus*, *Scinax littoralis*, *Scinax* sp. (aff. *perpusillus*), and *Physalaemus spiniger*)] (Frost, 2011). One of them [*Scinax* sp. (aff. *perpusillus*)] is restricted to the municipalities of the Lagamar Paulista. Our results showed that a small area of the Brazilian coast, located in the most developed region, can harbor a unique frog fauna, which might be threatened by the unplanned human occupation.

Although species richness and composition can be successfully used as tools to explain some ecological patterns, they are still insufficient parameters to support hypothesis that can explain the way a community is or was structured in insular habitats. Studies focusing on multiple aspects, such as the natural history of species, community ecology, molecular biology, and geographic history are needed to further investigate the hypotheses proposed in this study.

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