Foraging behavior of Purple-rumped sunbird (*Leptocoma zeylonica*) and Long-billed sunbird (*Cinnyris lotenius*) in selected habitats in Kandy district, Sri Lanka

N. Perera and C.S. Wijesundara

Highlights

- Occurrence of sunbirds depends on the plant composition and human activities
- Feeding activities of the Long-billed and Purple-rumped sunbirds show a significant difference due to the difference in their body size
- Long-billed sunbird foraging strategies have a significance with glucose concentration of flowers
- Purple-rumped sunbird foraging strategies have a significance with flower morphology: corolla length and flower count

RESEARCH ARTICLE

Foraging behavior of Purple-rumped sunbird (*Leptocoma zeylonica*) and Long-billed sunbird (*Cinnyris lotenius*) in selected habitats in Kandy district, Sri Lanka

N. Perera and C.S. Wijesundara

Department of Zoology, Faculty of Science, University of Peradeniya, Peradeniya, Sri Lanka.

Received: 24/10/2019; Accepted: 25/06/2020

Abstract: Sunbirds (Passeriformes: Nectariniidae) are small passerines that feed largely on nectar. The aim of this work was to study the occurrence of sunbirds in different habitats, to observe and describe their activity frequencies, to observe the relationship of the Long-billed sunbird *Cinnyris lotenius* and Purple-rumped sunbird *Leptocoma zeylonica* with their host flowers, and to examine their behavioral relationships with the colour of the flower, flower count, nectar glucose concentration and the length of corolla of flowers. The study was carried out in five different habitat types in the Kandy district, Sri Lanka: a forest reserve, home garden habitats at two widely separated locations, a roadside habitat, and a botanical garden. The study was carried out between March and September 2013. Results show that during the day, sunbirds spent most of their time in foraging than in acquiring food. In the study, 21 different plants were recognized as nectar feeding plants for sunbirds. The number of visits by sunbirds did not depend on the plant species or the colour of the flower. The results also indicated that the correlation between the flower count and the occurrence of the Long-billed sunbird was not significant. However, there was a significant correlation between the flower count and the occurrence of the Purple-rumped sunbird. Furthermore, there was a significant correlation with the glucose concentration and the occurrence of the Long-billed sunbird; whereas no such correlation between the glucose concentration and the occurrence of Purple-rumped sunbird. There was no significant correlation with the length of corolla and the occurrence of the Long-billed sunbird, but there was a significant correlation in occurrence of Purple-rumped sunbird and the length of corolla. These correlations are due to the difference in their body size and bill length. The difference in feeding plants is due to their bill length and that allows both of them to share a common habitat.

Keywords: Sunbirds; occurrence; behavior; correlation; habitat.

INTRODUCTION

Animals need to make appropriate resource and time allocation choices because those can directly affect their survival and reproduction. Resource and time allocation strategies associated with foraging for food can strongly affect an animal's fitness (Stephens and Krebs, 1986). An animal's foraging strategy is the product of the individual's energy requirements and the nature of the environment which they inhabit (McNamara and Houston, 1986). Foraging strategies can be either short term strategies (e.g. seasonal) or long-term strategies (e.g. annual or across a

lifetime) (McNamara and Houston, 2008; Arthur *et al.*, 2016). Birds are unique among terrestrial animals when examining foraging decisions because they forage in a three-dimensional environment, moving both vertically and horizontally in search of food (Kooyman, 2012). Small birds must balance energy intake and expenditures over relatively short time periods (Calder and Booser, 1973; Carpenter, 1974; Wolf, 1975). Intake of energy depends on quality and quantity of available resources whereas energy expenditure depends on foraging time and metabolic costs for other activities.

Sunbirds (Nectariniidae) are Old World ecological equivalents of hummingbirds (Wolf, Hainsworth and Gill, 1975). They are often brightly colored with iridescent plumage and have short, long, and markedly curved bills. They are highly vocal, sing chattering songs, and often call between feeds. Sunbirds feed primarily on nectar and small insects (Burton and Burton, 2002).

Three sunbird species have been recorded from Sri Lanka, i.e. Purple-rumped sunbird (*Leptocoma zeylonica*), Purple sunbird (*Cinnyris asiaticus*), and Long-billed sunbird (*Cinnyris lotenius*) (Clements Checklist, 2019). Of these, only the Purple-rumped and Long-billed sunbirds can be seen in the Kandy District (Harrison, 2011). Even though feeding ecology of hummingbirds (e.g. Ruby-throated hummingbird *Archilochus colubris* (Norris, Connell and Johnston, 1957) and some of the sunbirds (e.g. Orange-breasted Sunbird *Anthobaphes violace* (Rebello and Siegfried, 1985; Heystek *et al.*, 2014), Bronzy Sunbird *Nectarinia kilimensis*, Malachite Sunbird *Nectarinia famosa* (Wolf, Hainsworth, and Gill 1975) are being recorded, the feeding ecology of Purple-rumped and Long-billed sunbirds in Sri Lanka is not well known. A variety of bird characteristics that relate to energy expenditure such as body size and ability to extract nectar from flowers influence the total foraging time of hummingbirds and sunbirds (Wolf, Hainsworth and Gill, 1975). The ability of extracting nectar from flowers largely depend on bill length relative to corolla length (Wolf, Hainsworth and Gill, 1975).

Foraging choices of animals depend on different polymorphic traits of plants (Heystek *et al.*, 2014). Nevertheless, plant traits manipulate animal behaviors and choices of animals as well (Heystek *et al.*, 2014). Flower

*Corresponding Author's Email: chamindaw@sci.pdn.ac.lk

color is a very commonly studied plant trait that has a large impact on driving animal behaviors (Schemske and Bierzychudek, 2007). Response of animals to color of a flower depend on their learned preferences and their sensory system (Chittka, Thomson and Waser, 1999). Animals forage optimally by selecting best nectar source through the trade-off between floral advertisement and nectar reward (Montgomerie, Eadie and Harder, 1984). Animals might also have inconsistent preferences depending on flower abundance (M. Eckhart *et al.*, 2006) and nectar properties (Niovi Jones and Reithel 2001).

As nectar is an important part of the diet of sunbirds, flower abundance, floral color, flower morphology and nectar properties may affect their feeding behavior (Wolf, Hainsworth, and Gill, 1975). Since foraging behavior of sunbirds in Sri Lanka is poorly explored (Perera and Wijesundara 2013), the aim of this study was to gather information on the feeding ecology of sunbirds. In this study, we are testing the prediction that flower abundance, flower morphology, colour of the flower and nectar properties affect the foraging behavior of sunbirds using Long-billed sunbird *Cinnyris lotenius* and Purple-rumped sunbird *Leptocoma zeylonica*. Conversely, the null hypothesis for this study was that the flower abundance, flower morphology, colour of the flower and nectar properties does not affect the foraging behavior of sunbirds. Specifically, we are addressing whether two species of sunbirds of interest have different foraging behaviors in terms of measurable parameters such as 1) flower abundance 2) colour of the flower 3) flower morphology (corolla length) 4) nectar properties (glucose concentration). These questions were addressed by collecting data on five different sites in Kandy district, Sri Lanka.

MATERIALS AND METHODS

Study species 1: The Purple-rumped sunbird is native to Bangladesh, India, Myanmar, and Sri Lanka. Local race of Purple-rumped sunbird (*Leptocoma zeylonica zeylonica*) is endemic to Sri Lanka (Clements Checklist, 2019). Its global and local populations have not yet been quantified, but the species is described as common (Mann and Cheke, 2010). The population is suspected to be stable in the absence of evidence for any declines or substantial threats (BirdLife International, 2018). It is categorized under least concern in the IUCN Red List (Weerakoon and Gunawardena, 2012). In Sri Lanka, the Purple-rumped sunbird can be often seen in well-wooded home gardens, cultivations, and open forests in all areas except the high mountains (Harrison, 2011). The sexes differ in their plumages.

Study species 2: Long-billed sunbird, the largest of local sunbirds (14.14 cm), has a much longer down-curved bill than other sunbirds (Harrison 2011). The local race of Long-billed sunbird (*Cinnyris lotenius lotenius*) is endemic to Sri Lanka. It is common in open areas with trees in the low country and lower hills, and avoids deep forests. It is less frequent in high hills to 2000 m (Harrison, 2011). Although the species is described as generally common, the global population size has not been quantified. The population is considered to be stable as there is no evidence for any declines or significant threats (BirdLife International,

2018). It is categorized under least concern in the IUCN Red List for Sri Lanka (Weerakoon and Gunawardena, 2012).

Data were collected using continuous focal sampling method (Altmann, 1974; Martin, Bateson and Bateson, 1993) between March 2013 and September 2013 in the Udawattakele Forest Reserve (7°17'58"N 80°38'20"E), a garden habitat in the campus of the University of Peradeniya (7°25'94"N, 80°59'74"E), a road side habitat at Doluwa (7°16'72"N, 80°55'42"E), and a home garden habitat at Gampola. (7°16'72"N 80°55'42"E) (Figure 1). In each site, the focal individual was observed from a single point of observation. On a given day, Long-billed sunbird's behavior was observed during the first hour of observations and then the Purple-rumped sunbird's behavior was observed in the next hour. On the next day, the Purple-rumped sunbird was observed during the first hour followed by the Long-billed sunbird's behavior in the next hour. This pattern of observation was consistent for the duration of the study period. For observing birds, a pair of 10 × 50 Bushnell binoculars was used. Observations were carried out mostly in the morning hours when sunbird activity was relatively high. At each site, total of 1500 minutes was spent observing bird behavior; both Purple-rumped sunbird and Long-billed sunbird throughout the study period.

Their activities were recorded by verbal descriptions of behavior dictated to a digital audio recorder. Later they were transcribed on to check sheets. The cumulative time of the focal individual in view was recorded using a stopwatch. Bird behaviors were categorized as hopping, perching, probing, hovering, piercing, interspecific aggressive, intraspecific aggressive, preening, flitting, and rubbing (Remsen Jr and Robinson, 1990).

Plant species which sunbirds visited were identified using a field guide (Vlas and Vlas-De Jong, 2008) from parts of plants (flowers, leaves, fruits) that were collected. The flower count was estimated using a photographic method (Adamsen *et al.*, 2000; Crimmins and Crimmins, 2008). First, a photograph of the plant was taken using a Canon 60D digital camera. Then the photo was divided in to 2×2 cm grids and the flowers were counted in 20 grids which were selected using the simple random sampling method. Finally, the number of flowers in the whole tree was estimated. Several images were examined manually to determine the optimal number of flowers of the plant. Behavior of sunbirds was observed only in the visible parts of the tree. Hence the flowers that were not visible in the photograph were not considered for sampling.

The glucose concentration of flower nectar was measured using a model GU Accu-Chek Active glucose meter, on each day of observations. Glucose concentration was measured in 10 randomly selected flowers of the same species per day and the average was obtained. When the glucose concentration was higher than the value that could be measured from the meter, a drop of nectar was taken on to a glass slide and it was diluted to a known factor using distilled water and the reading was obtained. Later, the exact concentration was estimated by calculations.

Figure 1: Locations of study sites in Kandy District, Sri Lanka.

Length of flower corolla of feeding plants was measured using a venire caliper. Average of flower corolla length in five randomly selected flowers of the same species was measured each day.

Data analysis

Total time of focal individuals in view was added up together combining all sample days. Then the occurrence of the Long-billed and Purple-rumped sunbirds at each site was obtained from the ratio of the total time the focal individual was in view to the total time of observation (all sample units combined).

Occurrence of sunbird =

$$\frac{\text{Total time focal individuals in view}}{\text{Total time of observation}} \times 100\%$$

To find the relationship between the number of visits by sunbirds and the plant species, the Friedman test was used. Friedman test was also used to find the relationship between the number of visits by sunbirds and the flower color. To find the correlation with the number of visits by Long-billed and Purple-rumped sunbird with flower count, nectar glucose concentration, and the flower corolla length, the ranked Pearson correlation test was conducted using Minitab software.

RESULTS

The Long-billed and Purple-rumped sunbirds were in view for different time periods of the study time. At the garden habitats at the University of Peradeniya, the Long-billed and Purple-rumped sunbirds were in view approximately for a similar time period during the total observation time (Long-billed and Purple-rumped sunbird 29.33% and 21% respectively). However, at the road side habitat Purple-rumped sunbirds were in view for a larger part of the total observation period (Long-billed and Purple-rumped

sunbird 2.93% and 12.73% respectively), and at home garden habitat at Gampola, Long-billed sunbirds were in view for most of the observation time (Long-billed and Purple-rumped sunbird 33.8% and 1.6% respectively). At Udawattakele Forest Reserve, sunbirds were not observed although their calls were recorded (Figure 2).

The frequencies of categorized activities varied with the study site. The most frequent activity of sunbirds (both Long-billed and Purple-rumped sunbirds pooled) at garden habitat at University of Peradeniya was hopping (12.45 hopping per minute) followed by probing (8.65 probing per minute) (Figure 3).

Although hopping was more prominent at garden habitats in the University Campus (both Long-billed and Purple-rumped sunbirds pooled), probing activity (9.87 probing per minute) was more frequent than hopping (9.28 hopping per minute) at the roadside habitat. Some activities such as interspecific aggressive behaviour were not shown by the sunbirds at the roadside habitat (Figure 4).

In the home garden habitat at Gampola, hopping (12.06 hopping per minute) was the most frequent activity, followed by probing (6.14 probing per minute) (both Long-billed and Purple-rumped sunbirds pooled). It was also observed that activities such as interspecific and intraspecific aggressive behaviours were shown only by the Long-billed sunbirds, but not the Purple-rumped sunbirds (Figure 5).

The F-test showed that the sample variances were equal (F-value = 0.83; P-value = 0.555; DF = 41). The T-test showed that there was a significant difference between the frequency of feeding activity of Long-billed and Purple-rumped sunbirds (T-value = 3.71; P-value < 0.001 ; DF = 82).

In this study, 12 different plant species were identified as plants used by sunbirds for nectar feeding (Table 1).

Figure 2: Occurrence of sunbirds at different sites (LBSU= Long-billed sunbird, PRSU= Purple-rumped sunbird, UFR=Udawattakele Forest Reserve, UOP=Garden habitats at University of Peradeniya, RSH=Roadside habitat, Doluwa, HGH=Home garden habitat, Gampola).

Figure 3: Frequencies of different activities at Garden habitats at University of Peradeniya (LBSU_F= Long-billed sunbird Female, LBSU_M= Long-billed sunbird Male, PURS_F= Purple-rumped sunbird Female, PURS_M= Purple-rumped sunbird Male, Hop= Hopping, Perch= Perching, Prob= Probing, Hover= hovering, Pierce= Piercing, Inter A= Interspecific aggression, Intra A= Intraspecific aggression, Preen= Preening, Flit= Flitting, Rub= Rubbing the beak).

Figure 4: Frequencies of different activities at Road side habitat, Doluwa (LBSU_F= Long-billed sunbird Female, LBSU_M= Long-billed sunbird Male, PURS_F= Purple-rumped sunbird Female, PURS_M= Purple-rumped sunbird Male, Hop= Hopping, Perch= Perching, Prob= Probing, Hover= hovering, Pierce= Piercing, Inter A= Interspecific aggression, Intra A= Intraspecific aggression, Preen= Preening, Flit= Flitting, Rub= Rubbing the beak).

Figure 5: Frequencies of different activities at Home garden, Gampola (LBSU_F= Long-billed sunbird Female, LBSU_M= Long-billed sunbird Male, PURS_F= Purple-rumped sunbird Female, PURS_M= Purple-rumped sunbird Male, Hop= Hopping, Perch= Perching, Prob= Probing, Hover= hovering, Pierce= Piercing, Inter A= Interspecific aggression, Intra A= Intraspecific aggression, Preen= Preening, Flit= Flitting, Rub= Rubbing the beak).

The Friedman test showed that the feeding plant species visited by the two species of sunbirds were not significantly different (Friedman coefficient = 0.014; P -value = 0.705). The Friedman test also showed that the number of visits of the two species of sunbirds were not significantly different when considering the colour of the flower (Friedman coefficient = 0.200; P -value = 0.655).

Pearson correlation test showed that there was no significant correlation between the flower count and the number of visits by the Long-billed sunbird (Pearson correlation coefficient = 0.082; P -value = 0.500). However, the Purple-rumped sunbird's visits had a significant correlation with the flower count (Pearson correlation coefficient = 0.293; P -value = 0.014).

There was a significant correlation between the number of visits made by the Long-billed sunbird and the nectar glucose concentration (Pearson correlation coefficient = 0.267; P -value = 0.025). However, there was no significant correlation between the number of visits made by the Purple-rumped sunbird and the nectar glucose concentration (Pearson correlation coefficient = 0.175; P -value = 0.148).

A correlation test showed that there was no significant correlation between the number of visits by the Long-billed sunbird and the length of corolla of flower (Pearson correlation coefficient = -0.173; P -value = 0.153). However, the correlation of number of visits by Purple-rumped sunbird with the length of corolla of flower was significant (Pearson correlation coefficient = -0.415; P -value < 0.001).

DISCUSSION

From the results, it shows that the niches of Long-billed and Purple-rumped sunbirds are overlapping. Although they have similar food preferences, the resources have been partitioned due to their morphological characters. To verify the results obtained from this study, further studies can be carried out, at different habitats with different food

plant compositions. According to (Brown, Calder, and Kodric-Brown, 1978), community patterns which reflect the effects of body size on competition among nectarivores and on plant-pollinator specificity are particularly evident in nectar feeding birds. Several nectar feeding birds that coexist in the same habitat usually differs in body size and they subdivide the bird-pollinated plants on the basis of size (Brown, Calder and Kodric-Brown, 1978). This minimizes interspecific competition for nectar.

The occurrence of bird species correlates with vegetation structure (Roth, 1976; Finch, 1989). Temperature and environmental gradient associated with elevation are the other factors that determine the occurrence of bird species (Waterhouse, 2002). Also, the species diversity and community development depend on the abundance and variety of resources and their ability of utilizing them (MacArthur 1984). Although the amount and type of forest attributes change with elevation, other factors such as temperature and forage productivity also influence the distribution patterns of birds (Waterhouse, 2002). The foraging time budgets also vary in relation to energy requirements, territory quality, and food availability or quality (Gill and Wolf, 1975).

Occurrence of sunbirds in general differed in study sites. Food resource availability and resource distribution play an important role in species occurrence (Bled, Alatawi and Belant, 2019). In addition to that human activities (urban development and road network) are considered to have a greater effect on species occurrence (Ellis, 2013; Chapin Iii *et al.*, 2000; Bled, Alatawi, and Belant, 2019; Blas *et al.*, 2016). Surprisingly, sunbirds were not observed at Udawattakele forest reserve even though they were heard, implying that sunbirds were present, but not seen. Due to the thick forest cover, sun exposure has reduced and therefore, the number of food plants for sunbirds is less. Hence, low occurrence of sunbirds at Udawattakele forest

Table 1: Food plants of sunbirds (+ indicates present, - indicates absent) (UFR= Udawattakele Forest Reserve, UOP= Garden habitats at University of Peradeniya, RSH= Roadside habitat, Doluwa, HGH= Home garden habitat Gampola, RBG=Royal Botanical Gardens, Peradeniya).

Plant species	Common name	Family	Colour	UFR	U O P	R S H	H G H	R B G
<i>Hamelia patens</i>	Fire bush	Rubiaceae	Orange	-	+	-	-	+
<i>Thunbergia erecta</i>	Bush clock-vine	Acanthaceae	Purple	-	+	-	+	-
<i>Ixora coccinea</i>	Jungle flame	Rubiaceae	Orange	-	+	-	+	-
<i>Pyrostegia venusta</i>	Flame-vine	Bignoniaceae	Orange	-	+	-	+	+
<i>Caesalpinia pulcherrima</i>	Peacock flower	Caesalpinaceae	Yellow	-	+	-	-	+
<i>Hibiscus rosa-sinensis</i>	Shoe-flower	Malvaceae	Red	-	+	-	+	-
<i>Graptophyllum pictum</i>	Caricature plant	Acanthaceae	Purple	-	+	-	-	+
<i>Amherstia nobilis</i>	Pride of Burma	Caesalpinaceae	Red	-	+	-	-	-
<i>Jacaranda mimosifolia</i>	Fern tree	Bignoniaceae	Purple	-	+	-	-	-
<i>Bauhinia variegata</i>	Spring orchid tree	Caesalpinaceae	Purple	-	+	-	-	-
<i>Tecoma stans</i>	Yellow trumpet flower	Bignoniaceae	Yellow	-	+	-	+	-
<i>Odontonema tubiforme</i>	Scarlet firespike	Acanthaceae	Red	+	-	+	-	+

reserve. Since sun exposure is higher at the forest edge, sunbird activity could have been observed by the forest edge (Proesmans *et al.*, 2019). While this study unable to test this hypothesis, it could be done as a future direction. Since frequent presence of motorized vehicles has an increased anthropogenic impact on the presence of birds, sunbirds were observed relatively in low numbers at the roadside habitat. Conversely, sunbirds were observed more frequently at the garden habitat at University of Peradeniya owing to the fact that the food resources are concentrated in one spot.

Occurrence of two sunbird species also differed in study sites. Upon adequate resources Purple-rumped sunbirds' and Long-billed sunbirds' niches have overlapped at the garden habitat at University of Peradeniya. Hence their occurrence is approximately similar. Plant composition at the roadside habitat favours the occurrence of Purple-rumped sunbirds whereas plant composition at home garden habitat in Gampola favours the occurrence of Long-billed sunbirds.

Hopping is the most frequently used activity of sunbirds when searching for food among different flowers. Also, they use flitting activity when searching for food. Therefore, it can be implied that they use much of their time in searching food than acquiring food. Interspecific and intraspecific competition may force the individual to spend most of its time in search of food (Toledo and Moreira, 2008). Also, the availability and distribution of resources and the nutritive value of the nectar may affect the time spent on searching. Proteins are rich in amino acids which are a necessary element for many biological functions. This cannot be supplied alone by nectar. Nectar is rich in sucrose and is a better source of energy than proteinaceous sources. Another important factor is that nectar passes more rapidly through the digestive tract (Roxburgh and Pinshow, 2002) with a higher rate of assimilation (Wolf, 1975). These factors explain the greater number of visits in search of nectar. This compensates for the cost of obtaining it.

The high metabolic rate and their small size necessitate almost constant searches of food (Mann and Cheke, 2010). A bird must forage longer each day to maintain its 24-h energy balance when its rate of net caloric gain is lower (Wolf 1975). Accumulating adequate reserves to cover overnight energy expenditures is especially important in daily foraging effort (King 1972).

At the garden habitats of University of Peradeniya, sunbirds show aggressive behaviour towards the individuals of the same species and the individuals of the other species of sunbird and the Oriental white-eye (*Zosterops palpebrosus*). However, at the roadside habitat, the Purple-rumped male sunbird was observed showing aggressive behaviour towards the individuals of the same species. At the home garden habitat in Gampola, the Long-billed male sunbird had shown aggressive behaviour towards the individuals of the same species and towards the individuals of other species such as Pale-billed flowerpecker (*Dicaeum erythrorhynchos*), Oriental white-eye (*Zosterops palpebrosus*), and Red-vented bulbul (*Pycnonotus cafer*). At the University, the occurrences of both Long-billed and Purple-rumped sunbirds are almost

similar and therefore interspecific competition can be seen. They defend their food territory by chasing the individuals of the other species. Since there was more than one pair of birds in the area, sunbirds also showed aggressive behaviour towards the individuals of the same species.

At the roadside habitat, Purple-rumped sunbirds were more abundant. Therefore, intraspecific aggressive behaviour was prominent. Nectar producing flowers are often defensible because they are renewable resources (Gill and Wolf, 1975). Hence sunbirds defend their food territory. Usually such territories involve only one individual, occasionally coexisting with a female. Both the male and the female guard their territory (Gill and Wolf, 1975). Similarly, the Long-billed sunbirds dominate the area in the home garden habitat in Gampola and they guard their feeding territory from the individuals of the same species and also, they defend their territory from other nectar feeding species such as the Oriental white-eye. Usually sunbirds defend moderate to rich nectar sources whereas more dispersed sources are not defended (Ford 1981).

Probing, hovering, and piercing are the activities used by the sunbirds in acquisition of food. Therefore, the sum of these three activities was considered as the "feeding activity". The significant difference between the Long-billed and Purple-rumped sunbirds' feeding activity can be explained by their body size (Reed Hainsworth and Wolf, 1972). Ecologists generally consider that food selection by consumers should be profitable. This is usually expressed in terms of maximizing the rate of net energy gain (Reed Haisworth and Wolf, 1976). As Long-billed sunbird's body size is larger, their energy requirement is higher. Therefore, their feeding frequency is higher (17.1 feeding activities per minute) than Purple-rumped sunbird (14.55 feeding activities per minute).

Sunbirds' feeding preferences do not depend on the plant species or the flower colour. However, the feeding preferences depend on the flower count of the plant, nectar glucose concentration, and the length of corolla of flower. This is because they mainly target on the net energy gain and they mainly focus on extraction efficiency. Nectar extraction efficiency could be maximized by visiting flowers with the most concentrated nectar that provide the highest intake rates. Also, food choice could be influenced by nectar constituents such as glucose, sucrose, fructose, including the presence of amino acids (Reed Haisworth and Wolf, 1976).

The effect of the flower count, nectar glucose concentration, and the length of corolla are interconnected with the number of visits made by the sunbirds. The corolla length plays a major role in selecting the feeding plant of sunbirds. According to (Paton and Collins, 1989), bill lengths of nectarivores birds largely determine the range of floral lengths that can be probed. Maximum floral lengths exceed bill lengths, since sunbirds protrude their tongues beyond the tips of their bills. But the rate of extracting nectar decreases with increasing flower corolla length (Paton and Collins, 1989). Long-billed sunbird has a longer beak and they have the ability to probe into many flowers with

different corolla lengths. But the Purple-rumped sunbird's beak is relatively shorter and therefore it does not have the ability to probe into many flowers that the Long-billed sunbird is able to. As such, the Purple-rumped sunbird has a significant correlation with the flower corolla length. Also, the results showed that the Purple-rumped sunbird's visits decrease with increasing corolla length. The main reason behind this the beak size. It is also observed that Purple-rumped sunbirds get nectar by piercing the base of the flower in which Long-billed sunbirds get nectar by probing. This supports the idea that feeding plants of sunbirds mainly depend on their beak size.

Foraging requires energy and it is costly. As the Long-billed sunbird has the ability to probe many flowers, their extracting efficiency can be increased by getting nectar from flowers which have a higher glucose concentration. Therefore, their visiting frequency has a significant correlation with the nectar glucose concentration. Since Purple-rumped sunbirds cannot feed on every flower on which the Long-billed is able to, they select suitable flowers and defend them from the other invaders. Furthermore, the dependency of the Long-billed sunbirds on the glucose concentration can be due to the body size, as explained earlier.

Since Purple-rumped sunbirds have a preference of flowers according to their bill length, they get their daily energy requirement by probing into many flowers. Therefore, the occurrence of Purple-rumped sunbirds has a significant correlation with the flower count. However, to verify the outcomes of these observations, further studies are needed. In this study, measuring the glucose concentration was appropriate because, glucose and fructose (hexose sugars) are the prevalent sugars in nectar of almost half the passerine-pollinated plants (Fleming *et al.*, 2004).

CONCLUSION

In conclusion, it can be said that the occurrence of sunbirds depends on the plant composition and human activities and that the feeding activities of the Long-billed and Purple-rumped sunbirds show a significant difference due to the difference in their body size. It may be said that Long-billed sunbirds' foraging strategies has a significance with glucose concentration of flowers. But flower morphology and flower count does not affect their foraging behaviors. Since long-billed sunbirds has the ability to probe on many flowers, their main focus is on optimizing nectar gain with less foraging effort. Therefore, they forage on flowers with high-concentrated glucose. However, Purple-rumped sunbirds' foraging strategies have a significance with flower morphology: corolla length and flower count. Glucose concentration of flowers does not affect foraging strategies of Purple-rumped sunbirds. Since Purple-rumped sunbirds have a comparatively shorter bill, their foraging ability is limited by the flower corolla length. To fulfill their daily nectar intake, Purple-rumped sunbirds have to forage on more flowers. The choice of selecting the plant species is due to their beak size. As they have morphological dissimilarities, they share a common niche although they feed on same food sources. These results support the co-evolution of bill morphology of sunbirds

and flower morphology. However, as far as Sri Lanka is concerned, further studies are needed in order to understand their ecology and to conserve them.

ACKNOWLEDGEMENTS

Authors wish to thank the Department of Zoology, University of Peradeniya for providing equipment and other facilities for this study. We are also thankful for field assistants that helped with field observations.

STATEMENT OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

- Adamsen, F.J., Coffelt, T.A. John, M. Nelson, Edward M. Barnes and Robert C. Rice. (2000). Method for Using Images from a Color Digital Camera to Estimate Flower Number. *Crop Science* **40**(3): 704-9. <https://doi.org/10.2135/cropsci2000.403704x>.
- Jeanne A. (1974). Observational Study of Behavior: Sampling Methods. *Behaviour* **49**(3-4): 227-66. <https://doi.org/10.1163/156853974X00534>.
- Arthur, Benjamin, Mark Hindell, Marthan, N., Bester, W. Chris Oosthuizen, Mia Wege, and Mary-Anne Lea. 2016. South for the Winter? Within-Dive Foraging Effort Reveals the Trade-Offs between Divergent Foraging Strategies in a Free-Ranging Predator." *Functional Ecology* **30**(10): 1623-37. <https://doi.org/10.1111/1365-2435.12636>.
- August 2019 | Clements Checklist." n.d. Accessed October 3, 2019. <https://www.birds.cornell.edu/clementschecklist/overview-august-2019/>.
- Blas, Julio, Teresa Abaurrea, Marcello D'Amico, Francesca Barcellona, Eloy Revilla, Jacinto Román, and Martina Carrete. (2016). Management-Related Traffic as a Stressor Eliciting Parental Care in a Roadside-Nesting Bird: The European Bee-Eater *Merops apiaster*. *PLoS ONE* **11**(10). <https://doi.org/10.1371/journal.pone.0164371>.
- Bled, Florent, Abdulaziz, S., Alatawi and Jerrold Belant, L. (2019). Anthropogenic and Environmental Factors Affecting Avian Species Richness and Occurrence in an Ecological Oasis within a Desert Ecosystem. *Acta Ornithologica* **54**(1): 11-34. <https://doi.org/10.3161/00016454AO2019.54.1.002>.
- Brown, James, H., William, A., Calder and Astrid Kodric-Brown. (1978). Correlates and Consequences of Body Size in Nectar-Feeding Birds. *Integrative and Comparative Biology* **18**(4): 687-738. <https://doi.org/10.1093/icb/18.4.687>.
- Burton, Maurice, and Robert Burton. (2002). *International Wildlife Encyclopedia: Index Volume*. Marshall Cavendish.
- Calder, William, A. and Joanna Booser. (1973). Hypothermia of Broad-Tailed Hummingbirds during Incubation in Nature with Ecological Correlations. *Science* **180**(4087): 751-53. <https://doi.org/10.1126/science.180.4087.751>.
- Carpenter, F. Lynn. (1974). Torpor in an Andean Hummingbird: Its Ecological Significance. *Science*

- 183(4124): 545-47. <https://doi.org/10.1126/science.183.4124.545>.
- Chapin Iii, F. Stuart, Erika S. Zavaleta, Valerie T. Eviner, Rosamond L. Naylor, Peter M. Vitousek, Heather L. Reynolds, David U. Hooper, *et al.* (2000). Consequences of Changing Biodiversity. *Nature* **405**(6783): 234-42. <https://doi.org/10.1038/35012241>.
- Chittka, Lars, James D. Thomson, and Nickolas M. Waser. (1999). Flower Constancy, Insect Psychology, and Plant Evolution. *Naturwissenschaften* **86**(8): 361-77. <https://doi.org/10.1007/s001140050636>.
- Crimmins, Michael A., and Theresa M. Crimmins. (2008). Monitoring Plant Phenology Using Digital Repeat Photography. *Environmental Management* **41**(6): 949-58.
- Ellis, Erle C. (2013). Sustaining Biodiversity and People in the World's Anthropogenic Biomes. *Current Opinion in Environmental Sustainability*, Open issue, **5**(3): 368-<https://doi.org/10.1016/j.cosust.2013.07.002>.
- Finch, Deborah M. (1989). "Habitat Use and Habitat Overlap of Riparian Birds in Three Elevational Zones." *Ecology* **70**(4): 866-80. <https://doi.org/10.2307/1941355>.
- Fleming, P. A., B. Hartman Bakken, C. N. Lotz, and S. W. Nicolson. (2004). Concentration and Temperature Effects on Sugar Intake and Preferences in a Sunbird and a Hummingbird. *Functional Ecology* **18** (2): 223-<https://doi.org/10.1111/j.0269-8463.2004.00818.x>.
- Ford, Hugh A. (1981). Territorial Behaviour in an Australian Nectar-Feeding Bird. *Australian Journal of Ecology* **6**(2): 131-34. <https://doi.org/10.1111/j.1442-9993.1981.tb01282.x>.
- Gill, Frank B., and Larry L. Wolf. (1975). "Economics of Feeding Territoriality in the Golden-Winged Sunbird." *Ecology* **56**(2): 333-45. <https://doi.org/10.2307/1934964>.
- Harrison, John. (2011). *A Field Guide to the Birds of Sri Lanka*. Oxford University Press.
- Heystek, Anina, Sjikr Geerts, Phoebe Barnard, and Anton Pauw. 2014. Pink Flower Preference in Sunbirds Does Not Translate into Plant Fitness Differences in a Polymorphic Erica Species. *Evolutionary Ecology* **28**(3): 457-70.
- International, BirdLife. (2018). IUCN Red List for Birds. Downloaded From.
- King, J.R. (1972). Adaptive Periodic Fat Storage by Birds. In *Proceedings of the International Ornithological Congress*, **15**:200-217.
- Kooyman, Gerald L. (2012). *Diverse Divers: Physiology and Behavior*. Vol. 23. Springer Science & Business 37 Media.
- M. Eckhart, Vincent, Naomi S. Rushing, Georgia M. Hart, and Joseph D. Hansen. 2006. Frequency-Dependent Pollinator Foraging in Polymorphic Clarkia Xantiana Ssp. Xantiana Populations: Implications for Flower Colour Evolution and Pollinator Interactions. *Oikos* **112**(2): 412-21.
- MacArthur, Robert H. (1984). *Geographical Ecology: Patterns in the Distribution of Species*. Princeton University Press.
- Mann, Clive F., and Robert A. Cheke. (2010). *Sunbirds: A Guide to the Sunbirds, Flowerpeckers, Spiderhunters and Sugarbirds of the World*. Bloomsbury Publishing.
- Martin, Paul, Paul Patrick Gordon Bateson, and Patrick Bateson. (1993). *Measuring Behaviour: An Introductory Guide*. Cambridge University Press.
- McNamara, John M., and Alasdair I. Houston. (1986). The Common Currency for Behavioral Decisions. *The American Naturalist* **127**(3): 358-78. <https://doi.org/10.1086/284489>.
- McNamara, John M., and Alasdair I. Houston. (2008). Optimal Annual Routines: Behaviour in the Context of Physiology and Ecology. *Philosophical Transactions of the Royal Society B: Biological Sciences* **363**(1490): 301-19. <https://doi.org/10.1098/rstb.2007.2141>.
- Montgomerie, Robert D., John McA. Eadie, and Lawrence D. Harder. (1984). What Do Foraging Hummingbirds Maximize? *Oecologia* **63**(3): 357-63. <https://doi.org/10.1007/BF00390665>.
- Niovi Jones, Kristina, and Jennifer S. Reithel. (2001). Pollinator-mediated Selection on a Flower Color Polymorphism in Experimental Populations of Antirrhinum (Scrophulariaceae). *American Journal of Botany* **88**(3): 447-54.
- Norris, Robert A., Clyde E. Connell, and David W. Johnston. (1957). Notes on Fall Plumages, Weights, and Fat Condition in the Ruby-Throated Hummingbird. *The Wilson Bulletin* **69**(2): 155-63.
- Paton, D. C., and B. G. Collins. (1989). Bills and Tongues of Nectar-Feeding Birds: A Review of Morphology, Function and Performance, with Intercontinental Comparisons. *Australian Journal of Ecology* **14**(4): 473-506. <https://doi.org/10.1111/j.1442-9993.1989.tb01457.x>.
- Perera, N. and C. Wijesundara. (2013). Nectar Feeding Habits of Loten's Sunbird Cinnerys Lotenius and Purple-Rumped Sunbird Leptocoma Zeylonica in the Royal Botanical Gardens, Peradeniya, Sri Lanka. *Proceedings of International Forestry and Environment Symposium* **18**(0). <https://doi.org/10.31357/fesymposium.v18i0.1885>.
- Proesmans, Willem, Dries Bonte, Guy Smagghe, Ivan Meeus, and Kris Verheyen. (2019). Importance of Forest Fragments as Pollinator Habitat Varies with Season and Guild. *Basic and Applied Ecology* **34**(February): 95-107. <https://doi.org/10.1016/j.baae.2018.08.004>.
- Rebelo, A. G., and W. R. Siegfried. (1985). Colour and Size of Flowers in Relation to Pollination of Erica Species. *Oecologia* **65**(4): 584-90. <https://doi.org/10.1007/BF00379677>.
- Reed Hainsworth, F. and Larry L. Wolf. (1972). Energetics of Nectar Extraction in a Small, High Altitude, Tropical Hummingbird, Selasphorus Flammula." *Journal of Comparative Physiology* **80**(4): 377-87. <https://doi.org/10.1007/BF00696435>.
- Reed Haisworth, F. and Larry L. Wolf. (1976). Nectar Characteristics and Food Selection by Hummingbirds. *Oecologia* **25**(2): 101-13. <https://doi.org/10.1007/BF00368847>.
- Remsen Jr, J.V., and Scott K. Robinson. (1990). A Classification Scheme for Foraging Behavior of Birds in Terrestrial Habitats. *Studies in Avian Biology* **13**: 144-60.
- Roth, Roland R. (1976). Spatial Heterogeneity and Bird

- Species Diversity. *Ecology* **57**(4): 773-82. <https://doi.org/10.2307/1936190>.
- Roxburgh, Lizanne, and Berry Pinshow. (2002). Digestion of Nectar and Insects by Palestine Sunbirds. *Physiological and Biochemical Zoology* **75**(6): 583-89. <https://doi.org/10.1086/344494>.
- Schemske, Douglas W., and Paulette Bierzychudek. (2007). Spatial Differentiation for Flower Color in the Desert Annual *Linanthus Parryae*: Was Wright Right? *Evolution* **61**(11): 2528-43. <https://doi.org/10.1111/j.1558-5646.2007.00219.x>.
- Stephens, David W., and John R. Krebs. (1986). Foraging Theory. Princeton University Press.
- Toledo, M.C.B., and Moreira, D.M. (2008). Analysis of the Feeding Habits of the Swallow-Tailed Hummingbird, *Eupetomena Macroura* (Gmelin, 1788), in an Urban Park in Southeastern Brazil. *Brazilian Journal of Biology* **68**(2): 419-26. <https://doi.org/10.1590/S1519-69842008000200027>.
- Vlas, J. de, and J. de Vlas-De Jong. 2008. Illustrated Field Guide to the Flowers of Sri Lanka: Descriptions of Approximately 1000 Plant Species, Illustrated with More than 2000 Colour Photographs. Kandy: Mark Booksellers and Distributors.
- Waterhouse, Mather, and Seip. (2002). *Distribution and Abundance of Birds* **2**(2): 13.
- Weerakoon, Devaka K., and Kithsiri Gunawardena. 2012. The Taxonomy and Conservation Status of Birds in Sri Lanka. The National Red List, 114-17.
- Wolf, Larry L. (1975). Energy Intake and Expenditures in a Nectar-Feeding Sunbird. *Ecology* **56**(1): 92-104. <https://doi.org/10.2307/1935302>.
- Wolf, Larry L., F. Reed Hainsworth, and Frank B. Gill. 1975. Foraging Efficiencies and Time Budgets in Nectar-Feeding Birds. *Ecology* **56**(1): 117-28. <https://doi.org/10.2307/1935304>.
-