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DIET OF PARROTS IN AN URBAN AREA OF SÃO PAULO, SOUTHEAST BRAZIL[1]

DIETA DE PSITACÍDEOS EM ÁREA URBANA DE SÃO PAULO, SUDESTE DO BRASIL[1]

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ABSTRACT - Although some species of parrots have adapted to urbanised environments, studies on this subject remain scarce. This study aimed to quantify the diet of parrots within an urban area of São Paulo city, Brazil, encompassing trophic niche breadth and dietary overlap. Observations were conducted on the University of São Paulo campus along a 6-km transect over three years (June 2022-May 2025), totalling 933.4 h of observation. Feeding events were documented exclusively via photography, ensuring accuracy in the identification of the involved species and their interactions. A total of 2929 feeding events were recorded, involving six parrot species and 83 food items, of which 79 were plant species - predominantly trees (74). *Brotogeris tirica*, *Diopsittaca nobilis*, and *Amazona aestiva* accounted for 97% of the events. Trophic niche breadths were low for the species with the highest number of records, with a predominance of seeds, fruits, and nectar from few plant species. Dietary overlap was low, except for both species of the genus *Brotogeris*. The parrots exploit a wide variety of food resources from both native and exotic plants. However, 59.5% of the consumed plant species were native, corresponding to 67.7% of the feeding events, suggesting the relevance of regional species in urban greening schemes. The utilisation of exotic plants suggests parrot adaptive plasticity. The seasonal exploitation of flowers during dry periods suggests behavioural flexibility in response to temporal resource availability. This study contributes to the understanding of parrot feeding ecology in cities and provides a foundation for urban green space planning.

Keywords: Food habits, Psittacidae, Urban Environment, Neotropical Region.

RESUMO - Embora algumas espécies de psitacídeos tenham se adaptado a ambientes urbanizados, ainda são escassos estudos sobre esse tema. Este estudo teve como objetivo quantificar a dieta de psitacídeos em área urbana da cidade de São Paulo, Brasil, englobando a amplitude trófica e a sobreposição alimentar. As observações ocorreram no *campus* da Universidade de São Paulo, em trajeto de 6 km, durante três anos (junho/2022-maio/2025), totalizando 933,4 h de observação. Os eventos de alimentação foram documentados exclusivamente por fotografias, garantindo precisão na identificação das espécies envolvidas e das interações. Foram registrados 2929 eventos de alimentação envolvendo seis espécies de psitacídeos e 83 itens alimentares, dos quais 79 eram espécies de plantas, majoritariamente arbóreas (74). *Brotogeris tirica*, *Diopsittaca nobilis* e *Amazona aestiva* concentraram 97% dos eventos. As amplitudes de nicho trófico foram baixas para as espécies com maior número de registros, predominando o consumo de sementes, frutos e néctar de poucas espécies. A sobreposição alimentar foi baixa, exceto entre as espécies de *Brotogeris*. Os psitacídeos exploram ampla variedade de recursos alimentares, tanto de plantas nativas quanto exóticas. Contudo, 59,5% das espécies vegetais consumidas eram nativas, correspondendo a 67,7% dos eventos, sugerindo a relevância das espécies regionais na arborização urbana. A utilização de exóticas sugere plasticidade adaptativa dos psitacídeos. Houve sazonalidade na dieta, com maior exploração de flores em períodos secos, podendo refletir flexibilidade comportamental frente à disponibilidade temporal de recursos. Este estudo contribui para o conhecimento da ecologia alimentar de psitacídeos em cidades e subsidia o planejamento de suas áreas verdes.

Palavras-chave: Hábitos alimentares, Psittacidae, Ambiente Urbano, Região Neotropical.

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1 INTRODUCTION

Birds of the Order Psittaciformes, including the family Psittacidae, constitute a group characterised by a large brain, zygodactyl feet, conspicuous colouration, and a high, hooked beak (Collar 1997; Sick 1997; Toft and Wright 2015). Furthermore, most species exhibit the capacity for extensive movements (Whitney 1996; Sick 1997; Brightsmith et al. 2021). The 177 species within Psittacidae are predominantly distributed in the Southern Hemisphere, particularly in tropical and subtropical regions (Winkler et al. 2020), with 87 of these occurring in Brazil (Pacheco et al. 2021).

The group's diet is frequently described as generalist, based on plant reproductive structures such as fruits, seeds, and flowers (including nectar and pollen), rarely involving animals, such as invertebrates (Collar 1997; Benavidez et al. 2018; Bahia et al. 2022). Although typically associated with antagonistic relationships with plants, such as seed and flower predation (Collar 1997; Sick 1997; Forshaw 2010), an increasing number of reports in the literature highlight cases of mutualism, including seed dispersal and pollination (Sazima 2008; Tella et al. 2015; Blanco et al. 2018; Bahia et al. 2022; Silva 2022). Thus, studying the diet of parrots is fundamental for a better understanding of the antagonistic and mutualistic interactions established between birds and plants (Blanco et al. 2018; Bahia et al. 2022). Moreover, considering that approximately 38% of psittacid species are classified as being under some degree of extinction threat (Winkler et al. 2020), detailed knowledge of their diet is essential to inform management and conservation strategies (Bahia et al. 2022).

Until recently, a large proportion of studies on the diet of Brazilian parrots involved focal plants and/or birds (e.g., Francisco et al. 2002; Ragusa-Netto 2005; Silva 2005, 2007; Paranhos et al. 2007; Santos and Ragusa-Netto 2014). Studies addressing psittacid assemblages were scarcer, such as the pioneering work by Roth (1984) in the Amazon. Over the last two decades, there has been a significant increase in this line of research (e.g., Ragusa-Netto and Fecchio 2006; Luccas et al. 2009; Marques et al. 2018; Ragusa-Netto 2022). As highlighted by Bahia et al. (2022) in a global review of psittacid diet, most publications focus on natural or minimally altered areas, with few studies in urban zones (such as Santos and Ragusa-Netto 2014; Marques et al. 2018). Following this alert, at least two Brazilian publications have included studies on psittacid assemblages in urbanised areas (Leoni et al. 2023; Soares et al. 2023).

Urbanisation represents one of the primary challenges to global biodiversity due to landscape alterations and biotic and abiotic modifications in ecosystems (Marques et al. 2018; Álvarez-Castillo et al. 2022). The loss of native vegetation, the introduction of exotic plants, and changes in microclimate directly affect the occurrence and persistence of parrots and other birds in urban environments (Marques et al. 2018; Berthon et al. 2021; Bahia et al. 2022). However, the presence of green spaces, such as parks and tree-lined squares, can mitigate these impacts by providing food resources and refugia throughout the year (Álvarez-Castillo et al. 2022; Bahia et al. 2022). In this context, the present study is justified as an additional contribution to the knowledge of psittacid diet in urban areas, contributing to an understanding of how these birds can adapt to highly modified environments.

Therefore, this study aimed to quantitatively investigate the diet of free-living parrots observed in an urban area of São Paulo - SP, southeast Brazil, seeking to evaluate the trophic niche breadth of each species, the dietary overlap among the assemblage components, and the utilisation profile of native and exotic plants for obtaining food resources.

2 MATERIAL AND METHODS

2.1 Study area

The study area is located within the *campus* of the University of São Paulo (23°33'37.6"S, 46°43'50.6"W), specifically in the Cidade Universitária Armando Salles Oliveira (CUASO), São Paulo – SP (Figure 1). This is an urbanised environment with extensive tree cover, where at least 143 bird species have been recorded (Höfling and Camargo 1999). Of these, 11 belong to the family Psittacidae. The climate is humid subtropical (Cwa, according to the Köppen classification), characterised by dry winters and rainy summers (Dislich 2002). CUASO has a total area of 364 ha (FUNDUSP 1998). The vegetation present is diverse, including street trees, parks, and ornamental gardens, composed of both exotic and native species (Mendonça 2004). Additionally, remnants of secondary Atlantic Forest can be observed, contributing to the regional biodiversity (Höfling and Camargo 1999).

For data collection, we established a 6 km route in the central region of CUASO, encompassing the broad local landscape heterogeneity. The route traverses areas ranging from more open spaces dominated by lawns and sparse trees to regions with a higher concentration of buildings, as well as the edge of the remnant Atlantic Forest (Figure 1). Due to this landscape variation, the width of the transect with visibility for recording bird feeding events varied considerably (40-160 m). The sampled sub-area comprises approximately 60 ha, corresponding to 16.5% of the total area of CUASO.

2.2 Data collection and analysis

Fieldwork spanned three years, from June 2022 to May 2025, typically involving 8–12 sampling mornings per month. The 6 km route (Figure 1) was slowly traversed on foot by a single researcher, commencing shortly after sunrise to capitalise on the period of highest psittacid activity (Roth 1984), following an overnight fast. The mean ± standart deviation - SD duration was 2.4 ± 0.5 h, between 06:00 and 10:30, depending on the time of year. Feeding events were recorded using an adapted feeding bouts method (e.g., Galetti 2002; Soares et al. 2023). During the transect survey, signs of Psittacidae species activity were sought, such as vocalisations, movements in vegetation, and the dropping of food structures. The maximum possible number of feeding individuals was recorded. However, those without visual confirmation or photographic documentation were not included. Thus, we made a modification to the presence-absence method of Galetti (2002), by recording all observed individuals as in Ragusa-Netto and Fecchio (2006) and Silva (2013). To avoid potential biases related to time of day, transects were walked alternately in opposite directions, at their beginning and end. In this study, a feeding event was defined as the first act of ingestion on a given substrate (e.g., a plant), and subsequent feeding acts on the same substrate were not counted for dietary quantification, ensuring data independence (Filek et al. 2018; Ragusa-Netto 2022; Ónodi et al. 2024). If the same bird moved to another substrate distinct from the first (e.g., another plant) and fed again, it was considered a new event (cf. Galetti 2002). The focus was to assess the psittacid assemblage along the sample transect by sweeping, without delving into sequential behaviours.

To ensure greater rigour and accuracy in recordings, only events documented (e.g., Figure 2) via photographs (in continuous shooting mode) and, when possible, by videos. Photos were carefully analysed on a high resolution computer screen, allowing for the selection of the best images for each event and more reliable determination of the food type obtained. Exceptionally, on rare occasions, an event could be considered without a photo/video, but only when the researcher was certain of the naked-eye observation and there was documentation of evidence, such as photographed remnants of food structures discarded by the bird. To avoid duplication in counting feeding bird individuals, especially in large monospecific groups, individual differences in face, beak, and/or plumage were analysed through photographs (see Figures 2A vs. 2B).

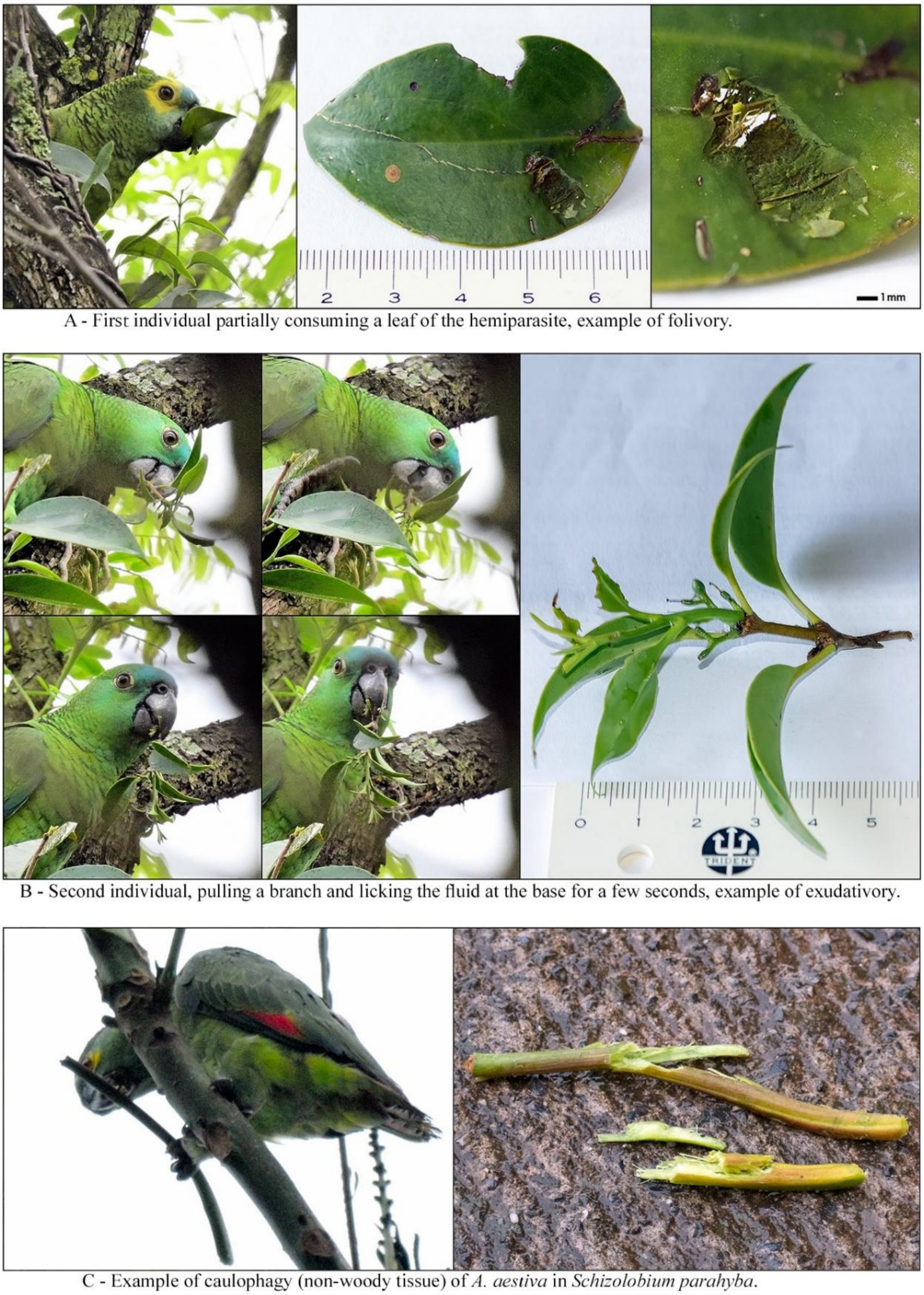
Various brands (Nikon, Olympus, Sony, and Canon) and models of cameras were used, but always equipped with larger sensors ranging from the standard 1-inch (13.2 × 8.8 mm) to full frame (36 × 24 mm), and with tele-zooms varying from 600 to 800 mm effective focal length (considering the sensor's crop factor relative to the full frame standard). Larger sensors ensure higher image quality (McHugh 2019), which allowed for greater cropping/enlargements for checking details of the feeding event on a computer. This non-invasive photographic method has been recently applied and recommended for more accurate recordings, enabling the acquisition of data that may be difficult to detect or be erroneously perceived by conventional visual observation methods (e.g., Tella et al. 2015; Gaglio et al. 2017).

The identification of used plants was performed through detailed photos of reproductive structures, branches and trunks, which were analysed by one of the authors (YK) and, if necessary, by other botanists (see acknowledgements section). All individual plants where feeding events occurred were marked with GPS points for subsequent in loco verification of identification if required. For the determination of native and exotic plants (in relation to their natural occurrence in the central-eastern part of São Paulo state), information available in the Flora e Funga do Brasil (2025) and Plants of the World Online (POWO 2025) was consulted.

The trophic niche breadth (or dietary diversity) was calculated using Levins' standardised index (Krebs 1999), ranging from 0 (specialist, only one item used) to 1 (generalist, all items exploited equitably). Dietary overlap between species was assessed using Pianka's symmetrical index (Krebs 1999), also ranging from 0 (no overlap) to 1 (total overlap). The computer program accompanying Krebs (1999) was used for the calculations. For verification and safety, the same analyses were run in electronically created spreadsheets according to Donovan and Welden (2002). Pearson's correlation coefficient was used in the analysis of diet seasonality.

Figure 1. Location of the study area showing (a) the state of São Paulo in Brazil, (b) the municipality of São Paulo within the state, (c) the boundaries of the municipality with the position of the CUASO (red rectangle), and (d) the route used (red line) inside the boundaries of the CUASO (yellow line). Satellite images adapted from Google Earth®.

Figura 1. Localização da área de estudo mostrando (a) o estado de São Paulo no Brasil, (b) o município de São Paulo no estado, (c) limites do município com posição da CUASO (retângulo vermelho), e (d) trajeto utilizado (linha vermelha) dentro dos limites da CUASO (linha amarela). Imagens de satélite adaptadas do Google Earth®.



A - First individual partially consuming a leaf of the hemiparasite, example of folivory.

B - Second individual, pulling a branch and licking the fluid at the base for a few seconds, example of exudativory.

C - Example of caulophagy (non-woody tissue) of *A. aestiva* in *Schizolobium parahyba*.

Figure 2. A and B: Examples of photographic documentation of two individuals of *Amazona aestiva* in the same *Struthanthus rhyncophyllus* hemiparasite. Photos by J.C. Motta-Jr. Note the differentiation of the individuals (A and B) by their faces. Example of caulophagy (C) by *A. aestiva*. Photos by Karina Macedo.

Figura 2. A e B: exemplos de documentação fotográfica em dois indivíduos de *Amazona aestiva* na mesma hemiparasita *Struthanthus rhyncophyllus*. Fotos de J.C. Motta-Jr. Note a diferenciação dos indivíduos (A e B) pelas faces. Exemplo de caulofagia (C) - por *A. aestiva*. Fotos de Karina Macedo.

3 RESULTS AND DISCUSSION

3.1 Sampling efforts

From June 2022 to May 2025 a total of 392 walks were conducted along the 6 km route, accumulating 933.4 hours of observations. This allowed for the recording of 2929 feeding events from six Psittacidae species, identified into 83 distinct items (Appendix) and grouped into 11 broad dietary categories (Figures 2, 3 and 4; Table 1). Even after three years of sampling effort, the rarefaction curve for new food item records has not yet stabilised. Extrapolated rarefaction analysis estimates approximately 107 food items (83 to 130 with 95% confidence), with stabilisation predicted after 1500 routes (Figure 5). This indicates the high diversity of food items exploited and those yet to be detected with continued observations.

3.2 Dietary composition and pant utilisation

Only three parrot species accounted for 97% of the recorded events: *Brotogeris tirica* (Plain Parakeet), *Diopsittaca nobilis* (Red-shouldered Macaw), and *Amazona aestiva* (Turquoise-fronted Amazon). In contrast, *Psittacara leucophthalmus* (White-eyed Parakeet) exhibited low values, while *B. chiriri* (Yellow-chevroned Parakeet) and *Forpus xanthopterygius* (Blue-winged Parrotlet) were detected on very few occasions (Table 1, Appendix). With the exception of *B. tirica*, which more evenly exploited fruits, seeds, and nectar, the other species concentrated their diet on seeds, particularly *D. nobilis* and *A. aestiva* (Table 1). The prevalence of granivory is corroborated by various authors, with this often being the primary interaction for this avian group (Francisco et al. 2002; Toft and Wright 2015; Benavidez et al. 2018; Bahia et al. 2022). Furthermore, frugivory and nectarivory are commonly reported in other studies as the next two most frequent interactions (Blanco et al. 2015; Benavidez et al. 2018; Bahia et al. 2022). As in the reviews of Benavidez et al. (2018) and Bahia et al. 2022), the prevalence of interactions with plant reproductive tissues was also recorded in our study (Appendix).

Figure 3. Parrot species with examples of the most common types of diet. Photos by J.C. Motta-Jr. (A), Rachel Fidelis (B), Luiza Ribeiro (C) and Gabriela Carvalho (D).

Figura 3. Espécies de psitacídeos com exemplos de tipos de dieta mais frequentes. Fotos de J.C. Motta-Jr. (A), Rachel Fidelis (B), Luiza Ribeiro (C) e Gabriela Carvalho (D).

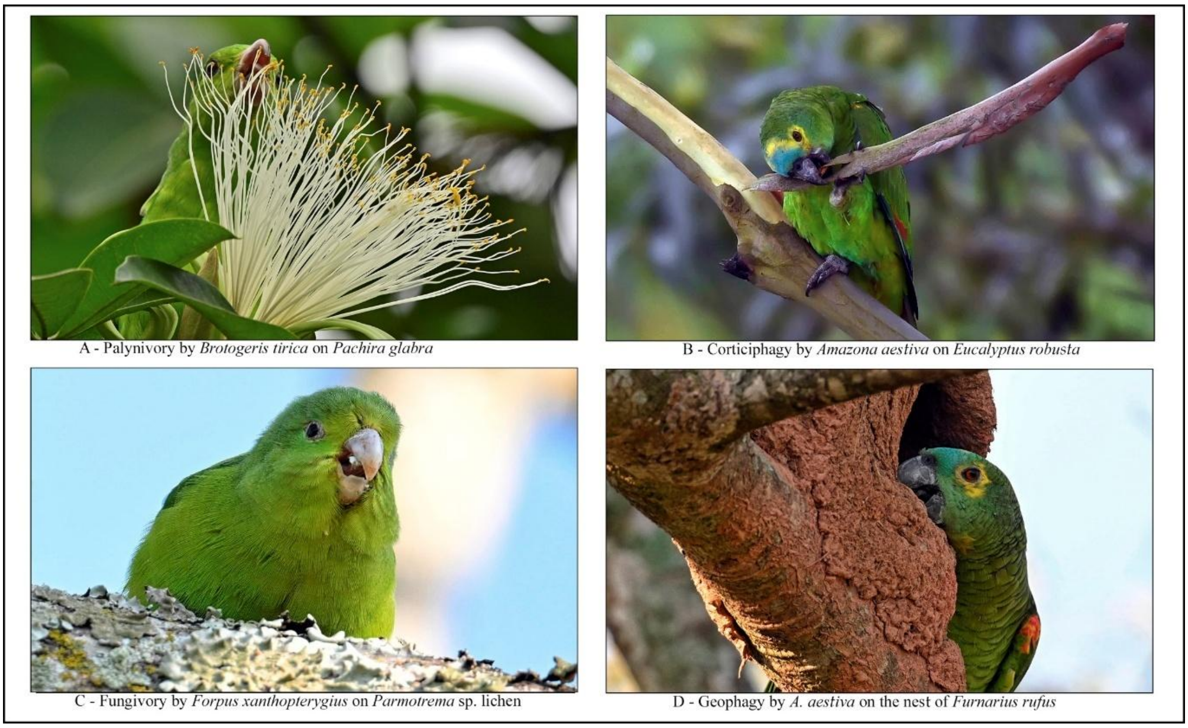


Figure 4. Parrot species recorded on the USP *campus* with examples of less frequent types of diet. All photographs by J.C. Motta-Jr.

Figura 4. Espécies de psitacídeos registrados no *campus* USP com exemplos de tipos de dieta menos frequentes. Todas as fotos de J.C. Motta-Jr.

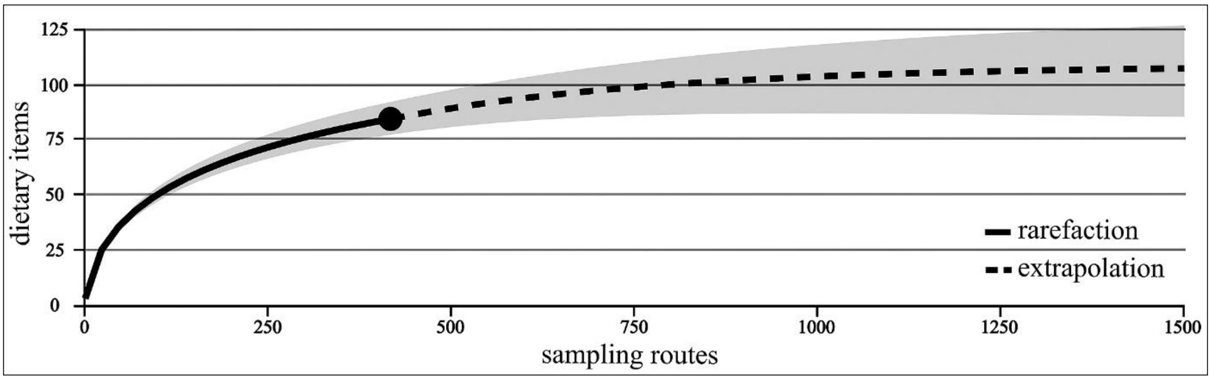


Figure 5. Average accumulated food item curve as a function of the number of routes traversed, generated by 1000 randomised iterations following Colwell et al. (2012) [iNEXT package]. The point indicates the 392 routes traversed in this study.

Figura 5. Curva média de itens alimentares acumulados em função do número de trajetos percorridos, gerada por 1000 iterações aleatorizadas seguindo Colwell et al. (2012) [iNEXT package]. O ponto indica os 392 trajetos realizados neste estudo.

Table 1. Diet of Psittacidae as a percentage of feeding events across major diet categories. Trophic niche breadth according to the standardised Levins index, both for the categories presented here (n = 11) and for the species level of the items (n = 83, see Appendix). Diet categories adapted/modified from Lopes et al. (2016).

Tabela 1. Dieta dos Psittacidae em porcentagem de eventos de alimentação por grandes categorias de dieta. Amplitude de nicho trófico segundo o índice de Levins padronizado, tanto para as categorias aqui apresentadas (n =11) como para o nível de espécie dos itens (n = 83, ver Apêndice). Categorias de dieta adaptadas/modificadas de Lopes et al. (2016).

Diet category\Psittacidae species	***A. aestiva***	***B. chiriri***	***B. tirica***	***D. nobilis***	***F. xanthopterygius***	***P. leucophthalmus***
GRANIVORY - seed	67.94	62.50	34.98	72.75	40.00	47.62
FRUGIVORY - fruit (pulp, aril)	12.56	25.00	37.30	22.63		23.81
NECTARIVORY - nectar	8.07	12.50	24.37	2.49		28.57
PALYNIVORY - pollen	0.45		1.61			
FLORIVORY - petals, calyx, or whole flower	2.69		1.09	0.12	20.00	
FOLIVORY - leaf, leaf buds	4.93		0.06	1.07		
EXUDATIVORY - extrafloral plant fluid	0.22			0.24		
CAULOPHAGY - non-woody stem	1.79			0.12		
CORTICIPHAGY - bark of trees and branches	0.90		0.58	0.36		
FUNGIVORY – fungus and lichens	0.22				40.00	
GEOPHAGY - earth, building wall (for minerals)	0.22			0.24		
Total number of feeding events	**446**	**16**	**1555**	**844**	**5**	**63**
Standardised Levins index by diet categories	**0.105**	**0.567**	**0.352**	**0.090**	**0.889**	**0.870**
Standardised Levins index by food item species	**0.225**	**0.639**	**0.163**	**0.093**	**0.889**	**0.574**

Among the 79 plant species exploited, only five accounted for 51% of the 2891 feeding events (Appendix): the natives *Syagrus romanzoffiana* (Queen Palm), *Psidium myrtoides* (Purple Guava), *Ceiba speciosa* (Silk Floss Tree) and *Pseudobombax majus* (White Floss Silk Tree), and the exotic *Melia azedarach* (Chinaberry Tree). Luccas et al. (2009) reported a strong use of *S. romanzoffiana* and *M. azedarach* by *B. tirica*; Silva (2005) corroborated the high demand for *M. azedarach* seeds by *D. nobilis*; Leoni et al. (2023) reported significant consumption of *S. romanzoffiana* fruits by *B. chiriri* and *P. leucophthalmus*, while Silva (2007) observed *C. speciosa* seeds being highly sought after by *B. chiriri*. Conversely, we found no reports of strong psittacid consumption of reproductive structures of *P. myrtoides* and *P. majus*; for these, the present study appears to be the first to report high consumption of seeds and fruits for the former (by *D. nobilis*), and seeds and nectar for the latter (by *B. tirica*).

Although the consumption of soil or small rock fragments is known in the literature and serves several non-mutually exclusive functions, such as mineral intake, adsorption of toxins from ingested plant parts, and mechanical aid in food trituration in the gizzard (Brightsmith 2008; Severo-Neto 2022), we recorded few instances. These included curious cases of *D. nobilis* consuming particles from building walls (an urban replacement for rocks) and *A. aestiva* ingesting soil from an abandoned Rufous Hornero (*Furnarius rufus*) nest (Figure 4 D). Rare events of exudate (Figure 2 B), stem (Figure 2 C), and bark (Figure 4 B) consumption by *A. aestiva* also occurred. Equally uncommon was the use of lichens by *F. xanthopterygius* (Figure 4 C) and fungi by *A. aestiva*, both rarely reported in the diet of Psittacidae (Collar 1997).

The majority of recorded food items comprised plant structures (79 plant species, Appendix), primarily reproductive parts. Almost all of these consumed plants were woody (74 tree and shrub species), consistent with the review by Benavidez et al. (2018), with the exceptions being one herbaceous plant (*Tithonia diversifolia*), two hemiparasites (*Phoradendron quadrangulare* and *Struthanthus rhynchophyllus*), and two epiphytes (*Rhipsalis teres* and *R. grandiflora*). Although the afforestation of CUASO predominantly includes exotic species (Mendonça 2004), we observed that 59.5% of the 79 species utilised by parrots are native. Furthermore, of the 2981 plant feeding events recorded, 67.7% involved interactions with native species. These findings corroborate previous research in urban areas of other Brazilian cities (Leoni et al. 2023, Soares et al. 2023). The predominance of native plants as a food source highlights the importance of prioritising regional species in revegetation and urban afforestation projects (Pena et al. 2017; Almeida et al. 2024). However, the significant use of exotic species also suggests the adaptive plasticity of Psittacidae in exploiting novel resources in altered areas (Matuzak et al. 2008; Silva 2013; Renton et al. 2015; Marques et al. 2018; Benavidez et al. 2018; Bahia et al. 2022; Leoni et al. 2023).

3.3 Trophic niche breadth and diet overlap

The most quantitatively specialised diet was that of *D. nobilis*, exhibiting the lowest Levins' index values (Table 1), which is explained by the concentration of feeding events on seeds and fruits of *Psidium myrtoides* (Appendix). Discounting the two species with very low numbers of feeding events, which can lead to index imprecision, the relatively most diversified diet belonged to *P. leucophthalmus*, although the low number of events (63) may also be problematic. Qualitatively, *B. tirica* had the most generalist diet, exploiting 43 distinct food items (Appendix); however, quantitatively its diet was more restricted as it concentrated the majority of its visits (58%) to only three plants: *Syagrus romanzoffiana*, *Ceiba speciosa*, and *Pseudobombax majus* (Appendix). Similarly, *A. aestiva*, despite showing low Levins' indices due to its strong granivory (Table 1) and concentrating its visits on a few plants such as *Hovenia dulcis* (Japanese Raisin Tree), *M. azedarach*, and *Anadenanthera peregrina* (Yopo), qualitatively tied with *B. tirica* for the most generalist diet by exploiting 43 distinct food items (Appendix).

Dietary overlap among the six species was generally low, with the exception of the two congeneric *Brotogeris* species (Table 2). Although the low number of *B. chiriri* events may contribute to this in the latter situation, we consistently observed an individual (not necessarily the same one) of this species within *B. tirica* flocks, sharing the same food types.

As we chose to consider all documented individuals feeding, in contrast to Soares et al. (2023), the trophic breadths were relatively low. Since those authors adopted presence-absence in recording feeding events, their trophic niche width indices may be inflated. In computer simulations for Levins' and Pianka's indices using data from all observed individuals versus data with only one individual per flock, we noted this effect of increasing index values due to the flattening of numerical values (unpublished data). Therefore, we recommend that in future studies, information should not be discarded, advocating for the recording of all observed feeding events (as adopted by Ragusa-Netto and Fecchio 2006 and Silva 2013, for example). Psittacidae are gregarious birds, with large flocks (not rarely exceeding 10 individuals), and discarding feeding data from individuals who can be effectively documented seems inappropriate to us, and is likely to introduce mathematical artefacts into the index calculations.

3.4 Some differential consumption of seed and fruit according to maturity stage

When considering the use of seeds and fruits concerning their developmental or phenological stage, in most cases of granivory, parrots consumed immature seeds, and in cases of frugivory (with pulp/aril as the focus), they specifically sought mature fruits. Some examples for birds and plants with larger data volumes are:

Amazona aestiva: in cases of granivory, 100% immature seeds in *Anadenanthera peregrina* and *Hovenia dulcis* (n = 54 and 89 respectively); 96% immature in *Melia azedarach* (n = 97).
Brotogeris tirica: granivory in *Pseudobombax majus* showed 97% immature seeds (n = 138); for *Ceiba speciosa*, 44% immature (n = 239), while in *Tipuana tipu* (Tipu tree) there was a reversal with only 3% immature winged seeds (n = 67). Frugivory in *Syagrus romanzoffiana* showed 100% consumption of mature or nearly mature fruits (n = 378).
Diopsittaca nobilis: granivory in *M. azedarach*, 78% immature seeds (n = 155); for *Psidium myrtoides*, 98% immature (n = 303); in *T. tipu*, 70% immature winged seeds (n = 42). Frugivory in *P. myrtoides*, 100% mature or nearly mature fruits (n = 65).

This higher consumption of immature seeds can be explained by the fact that they are easier to break and have a higher protein, water, and mineral content in their composition compared to mature seeds (Janzen 1971; Forget et al. 2005; Toft and Wright 2015). Furthermore, the greater softness and consequent digestibility of immature seeds also contribute to their increased consumption (Janzen 1971; Forget et al. 2005).

Table 2. Overlap of the diet among Psittacidae species according to the Pianka's symmetric index. Calculation based on the level of species used (N = 83, Appendix) and major diet categories (N = 11, Table 1) – in parentheses. Aaes – *Amazona aestiva*; Bchi – *Brotogeris chiriri*; Btir – *B. tirica*; Dnob – *Diopsittaca nobilis*; Fxan – *Forpus xanthopterygius*; Pleu – *Psittacara leucophthalmus.*

Tabela 2. Sobreposição da dieta entre as espécies de Psittacidae segundo o índice simétrico de Pianka. Cálculo baseado no nível de espécies usadas (N = 83, Apêndice) e de grandes categorias de dieta (N = 11, Tabela 1) - entre parêntesis. Aaes – *Amazona aestiva*; Bchi – *Brotogeris chiriri*; Btir – *B. tirica*; Dnob – *Diopsittaca nobilis*; Fxan – *Forpus xanthopterygius*; Pleu – *Psittacara leucophthalmus.*

Species	Aaes	Bchi	Btir	Dnob	Fxan	Pleu
Aaes	1.000 (1.000)	0.044 (0.975)	0.098 (0.770)	0.219 (0.987)	0.085 (0.664)	0.118 (0.892)
Bchi		1.000 (1.000)	0.819 (0.882)	0.017 (0.985)	0.000 (0.609)	0.135 (0.950)
Btir			1.000 (1.000)	0.031 (0.798)	0.009 (0.418)	0.264 (0.949)
Dnob				1.000 (1.000)	0.040 (0.637)	0.179 (0.884)
Fxan					1.000 (1.000)	0.064 (0.525)
Pleu						1.000 (1.000)

3.5. Seed Rejection and biotic resistance to exotic plants

We noted instances of rejection for certain seeds which, despite being easily breakable (pers. obs.), were never predated by any Psittacidae; these birds merely consumed the fruit pulp, discarding the seeds intact. An example was *Eriobotrya japonica* (Loquat), an exotic species from Southeast Asia. In this case, part of the explanation is attributed to the high toxicity of these seeds (Weber and Garner 2002), a factor perceived by the birds even without an evolutionary history with the plant species. We observed identical parrot behaviour concerning *Syzygium cumini* (Java Plum, n=22), *S. jambos* (Rose Apple, n=12), and *Eugenia brasiliensis* (Grumichama, n=9); however, we found no literature reports on the toxicity of seeds from these species, which are also easily breakable.

For some exotic plant species where antagonistic relationships with parrots were observed, the phenomenon of biotic resistance (Levine et al. 2004; Silva et al. 2023) may be occurring – i.e., seed predation and flower destruction inhibiting plant dispersal. Among some of the most relevant cases, we can cite *Acrocarpus fraxinifolius* (Pink Cedar) – with most flowers destroyed; *Hovenia dulcis* (Japanese Raisin Tree) and *Melia azedarach* (Chinaberry Tree) – both with almost all seeds predated.

3.6 Diet Seasonality

Seasonality in the consumption of plant-derived items was evident (Figure 6), particularly for flowers (including nectarivory), which were more exploited during months with less rainfall, decreasing with more intense precipitation (Pearson correlation, r = -0.63; p = 0.029; n =12). When fruits (pulp, aril) were consumed more, there were fewer instances of granivory, and vice-versa (r = -0.60; p = 0.037; n =12). Other studies across Brazil (e.g., Ragusa-Netto 2005, 2022; Ragusa-Netto and Fecchio 2006; Paranhos et al. 2009) identified a greater prevalence of interactions with floral resources during drier periods, consistent with our data (Figure 6). This annual alternation in resource utilisation, as well as the increased exploitation of flowers and nectar during the dry season, are examples of adaptation to scarcity and the restricted reproductive period of targeted plant resources (Ragusa-Netto 2005; Ragusa-Netto and Fecchio 2006). This flexibility in resource utilisation is crucial for coping with spatial and temporal heterogeneity (Renton et al. 2015) and may be related to the differing availabilities of these resources throughout the year, both in richness and abundance (Ragusa-Netto and Fechio 2006; Silva 2013).

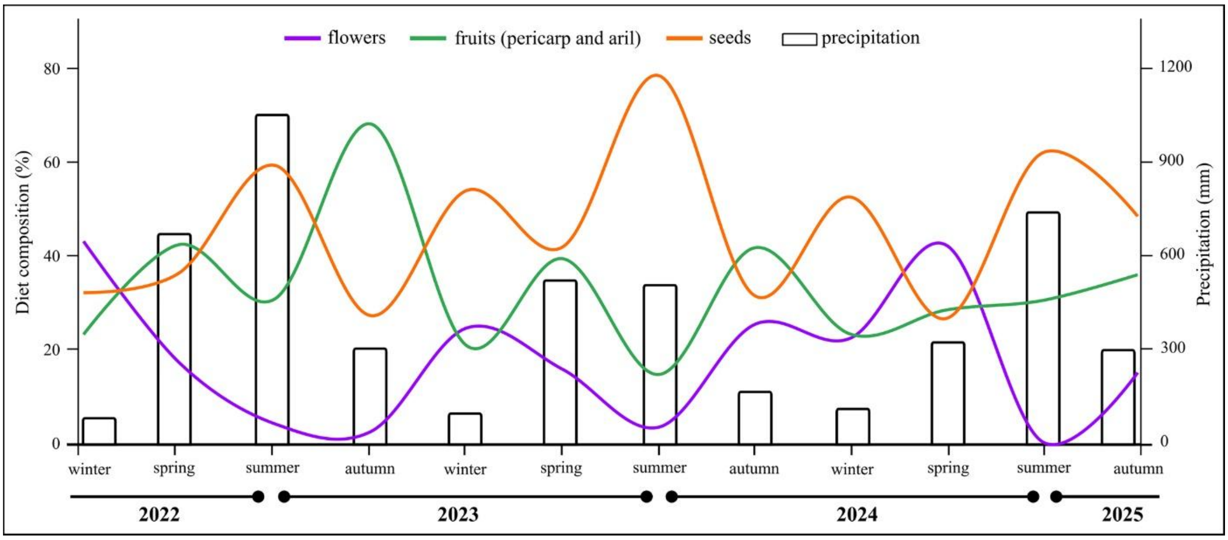


Figure 6. Percentage variation of major food resource groups exploited by six parrot species according to the climatic season and rainfall from June 2022 to May 2025, CUASO *campus*, São Paulo, SP. Chi-square-test of independence = 124.4; d.f. = 33; p < 0.0001.

Figura 6. Variação percentual de grandes grupos de recursos alimentares explorados pelas seis espécies de Psittacidae de acordo com a estação climática e pluviosidade de junho/2022 a maio/2025, *campus* CUASO São Paulo, SP. Teste qui-quadrado de independência = 124,4; g.l. = 33, p< 0,0001.

3.7 Psittacidae species origin

Schunck (2008) mentions that *A. aestiva*, *D. nobilis*, and *P. leucophthalmus* were introduced into the municipality of São Paulo through release or escape from captivity. Thus, these species would be considered "exotic" in the region. However, although generally considered non-migratory, parrots have records of long-distance movements – at least tens of kilometres – in their daily activities, such as movements from roosts to foraging sites (e.g., Whitney 1996; Sick 1997; Brightsmith et al. 2021). Therefore, it is also worth considering the possibility of natural expansion and extended distribution (see Silveira et al. 2023 for *A. aestiva*) in recent decades for at least part of the population of these three species, given the simplification of dense Atlantic Forest vegetation into semi-open areas, which is the usual habitat profile for these species (Sick 1997; Winkler et al. 2020).

4 CONCLUSIONS

This study is a valuable addition to the limited literature on urban ecology and provides a foundation for future investigations. Some research is already underway, such as assessing tree availability to determine if parrots are selective in their choice of food species. However, a wide range of avenues remains to be explored, such as bird-plant interactions, ecological networks, and the relationship between atmospheric fluctuations and dietary seasonality. Further studies could also involve an in-depth review of the functional, morphological, and biochemical attributes of both plants and parrots to explain patterns of differential consumption of plant parts. This documentation method allowed for a more faithful interpretation of the diet, as, unlike the traditional method of visual observation, it is independent of the observer's split-second perception and provided greater precision in subsequent interaction determinations. However, even with this approach, uncertainties remained in certain situations, such as whether seed ingestion involved breakage and/or digestion. Circumstances like these demand the collection of faeces from individuals consuming these seeds, which is quite challenging to perform in the field and was outside the scope of the study, but presents itself as a possibility for future studies, involving, for example, captive animals.

The research into the diet of Psittacide in CUASO suggests an adaptive plasticity of these birds to modified environments. The predominance of native plant species in the diet underscores the importance of urban afforestation projects that prioritise regional flora for biodiversity conservation, but without entirely discarding certain exotic species that can supplement the diet during periods of food scarcity (cf. Silva 2013). The identification of seasonality in resource consumption and the greater consumption of immature seeds demonstrate foraging strategies for survival in urban ecosystems. Moreover, the methodology based exclusively on photographic records establishes a standard for precision in documentation within free-living diet studies (Gaglio et al. 2017). The data can serve as a basis for the planning and management of urban green spaces (Pena et al. 2017), aiming to implement afforestation strategies that promote the conservation and well-being of psittacid populations, thereby contributing to the ecological sustainability of urban areas.

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AUTHOR CONTRIBUTIONS

Conceptualisation, J.C.M.J.; Methodology, J.C.M.J.; Identification of plant species, Y.K.; Data collection, all authors; Writing - original draft, all authors; Writing - review and editing, all authors; Supervision and project administration, J.C.M.J.; all authors read and approved this submitted manuscript.

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Appendix: Systematic list of food items consumed by Psittacidae on the CUASO *campus* with the number of feeding events and specific plant structure utilised given in parentheses. Botanical nomenclature follows Flora e Funga do Brasil (2025) and Plants of the World Online (POWO 2025). (*) exotic plants.

Apêndice - Lista sistemática de plantas e outros itens alimentares usados pelos Psittacidae no *campus* da CUASO com número de eventos e entre parênteses estrutura vegetal utilizada. A nomenclatura botânica seguiu Flora e Funga do Brasil (2025) e Plants of the World Online (POWO 2025). (*) plantas exóticas.

Food items	***A. aestiva***	***B. chiriri***	***B. tirica***	***D. nobilis***	***F. xanthopterygius***	***P. leucophthalmus***
*Acrocarpus fraxinifolius**	32 (3 Gra, 25 Nec, 3 Flo, 2 Cau)		47 (Nec)	15 (Nec)		4 (Nec)
Acrocomia aculeata	2 (Fol)					
Alchornea sidifolia				8 (Gra)		
Alchornea triplinervia				2 (Gra)		
Anadenanthera colubrina	3 (Gra)		1 (Cor)			
Anadenanthera peregrina	56 (54 Gra, 1 Cau, 1 Cor)			2 (Gra)		
*Archontophoenix cunninghamiana**			17 (Fru)	16 (1 Gra, 7 Fru, 8 Fol)		
*Bactris gasipaes**	7 (Fru)					
*Caryota urens**				1 (Fol)		
Ceiba speciosa	3 (Flo)	7 (Gra)	287 (239 Gra, 37 Nec, 6 Pal, 4 Flo, 1 Cor)	2 (1 Nec, 1 Cor)		
Cenostigma pluviosum	3 (2 Gra, 1 Fol)					
Centrolobium tomentosum			2 (Nec)			
*Chrysalidocarpus lutescens**				3 (Fru)		
Citharexylum myrianthum	6 (Nec)		17 (Nec)	4 (Nec)		
Colubrina glandulosa				2 (Gra)		2 (Gra)
*Cordia myxa**						14 (Gra)
Croton floribundus				4 (Gra)		
*Diospyros kaki**	2 (Fru)					
Enterolobium contortisiliquum	5 (Gra)					
*Eriobotrya japonica**	15 (Fru)		8 (Fru)	28 (Fru)		1 (Fru)
Eriotheca pentaphylla			6 (Gra)			
Erythrina falcata	2 (1 Nec, 1 Pal)		7 (6 Nec, 1 Pal)			10 (Nec)
Erythrina mulungu			1 (Nec)			4 (Nec)
Erythrina speciosa	3 (Gra)		34 (23 Nec, 11 Pal)			

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Food items	*A. aestiva*	*B. chiriri*	*B. tirica*	*D. nobilis*	*F. xanthopterygius*	*P. leucophthalmus*
Erythrina verna	5 (4 Nec, 1 Pal)		17 (13 Nec, 4 Pal)			
*Eucalyptus robusta**	1 (Cor)		22 (21 Nec, 1 Cor)			
Eugenia brasiliensis	3 (Fru)			6 (Fru)		
Eugenia uniflora				1 (Fru)		
*Ficus benjamina**			2 (Fru)			
Ficus cestrifolia			12 (Fru)			
Ficus guaranitica			2 (Fru)			
Ficus luschnathiana			89 (Fru)			
*Ficus microcarpa**			1 (Fru)			
Handroanthus chrysotrichus	19 (17 Gra, 1 Nec, 1 Flo)		25 (1 Gra, 19 Nec, 2 Pal, 3 Flo)	2 (Gra)		
Handroanthus heptaphyllus			26 (Nec)	1 (Cor)		
Handroanthus impetiginosus	1 (Gra)		5 (Nec)			
Handroanthus serratifolius	5 (Gra)		2 (Nec)			
*Hibiscus tiliaceus**			4 (Gra)			
*Hovenia dulcis**	93 (89 Gra, 4 Fru)		12 (10 Gra, 2 Fru)	18 (16 Gra, 2 Fru)		
Inga vera	5 (4 Gra, 1 Fru)	3 (1 Gra, 2 Nec)	77 (2 Gra, 30 Fru, 43 Nec, 2 Cor)	15 (1 Gra, 14 Fru)		2 (Fru)
*Jacaranda mimosifolia**			25 (14 Gra, 10 Nec, 1 Cor)			
*Lafoensia glyptocarpa**			5 (3 Gra, 2 Nec)			
*Leucaena leucocephala**	8 (Gra)			1 (Gra)		
*Ligustrum lucidum**				10 (Gra)		
*Livistona chinensis**	2 (Fru)			12 (2 Gra, 10 Fru)		
Lonchocarpus cultratus	1 (Fol)					
Luehea divaricata			1 (Flo)			
Machaerium nyctitans				2 (1 Gra, 1 Flo)		
*Melia azedarach**	59 (57 Gra, 2 Fru)		3 (Fru)	155 (Gra)		2 (Gra)
*Morus nigra**				23 (7 Gra, 16 Fru)	2 (Gra)	2 (Fru)

to be continued
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Food items	*A. aestiva*	*B. chiriri*	*B. tirica*	*D. nobilis*	*F. xanthopterygius*	*P. leucophthalmus*
Ocotea puberula	6 (Fru)					
Pachira glabra			45 (40 Gra, 1 Nec, 1 Pal, 1 Fol)			
Parapiptadenia rigida	3 (Gra)					
Peltophorum dubium				1 (Gra)		
*Persea americana**	1 (Fru)					
Phoradendron quadrangulare	1 (Fol)		5 (Fru)			
*Pinus elliottii**						3 (Gra)
Piptadenia gonoacantha	2 (Gra)					
*Platycladus orientalis**				2 (Gra)		
Pleroma granulosum			1 (Gra)			
Pseudalbizzia edwallii	5 (4 Gra, 1 Fol)					
Pseudobombax majus		2 (Gra)	232 (138 Gra, 85 Nec, 9 Flo)			
*Psidium guajava**	4 (1 Gra, 3 Fru)		8 (2 Gra, 6 Fru)	26 (17 Gra, 8 Fru, 1 Cor)		4 (Fru)
Psidium myrtoides				369 (303 Gra, 65 Fru, 1 Cor)		2 (Gra)
*Pyracantha coccinea**				2 (Fru)		
Rhipsalis grandiflora			2 (Fru)			
Rhipsalis teres		1 (Fru)	21 (Fru)			
Schizolobium parahyba	13 (9 Gra, 4 Cau)					
*Spathodea campanulata**	35 (33 Gra, 2 Flo)		15 (13 Gra, 2 Cor)	3 (1 Nec, 2 Exu)	1 (Flo)	
Struthanthus rhynchophyllus	17 (16 Fol, 1 Exu)					
Syagrus romanzoffiana	5 (Fru)	3 (Fru)	379 (378 Fru, 1 Nec)			6 (Fru)
*Syzygium cumini**	5 (4 Fru, 1 Cor)			17 (Fru)		
*Syzygium jambos**			2 (Fru)	10 (Fru)		
Tabebuia aurea	3 (Flo)		3 (Nec)			
*Tabebuia rosea**	1 (Cau)		15 (Nec)			

to be continued
continua

continuation – Appendix
continuação – Apêndice

Food items	***A. aestiva***	***B. chiriri***	***B. tirica***	***D. nobilis***	***F. xanthopterygius***	***P. leucophthalmus***
*Terminalia catappa**	1 (Fru)			2 (Fru)		
*Tipuana tipu**	1 (Cor)		68 (67 Gra, 1 Cor)	42 (Gra)		5 (Gra)
*Tithonia diversifolia**						2 (Gra)
Triplaris americana			2 (Gra)	35 (Gra)		
Parmotrema sp. (lichen)					2 (Fun)	
Phellinotus piptadeniae (fungus)	1 (Fun)					
Building wall				2 (Geo)		
Earth (*Furnarius rufus* nest)	1 (Geo)					
TOTALS	**446**	**16**	**1555**	**844**	**5**	**63**
GRANIVORY - Gra	303	10	544	614	2	30
FRUGIVORY - Fru	56	4	580	191		15
NECTARIVORY - Nec	36	2	379	21		18
PALYNIVORY - Pal	2		25			
FLORIVORY - Flo	12		17	1	1	
FOLIVORY - Fol	22		1	9		
EXUDATIVORY - Exu	1			2		
CAULOPHAGY - Cau	8			1		
CORTICIPHAGY - Cor	4		9	3		
FUNGIVORY - Fun	1				2	
GEOPHAGY - Geo	1			2		