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Cover: Whale Shark *Rhincodon typus* and Reef - made with poster colours. © P. Kritika.

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COMMUNICATION

Food availability and food selectivity of Sri Lanka Grey Hornbill *Ocyceros gingalensis* Shaw, 1811 in Mihintale Sanctuary, Sri Lanka

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Abstract: This study was focused on explaining food selectivity in endemic Sri Lanka Grey Hornbill *Ocyceros gingalensis* to fill the gaps in the behavioral ecology of this endemic species. The study was conducted within Mihintale Sanctuary for five months from December 2015 to April 2016. Ringed hornbills were used to monitor the number of food items that were consumed from within the Food Abundance Index (FAI) and quantify the distribution and availability of resources to examine the potential of fruit selectivity. Thirteen fruiting plant families were recorded as preferred food. Food consumption and FAI values are not significantly correlated ($r = 0.60$, $p = 0.285$). The dietary composition increased in the breeding season due to a higher requirement for nutrients by the nestlings. Nutrient analysis results revealed that moisture ($H = 7.50$, $p = 0.006$), fiber ($H = 6.53$, $p = 0.011$), and ash ($H = 6.07$, $p = 0.013$) components were significant between eaten and non-eaten fruits. The amount of all the nutrients available in the fruits as well as FAI does not directly affect the fruit selectivity of the Sri Lanka Grey Hornbill in the Mihintale Sanctuary. This fruit selection and the seed dispersal ability of the Sri Lanka Grey Hornbill contributes to maintaining the ecosystem diversity and forest regeneration, especially in the Dry Zone in Sri Lanka.

Keywords: Dry zone, FAI, food abundance index, forest regeneration, nutrients, seed dispersal ability.

Abbreviations: A—Avoidable fruits | FAI—Food abundance index | P—Preferable fruits | SLGH—Sri Lanka Grey Hornbill.

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Author contributions: IW—Field data collection, lab works, data handling, data analysis, writing, PP— Field data collection, lab works, data handling, reviewing, SW—Conceptualization, study plan, reviewing, editing and supervision.

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IDEA WILD

INTRODUCTION

During the past 27 years, 8% of the net forest cover loss has been observed in the Dry Zone of Sri Lanka (Ranagalage et al. 2018). Conserving the forest cover under this kind of situation is especially important in understanding the seasonal patterns, abundance, and distribution within ecosystems, highlighting the importance of the forest systems for conservation purposes. Plant-animal interaction is one such important example for describing interspecific relationships. Seed dispersers play a vital role in maintaining the sustainability of ecosystems. The plants within these ecosystems also benefit from highly diverse seed vectors such as birds and mammals. The strategies of fruit production and nutritional rewards must evolve to attract the greatest possible variety of seed dispersers (Snow 1981) which prefer to consume fleshy parts of the fruit (Bascompte & Jordano 2007). Most of the frugivorous birds typically swallow the whole fruit, such as *Ficus* spp. (Zach 1979), and remove the seed with the fecal matter after completing their digestive process which contributes to the process of plant seed dispersal.

Various conditions of the fruit can affect selectivity, such as nutrition, secondary compounds, palatability, digestibility; and spatial aspects of fruit display should also be taken into account (Coelho et al. 1976; Janson et al. 1986; Sourd & Gautier-Hion 1986). More than any of the above requirements, a bird or vertebrate's food can also be influenced by the changes and the stages of their lifecycle. Avian diet selection is mostly sensitive to seasonal changes in their life cycle, such as in their breeding season when they may have different behaviors in selecting fruits because the fruits are relatively deficient in minerals, which are critical for reproduction (Lamperti et al. 2014).

Hornbills are large frugivores and play an important role in dispersing seeds of the fruiting species in the tropical forests of Asia and Africa (Kitamura 2011; Corlett 2017). There are only two hornbill species in Sri Lanka—*Ocyceros gingalensis* (Sri Lanka Grey Hornbill – SLGH here onwards) and the *Anthracoceros coronatus* (Malabar Pied Hornbill). The SLGH is endemic to Sri Lanka and common in the forested areas of the low country, in both the Dry Zone and the Wet Zone (Henry & Thilo 1998). According to the National Red List of Threatened Flora and Fauna (MOE 2012) conservation status of SLGH is mentioned as Least Concern (LC).

Due to endemic status and the reducing habitats for these species, the provisional status report on biological diversity in 1989 and the subsequent revision in 1999 (IUCN Sri Lanka 2000) mentioned this species as a threatened species. The SLGH is a shy bird that lives in pairs or small flocks numbering 5–6 individuals (Legge 1880) in tall forests. In terms of breeding biology, this species requires tree cavities, and the cavities are not common in the areas of human habitations due to the absence of mature old trees (Kotagama et al. 2011; Wijerathne & Wickramasinghe 2019). Though Wimalasekara & Wickramasinghe (2014) observed and mentioned SLGH as an arboreal frugivore in the Mihintale Sanctuary, there are no records of dietary requirements during the breeding season. Due to the lack of scientific and systematic breeding biological records of this bird (Kotagama et al. 2011; Wijerathne & Wickramasinghe 2018), this study was conducted to cover both the breeding and non-breeding periods of the lifecycle specifically to highlight the food availability and selectivity patterns in the Dry Zone of Sri Lanka. The main objective of the study is to understand the patterns of dietary requirements at different stages of the lifecycle and food selection factors as with the influence of available fruiting trees in the area specially to fill up the remaining gaps in the avian ecology of the Dry Zone forests.

MATERIALS AND METHODS

Study area

The study was conducted in the Dry Zone of Sri Lanka where the mean annual rainfall is 1,200–1,900 mm (Alahacoon et al. 2021). A study plot of more than 4.0 km^2 was selected in Mihintale Sanctuary (Image 1) Anuradhapura District Sri Lanka (8.351057N & 80.51812E). This area comprises both suburban and forested areas (Image 2) where the nesting cavities and fruit bearing trees being observed are present.

Field observations

March to June was recognized as the breeding season of SLGH (Wijerathne & Wickramasinghe 2018) in the Dry Zone. The study period was selected to represent both breeding and non-breeding (post fledging) stages of the life cycle from 2015 to 2016. Nine nest cavities were identified in the study site, mostly on the periphery of the forested areas (Wijerathne & Wickramasinghe 2018, 2019). The volume of fruits (fruiting species and the number of fruits consumed from each species per observation time slot) consumed by selected individuals (ringed male hornbills during 2011 by field ornithology group of Sri Lanka) within non-breeding and breeding

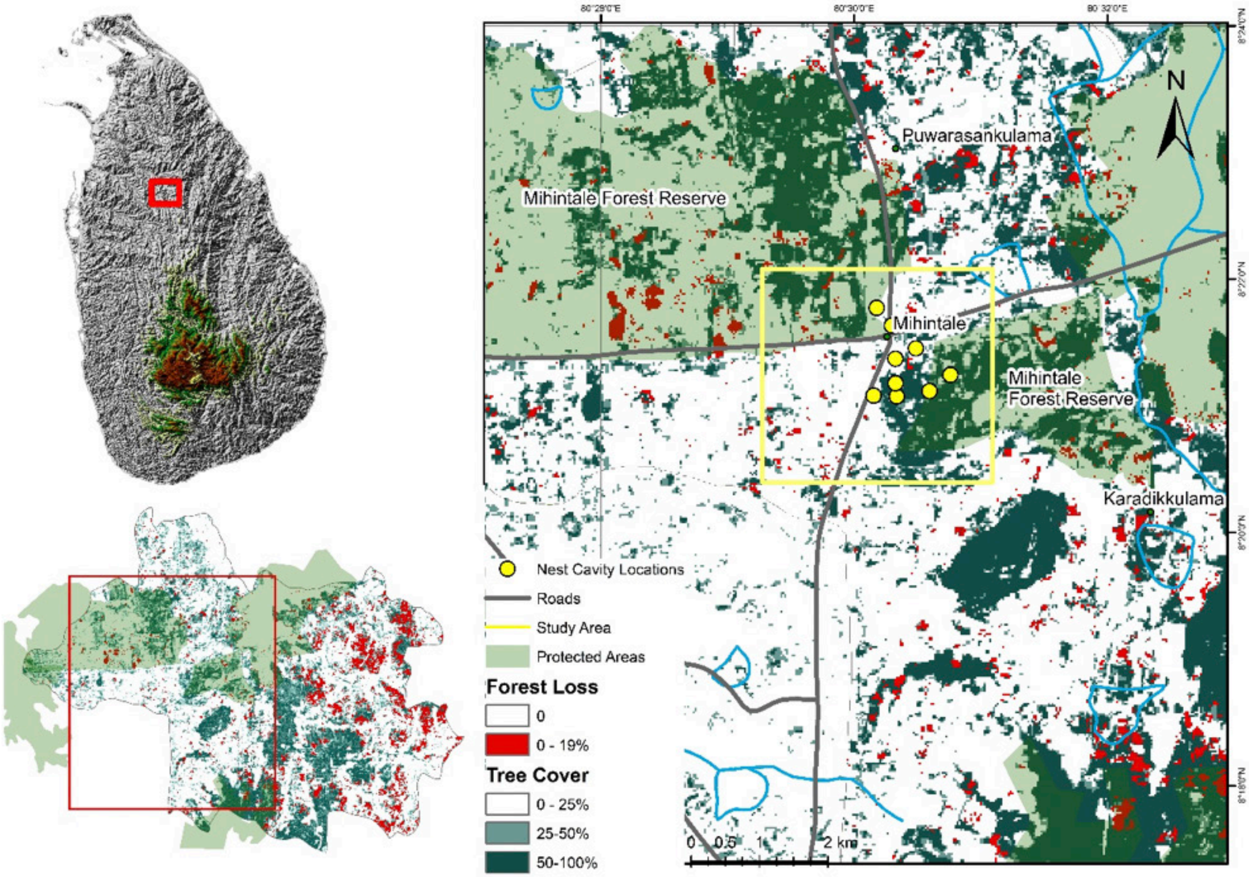

Image 1. Study area of Mihintale Sanctuary within Mihintale Divisional Secretariat (DSD).

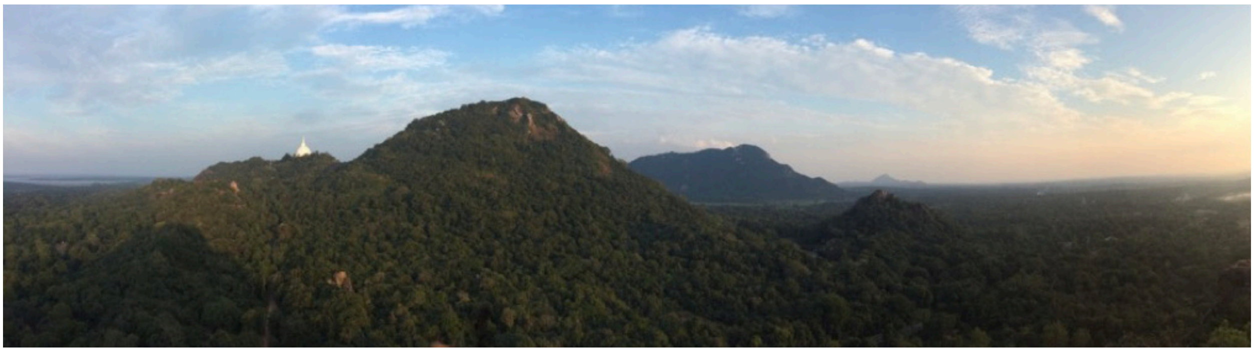

Image 2. Mihintale Sanctuary, the study site with the Dry Zone forest habitat conditions for Hornbill species.

seasons were noted using the scan sampling method (Simpson & Simpson 1977) for generating fruit selectivity (Lamperti et al. 2014) index (Krebs 1973).

Fruit availability and abundance

Floral diversity of the study site was conducted using 10 x 10m random quadrats (16) along transects lines. All the trees with DBH ≥10 cm were identified to genus level and measured. Tree heights were measured using clinometers (SUNTO code PM 5/1520), DBH (Diameter at breast height) was measured by a standard DBH meter, and basal area/ha and density of trees were calculated.

Randomly selected 20 fruiting trees were monitored from the beginning of each week to record the phenological data to produce a quantitative measure of food abundance. This set of trees included both preferred and non-preferred fruiting trees for SLGH. Tree crowns were scanned using binoculars (Bushnell 8 × 10) to observe the availability of ripened fruits and fruit abundance was determined as four classes concerning the canopy coverage 4 (100% ripened fruits present), 3 (75%), 2 (50%), 1 (25%) and 0 (0%). This criterion was based primarily on color changes indicating ripeness (Wijerathne & Wickramasinghe 2018) and was used for determining the monthly relative abundance of fruiting trees.

A food abundance index (FAI) (Anderson et al. 2005) was used to estimate the monthly food availability of each fruiting species from December 2015 to April 2016 with weekly collected phonological data.

FAI (per fruiting species) = $D_k \times B_k \times P_{km}$

D_k—Density of species k in home range (stems per ha)

B_k—Mean basal area of species k in each home range

P_{km}—Percentage of observed trees of species k that produce ripe fruits in each period.

Diet composition and quantity of food types.

Locations of nine nest cavities of SLGH were identified based on the previous studies conducted by Wijerathne & Wickramasinghe (2018, 2019). Three nests were selected from the above for frequent weekly nest feeding observations. All the observations were made between 0600–1700 h from 10 to 25 m distance from the cavities. Behavior patterns, food items, frequencies related to these, and visits of the parent birds to the cavities were recorded. Seed traps were laid under these nest cavities to collect fecal samples weekly. Dry weight of each sample was measured and seeds and other debris were separated and identified.

Food selection

Foraging ratios *(wi)* (Krebs 1973) or food selectivity index was calculated for each dietary species consumed by SLGH.

$$W_i = \frac{oi}{pi}$$

oi—percentage of species *i* in the diet

pi—percentage of species I available in the environment.

Forage ratios >1.0 indicate preference while values <1.0 indicate avoidance.

Chemical characters

Nutrient analysis of the two selected types of fruits which were observed as preferable and non-foraged by SLGH (Wijerathne & Wickramasinghe 2018) were used to test the selectivity influenced by the available nutrient capacity. Due to limitations of chemicals and equipment, all available fruits of the area could not be used for nutrient analysis. The moisture (Drying method), Ash (Dry method; Park 2016), Fat (Bligh & Dyer method; Smedes & Thomasen 2003), Protein (Kjeldahl method; Kirk 1950), and Fiber (Weende method; Williams & Olmsted 1935) content of the selected fruits were analyzed.

Analysis

R statistical package (R Team 2020) was used to analyze the data sets to compare the dietary requirements in the breeding and non-breeding seasons of the SLGH. The Kruskal-Wallis test (Kruskal & Wallis 1952) was used as a non-parametric method of analysis.

RESULTS

The number of individuals in the flocks observed within the study site varied 5–13 and they gathered mostly for foraging (Image 3a–c). The abundance of fruiting trees (Food availability index total) – there were 56 plant species belonging to 23 plant families recorded within a 4 km^2 area. Out of 23 plant families, 13 were recognized as the preferred food for the hornbills. Weekly FAI-Total varied particularly in the non-breeding season. Hence, the number of fruiting species did not influence the FAI-Total. Mean FAI-Total, including hornbill food (n = 10) and non-foraged food (n = 10) for all months, was 316192.00 ± 90613.5 (means: 269374.0 ± 59693.8 in breeding and 386418.3 ± 77045.4 in non-breeding seasons). The FAI-Total in the breeding season declined in February at the beginning and reached a peak in March, while in the non-breeding season within the observed two-month period it reached a peak in January (Figure 2a–b). Except for the month of April, all the others left skewed plots representing the lower rain conditions during the study period where the mean values were less than the median in Figure 3a, but, as per the Figure 3b, FAI for most of the same selected months show normal distribution and higher FAI in January compared to the other months. As per Figure 3c, hornbill abundance of the area varied from normal distribution in December to gradually fewer distribution in the other months. FAI was not altered significantly with rainfall (0.019, P 0.937 > 0.05, n = 20) and hornbill abundance according to the Spearman rank correlation (0.245, p 0.286 > 0.005, n = 20).

Considering the fecal sample gathered during the breeding season, the amount of averaged animal diet was 1.38%±0.59, the amount of *Ficus* spp. seeds was 31.52%±9.79 and fruit seeds and other remaining diet

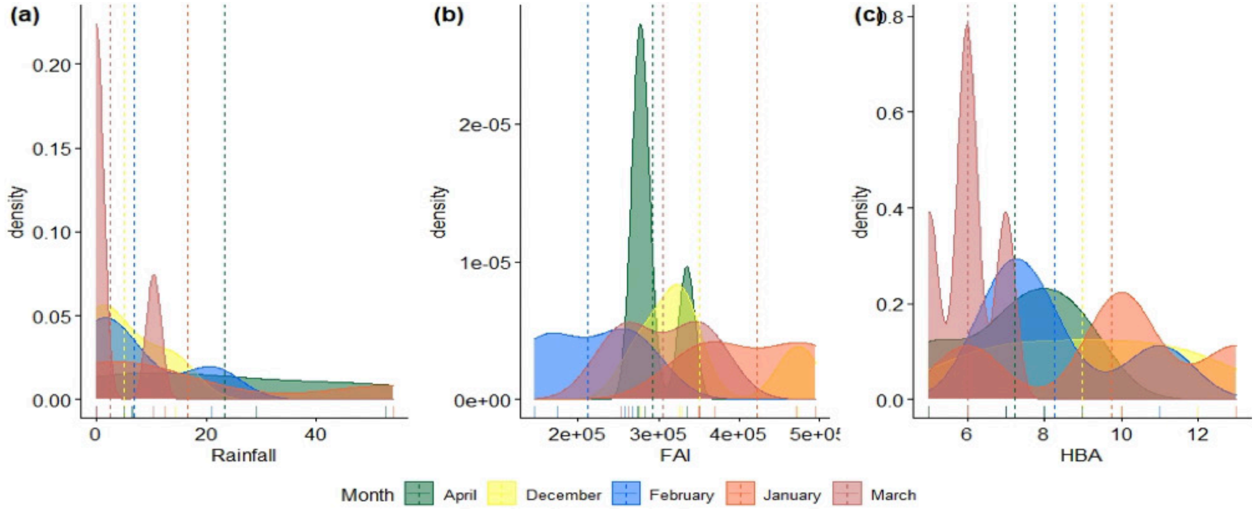

Figure 1. Dual axis plots for a—Hornbill abundance per km2 area vs the food availability index and averaged rainfall vs food availability index of the study area Mihintale sanctuary.

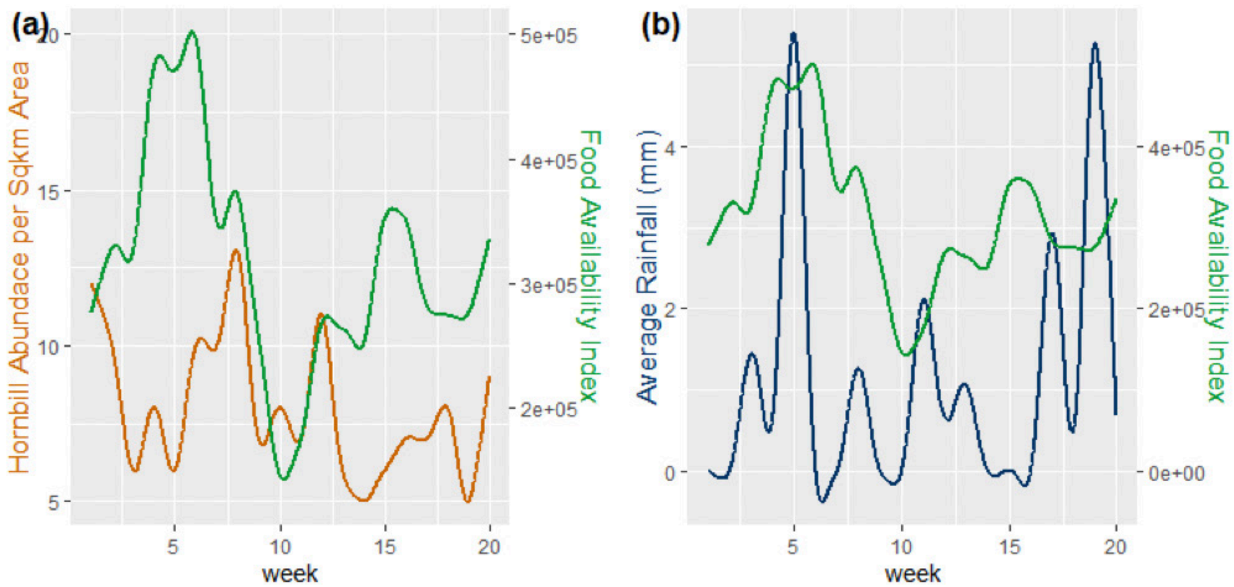

Figure 2. Density plots for: a—Rainfall | b—Food availability index | c—Hornbill abundance in Mihintale Sanctuary. Dashed lines show the mean value for each variable.

(lamp wicks and other unidentified) composition was 67.10%±10 (Figure 3).

The percentage of seeds present within the fecal matter, which was collected, and according to the visual observations during the non-breeding season showed several important plant species consumed by SLGH (Table 1). *Ficus benjamina*, *F. benghalensis*, *F. religiosa*, and *F. racemosa* were categorized into one group as *Ficus* spp. due to the difficulty of identification and separation of pulp and seed content. As high average consumption based on fecal sample analysis, *Ficus* sp. (55.85%), *Ptychosperma* sp. (6.6%), *Filicium decipiens* (12.45%), and *Manilkara hexandra* (4.5%) were recognized as the most important fruiting plant species in both seasons.

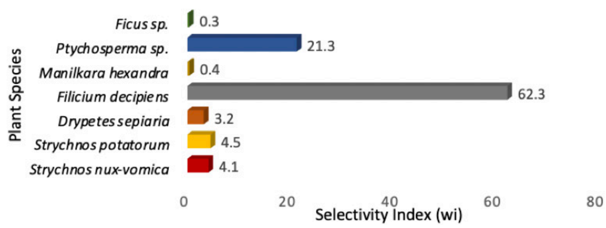

Figure 3. Selectivity index (Foraging ratio) values per seven selected fruiting plant species in the Mihintale Sanctuary.

Image 3a–c. Foraging behavior of the Sri Lankan Grey Hornbills as flocks mostly within the non-breeding season: a—Flocking behavior and foraging mostly as flocks (PC: Damindu Wijewardana) | b—Fruit sharing between coupled birds immediately before breeding starts, | c—Female bird feed on Ficus spp. © Gehan Rajeev.

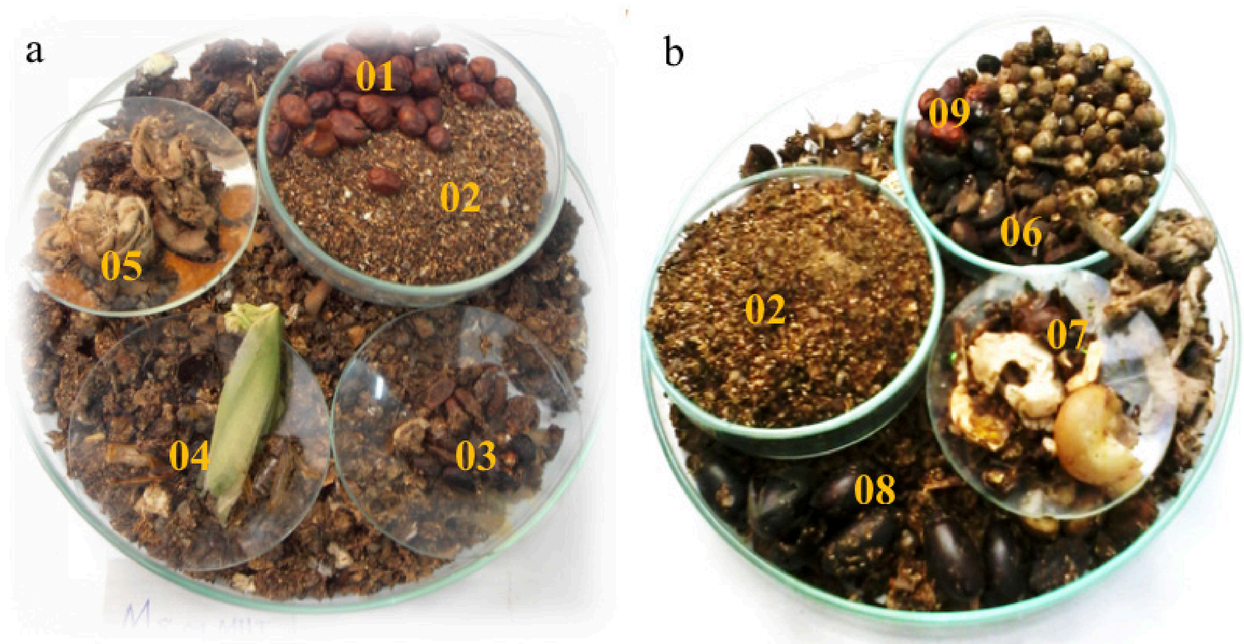

Image 4a–b. Separated fecal samples collected from seed traps during the breeding season: 1—*Ficus decipiens* | 2—*Ficus* spp. (including all types of *Ficus* spp.) | 3—*Manilkara hexandra* | 4—Wings of insects | 5—Wicks of oil lamps | 6—*Drypetes sepiaria* | 7—shells of insects and vertebrate bones | 8—*Stirculia foetida* | 9—*Ptychosperma* sp.

The food selectivity index was calculated for each consumed fruiting species following the FAI values which were calculated monthly based on selected species individually for seven selected important fruiting species (Figure 4). The highest food selectivity index shows *Filicium decipiens* (62.3) and the lowest index shows *Ficus* spp. (0.3). The *Filicium decipiens* and *Ptychosperma* sp. (21.2) were highly selected while *Ficus* spp. and *Manilkara hexandra* (4,112 m^2) were *the* least selected and represented in comparatively larger average basal areas.

There was no significant difference between nutritional components of preferred fruits and non-foraged fruits (Table 2), except for the moisture, ash, and fiber under the 0.05 significance level. According to the Kruskal-Wallis test for the 10 species for moisture (H = 7.50, p = 0.006), ash (H = 6.07, p = 0.013), & fiber (H = 6.53, p = 0.011) with significant differences, while crude lipid (H = 0.53, p = 0.465), protein (H = 0.00, p = 1.000), and carbohydrate (H = 0.30, p = 0.584) showed no significant difference between values of preferable and non-preferable. Although the results indicate that there was a relatively higher moisture content in eaten fruits than in non-eaten fruits.

Table 1. List of important fruiting species identified as foraged species of Sri Lankan Grey Hornbills according to seed sampling during breeding season and observations from the non-breeding season.

Family	Species
Arecaceae	*Ptychosperma* sp.
Boraginaceae	*Cordia monoica*
Ebenaceae	*Diospyros* sp.
Loganiaceae	*Strychnos nux vomica*
Loganiaceae	*Strychnos potatorum*
Malvaceae	*Sterculia foetida*
Meliaceae	*Azadirachta indica*
Moraceae	*Artocarpus heterophyllus*
Moraceae	*Syzygium cumini*
Moraceae	*Ficus* spp.
Moringaceae	*Moringa oleifera*
Myrtaceae	*Psidium guajava*
Putranjivaceae	*Drypetes sepiaria*
Rhamnaceae	*Ziziphus oenopolia*
Sapindaceae	*Schleichera oleosa*
Sapindaceae	*Filicium decipiens*
Sapotaceae	*Manilkara hexandra*

DISCUSSION

Hornbills gather as groups mostly for foraging. They are usually frugivorous (Kitamura 2011), and seemingly depend on a fruiting diet throughout the year. They have an important ecological role, contributing to forest ecosystems as frugivorous and as seed dispersers by defecating most of the seeds of the plants away from the parental plants (Kitamura 2011). This frugivory is one of the essential processes for plant populations for the dispersal, especially when plant regeneration is strongly dependent on seed dissemination by zoochory (Armesto & Rozzi 1989; Aizen et al. 2002; Cousens et al. 2008; Moran et al. 2009). Three categories of frugivory are described in literature according to the habit of taking fruit: (1) legitimate seed dispersers: swallow the whole fruit, defecating or regurgitating the intact seed (endozoochory); (2) pulp consumers: peck fruits to obtain the pulp, dropping the seed; and (3) seed predators: feed on the seeds, eliminating fruit pulp or swallowing fruits, and digesting the whole content (Jordano 1987; Aizen et al. 2002; Bascompte & Jordano 2007). These species have all types of zoochronous

Table 2. Summary of nutritional values presence within the preferable food and non-eaten food of Sri Lanka Grey Hornbills.

	Moisture (g%)	Crude lipid (g%)	Protein (g%)	Ash (g%)	Fiber (g%)	Carbohydrate (g%)
Preferable (n = 6)						
N	6	6	6	6	6	6
Minimum	58.7	0.352	0.88	0.33	18.75	1.2
Maximum	64.5	7.09	4.03	2.9	34.37	5.2
Mean	61.1	2.8	2.7	1.4	30.5	2.2
SD	2.1	2.2	1.1	0.8	5.5	1.5
Non-preferable (n = 5)						
N	5	5	5	5	5	5
Minimum	2.1	2.2	1.1	0.8	5.0	1.5
Maximum	61.1	5.0	5.0	5.0	30.5	5.0
Mean	13.6	2.0	1.8	1.4	8.2	1.7
SD	27.2	1.2	1.6	1.9	11.9	1.5

*Preferable—*Manilkara hexandra*, *Strychnos nux-vomica*, *Strychnos potatorum*, *Filicium decipiens*, *Drypetes sepiaria*, *Ptychosperma* sp.
*Non-preferable—*Durantha repens*, *Phyllanthus emblica*, *Tamarindus indica*, *Ziziphus oenopyrs*, *Phyllanthus reticulatus*.

Image 5a–h. Foraging behavior of the Sri Lankan Grey Hornbill during the breeding period for nourishing the prisoned family members inside the cavity: a—Carrying a grasshopper | b—spying around the cavity before feeding with a long-horned insect | c—waiting to feed with a fruit to the nesters | d—carrying juvenile bird as a diet | e—carrying an insect | f—female starts feeding juveniles at the end of nesting period | g—carrying a fruit by male | h—carrying an insect diet by male. © Gehan Rajeev.

Image 6. Ripe fruit species used for the nutrient analysis: *P*—Preferable | *A*—(Avoidable) fruit species.

behaviors mentioned above throughout their life cycle but, dietary composition varies due to the stages of their life cycle.

The breeding cycle of SLGH normally includes pre-laying, laying, incubating, and nesting periods. They start nesting in the period March–April (Wickramasinghe et al. 2018; Wijerathne & Wickramasinghe 2018, 2019) where a high FAI index was observed during the study period. But also, these FAI could have been affected by the changes of the climate specially the rainfall.

The selectivity index was calculated directly from the foraged dietary composition, seasonal available fruiting species and the nutrient requirements. Other influential factors were neglected such as potential for competition for resources by other evolutionary closely related species like the Malabar pied hornbills (Gonzalez et al. 2013) which occupy similar ecological niches (MacArthur 1958) in mostly the same geographical distribution.

Considering the selectivity index *Ficus* spp. species didn't perform high in the selectivity index with the availability throughout the year. Due to their asynchronous fruiting, *Ficus* species were considered a keystone plant resource, defined as a reliable food that plays a prominent role in sustaining frugivores through periods of general food scarcity. But this prominent behavior of *Ficus* spp. can be depleted during general periods of food productivity when other species are fruiting abundantly (Lambert & Marshall 1991). The results provide evidence that figs in Mihintale Sanctuary are consumed by the hornbills during both breeding and non-breeding periods. Besides, throughout the breeding season, all the fig species (Image 5a–l) are shown to be the most important in the diet every month for SLGH.

Manilkara hexandra like species bearing high selectivity index but due to seasonal ripening reduce the availability. There are 13 fruiting plant families, out of a total of 23 species present within the area, which are preferred by hornbills. According to the analysis of the FAI, rainfall, and hornbill abundance within the area do not depend on each other. With the effect of climate change, rainfall patterns have changed. Lacking sufficient rainfall at the correct time directly impacts fruiting phenology (Dunham et al. 2018) and fruits ripened earlier than expected. But, the abundance of the flocks does not vary much and fluctuated around a constant range within the study period. Fruit nutrition characteristics of the plant during breeding and non-breeding season are similar, but the nutritional content of eaten and non-eaten food is not similar (Table 2) because hornbills tend to select those fruits with a greater moisture content over those lower moisture fruits. According to the results though the birds should consume less water content to reduce their body weight for flying (Carmi et al. 1992), due to the difficulties that they face with the consumption of water, they tend to consume highly moist fruits to fulfill the moisture requirements of the body. Also, they prefer to have fruits with high fiber and ash content. SLGH fulfills most of the protein requirements of an animal diet (Image 4a–h). Protein demand is very high during the breeding season (Poonswad et al. 2004). Due to the growing requirement of nestlings, SLGH's highest amount of protein provisioning was through the animal's diet and contained both vertebrates and invertebrates. The insect diet supplied particularly good percentages and is a good source of protein. The fecal materials collected from the nesting sites showed carapaces, parts of insects and appendages, mollusk shells, bird bones, feathers, and scales of lizards. *Calotes calotes*, *Schwarzerium* spp. (long-horned beetles) were the most preferred protein-rich diet and were found within the fecal materials (Average 1.38% ± 0.59 from fecal materials) most frequently.

The diversity of fruiting trees within the Mihintale Sanctuary is comparatively high where preferable fig items are present in both forested and adjacent forest boundaries (home gardens). Also, there is no correlation between food availability and selectivity as observed during the study period, which can be used to predict that there is minimum limitation for food selectivity in the Mihintale Sanctuary. The selection of food items by SLGH was directly influenced by the seasonal requirements of lifecycle and they are the largest omnivorous birds present in Sri Lanka. The influence of the morphological characteristics of the food items, changes in the dietary requirements of the lifecycle, and changes in the secretions of the endocrine system are likely factors for the selection of food by these birds and are recommended for further study to gain a better understanding of the physiological and ecological relationships of these birds for conservation across the entire ecological systems.

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