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FEEDING HABITS OF THE EGYPTIAN FRUIT BAT *ROUSETTUS AEGYPTIACUS* ON CYPRUS ISLAND: A FIRST ASSESSMENT

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ABSTRACT - *Rousettus aegyptiacus* is the only fruit bat occurring in Europe. A dramatic, poorly understood decline was recently reported for the important population occurring on the island of Cyprus (Eastern Mediterranean). Assessing diet in this population is important to tailor appropriate conservation measures and help mitigate conflicts with farming. In this study, we present a first assessment of diet for the Cyprus population, mainly based on the occurrence of fruit remains in droppings. We analyzed 222 droppings (corresponding to 281 food items) collected at two cave roosts over three seasons. We identified 11 plant species from 8 families. *Melia azedarach*, *Morus* spp. and *Ceratonia siliqua* had a frequency of occurrence in diet > 0.1; *Eryobotria japonica*, *Ficus* and *Arbutus andrachne* were of intermediate importance, and the remaining food types were less common. Considerable differences in the occurrence frequencies of food types were detected between sites. Five out of 11 plant species found in the diet are commercially grown on Cyprus for fruit crop, but most were of secondary importance for bats. The occurrence of economically important plants in the diet was quite limited. *M. azedarach*, important for one of the colonies, is an alien species on Cyprus cultivated as an ornamental plant. Our data may help manage food resources to improve the population's conservation status, but countering other threats including pesticide use and direct persecution would also be of chief importance.

Key words: Chiroptera, conservation, diet, Egyptian fruit bat, Mediterranean

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INTRODUCTION

The Egyptian fruit bat, *Rousettus aegyptiacus* (Geoffroy, 1810) is a widespread pteropodid found in the entire sub-Saharan Africa, Egypt, Cyprus, the southern coast of Turkey, the Near East, part of the Arabian peninsula and east to Pakistan and northwest India (Kwiecinski and Griffiths 1999; Dietz et al. 2009). Its subspecies *R. a. aegyptiacus* is the only fruit bat occurring in Europe (Cyprus and Turkey). Although it may also use buildings or trees in summer, the species mainly roosts in caves (unlike other megabats, *R. aegyptiacus* may navigate in complete darkness thanks to its peculiar echolocation system; Holland et al. 2004) – where colonies may number up to several thousand individuals (Dietz et al. 2009). Fruits constitute the bulk of its diet, although leaves and pollen are also eaten (Korine et al. 1999). Because *R. aegyptiacus* also feeds on cultivated fruits, in Israel it has been classified as a pest, but its impact on crops has been largely overestimated (Korine et al. 1999). In Israel and Cyprus, conflict with farmers has led to control campaigns that have strongly reduced population size (Boye et al. 1990; Korine et al. 1999; Hadjisterkotis 2006). Besides harming *R. aegyptiacus*, such non-selective actions also seriously affected other non-target insectivorous bats roosting at the same sites (Hadjisterkotis 2006).

On Cyprus the species is protected by a law ratifying the 82/72/EEC Convention on the Conservation of European Wildlife and Natural Habitats (Hadjisterkotis 2006). Inthe European Mammal Assessment (2006), the conservation status of R. aegyptiacus is classified as "not applicable" because of the species' marginal occurrence in Europe, whereas on a global scale this bat is regarded as a "least concern" taxon.

The Mediterranean populations have special conservation and biogeographycal value: according to Horáček et al. (2010), they should be regarded as a separate, endemic species because of a 10% mtDNA divergence from sub-Saharan populations.

Despite, as we have seen, the IUCN large-scale assessment defines *R. aegyptiacus* a "least concern" taxon whose global population is stable, the current situation of this bat on Cyprus is seriously worrying. In 2006-2010 a population crash was recorded on the island: the population declined from ca. 10000 bats in the beginning of 21st century to 1500 individuals (Nicolaou 2009). The reasons are unclear, and several hypotheses have been put forward, including the hot and dry summers of 2006-2008 as well as the possible impact of pesticides.

While the diet of R. aegyptiacus has been investigated in Israel (Korine et al., 1999) and Turkey (Albayrak et al. 2008), so far only anecdotal reports have been available for Cyprus.

Assessing the diet of this bat is essential to implement appropriate conservation guidelines and manage resources which might prove vital for it; it is also useful to evaluate the real impact on crops and develop mitigation measures. Protecting potential feeding sites or planting suitable food plants near the roosts or along the routes followed by bats may increase the carrying capacity of foraging habitats for this threatened population.

Although ongoing research (Lučan et al. 2010) will probably provide a more complete picture of *R. aegyptiacus* ecology on the island, given the urgency of providing data which may help population management, we carried out a first assessment of the species' diet based on analysis of droppings.

MATERIALS AND METHODS

In January – August 2008 we collected droppings at two artificial caves (in Mammari and Pissouri) where bats roost year round, respectively. The Mammari area is located ca. 12 km west of Nicosia (elevation 205 m a.s.l.), and is surrounded by shrubby vegetation ("phrygana") dominated by *Corydonthymus capitatus* and *Sarcopoterium spinosum* along with xerophilous grassland. The Pissouri area (ca. 20 km west of Limmassol and close to the sea at 65 m a.s.l.) is dominated by Mediterranean scrubland (*Olea europea*, *Pistacia lentiscus* and *Ceratonia siliqua*) and phrygana.

At both roosts colony size recently showed a dramatic, unexplained decline (Nicolau 2009): in Mammari, it dropped from 500 to 150 bats in 2006 – 2009, whereas in Pissouri the decline was even greater (from

Table 1 - List of plant species selected for reference (ordered alphabetically according to family), their status on Cyprus (C = cultivated, W = wild, EGP = escaped garden plant) and origin (N = native; A = alien); letters M, P, in column "Site" indicate plants found in the droppings of *Rousettus egyptiacus* at two localities (M = Mammari, P = Pissouri).

Family	Taxon	Common name	Status	Origin	Site
Anacardiaceae	*Mangifera indica*	Mango	C	A	
Arecaceae	*Phoenix dactylifera*	Date palm	C/W/EGP	A	
	Washingtonia filifera	Washingtonia	C/W	A	M, P
Ericaceae	*Arbutus andrachne*	Eastern strawberry tree	W	N	M, P
Fabaceae	*Ceratonia siliqua*	Carob tree	C/W	N	M, P
Lythraceae	*Punica granatum*	Pomegranate	C	A	
Meliaceae	*Melia azedarach*	Persian lilac	C/EGP	A	M, P
Moraceae	*Ficus carica* / *F. microcarpa*	Common fig tree / Laurel fig	C/W, C	N, A	M, P
	Morus spp.	Plum tree	C	A	M, P
Musaceae	*Musa paradisiaca*	Banana	C	A	
Myrtaceae	*Psidium guajava*	Quava	C	A	
Rosaceae	*Eriobotrya japonica*	Loquat	C	A	M
Rosaceae	*Crataegus azarolus*	Mediterranean hawthorn	W	N	M
	Pyrus communis, *P. malus*	Pear tree, Apple tree	C	A	
	Prunus armeniaca	Apricot	C	A	
	Prunus avium	Cherry tree	C	A	
	Prunus persica	Peach tree	C	A	
	Prunus p. var. *nucipersica*	Peach tree	C	A	
	Prunus domestica	Bullace plum	C/W	A	
Rutaceae	*Citrus sinensis*	Orange tree	C	A	M
Styracaceae	*Styrax officinalis*	Stirax	W	N	M, P
Vitaceae	*Vitis* spp.	Grape	C	A	

1500 to 60 bats in 2008–2009).

Once each sampling month, at both sites we placed three 1.5x1.5m nylon sheets under the largest bat cluster. Sheets were laid down in the morning and recovered 48 hours later. Droppings were stored into plastic tubes at 18°C; for analysis, they were dissolved in fresh water and filtered with a 0.3 mm mesh sieve.

We mainly based our analysis on the presence of fruits. Food items were examined with a light microscope and identified according to a reference collection of 24 local fruit types (*Tab. 1*) known to feature in *R. aegyptiacus* diet according to preliminary observations and knowledge gathered in other geographical areas (Korine et al. 1999); for comparison, skin, pulp and seeds of all reference fruits were processed with a mixer to simulate the mechanical action of chewing and stored at the same temperature as droppings.

Species eaten were categorized as cultivated, wild, escaped garden plant, native or alien according to the expert judgement of one of the authors (HN).

At both sites, we calculated the frequency of occurrence for each food type i.e. the number of occurrences of each food type divided the total number of occurrences of all food items.

A chi-square test was applied to analyze the variation in the frequencies of occurrence among sites and across seasons (winter: January-March; spring: April-June; summer: July-August).

RESULTS

We analyzed 222 droppings (corre-spondding to 281 food items), 113 from Mammari (containing 127 food items) and 109 from Pissouri (154 food items). The diet mainly consisted of fruits and more rarely leaves, while no significant amount of pollen was noticed (*Tab. 1*, *2*; *Fig. 1*).

Table 2 - Seasonal frequency of occurrence of food items in the diet of *Rousettus aegyptiacus* on Cyprus. Diet significantly differed across seasons ($p < 0.0001$). Winter: January-March; spring: April-June; summer: July-August.

Species	Winter	Spring	Summer
Melia azedarach	0.38	0.23	0.00
Morus sp.	0.00	0.03	0.43
Ceratonia siliqua	0.19	0.17	0.00
Eriobotrya japonica	0.00	0.17	0.00
Ficus sp.	0.00	0.00	0.23
Styrax officinalis	0.08	0.06	0.06
Pyrus sp.	0.00	0.09	0.00
Arbutus andrachne	0.14	0.02	0.14
Citrus sp.	0.08	0.00	0.00
Crataegus azarolus	0.00	0.06	0.00
Washingtonia filifera	0.00	0.02	0.00
Arthropods	0.00	0.04	0.10
Leaves	0.06	0.00	0.00
Unidentified items	0.04	0.06	0.009

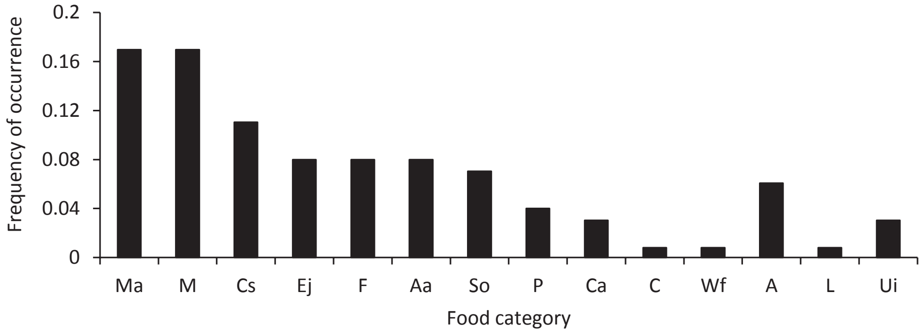

Figure 1 - Frequency of occurrence of food types eaten by two colonies of *Rousettus aegyptiacus* on Cyprus (pooled data from the two colonies); Ma: *Melia azedarach*; M: *Morus* sp.; Cs: *Ceratonia siliqua*; Ej: *Eriobotrya japonica*; F: *Ficus* sp.; Aa: *Arbutus andrachne*; So: *Styrax officinalis*; P: *Pyrus* sp.; Ca: *Crataegus azarolus*; C: *Citrus* sp.; Wf: *Washingtonia filifera*; A: Arthropods; L: Leaves; Ui: Unidentified items

We identified 11 plant species from 8 families (*Tab. 1*; *Fig. 1*, *2*). Pooling data from both sites, only *Melia azedarach*, *Morus* sp. and *Ceratonia siliqua* showed a frequency of occurrence > 0.1; *Eryobotria japonica* and *Ficus* and *Arbutus andrachne* showed somewhat lower frequencies of occurrence (0.07 – 0.1), and the remaining food categories had a minor importance. The diet differed significantly between sites ($\chi^2 = 93.02$, d.f.=13, $p < 0.0001$). *Morus* berries were the most frequent food in Mammari but by far rarer in Pissouri, while *M. azedarach* showed an opposite pattern (*Fig. 2*). *Eriobotria japonica*, *Crataegus azarolus* and *Citrus* sp. only occurred in Mammari, and leaf remains were noticed only for Pissouri. We found arthropods at both sites in 17 droppings: 7 coleopterans, four lepidopterans (caterpillars), two dipterans (fruit flies) and 4 ticks (surely ingested during grooming).

R. aegyptiacus diet varied significantly among the three seasons we investigated ($\chi^2 = 820.34$; d.f. = 26; $p < 0.0001$), matching plant species phenology (*Tab. 2*). The diet mostly consisted of *M. azedarach* in winter and *Morus sp.* in summer, while in spring *E. japonica*, *M. azedarach* and *C. siliqua* contributed almost equally to form the bulk of *R. aegyptiacus* diet.

DISCUSSION

As in other geographical areas (Marshall and MacWilliam 1982; Marshall 1983; Parry-Jones and Augee 1991; Funakoshi et al. 1993; Bhat 1994), the diet of *R. aegyptiacus* on Cyprus mainly consisted of fruits.

Although deliberate insect ingestion by *R. aegyptiacus* may occur, as reported for in South Africa (Barclay et al. 2006), most arthropods we found were likely to have been ingested accidentally. The number of plant species eaten was similar to that reported for Israel (Korine et al. 1999)

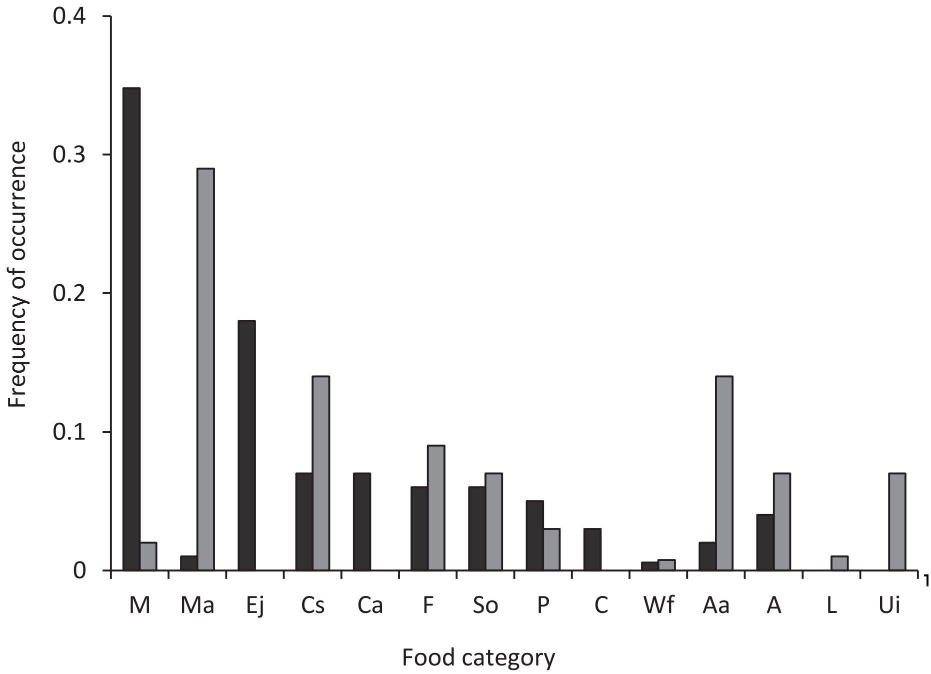

Figure 2 - Frequency of occurrence of food types eaten by two colonies of *Rousettus aegyptiacus* on Cyprus. Dark grey: Mammari colony (N-127); light grey: Pissouri colony (N=154). Diet differed significantly between sites ($p < 0.0001$). Ma: *Melia azedarach*; M: *Morus* sp.; Cs: *Ceratonia siliqua*; Ej: *Eriobotrya japonica*; F: *Ficus* sp.; Aa: *Arbutus andrachne*; So: *Styrax officinalis*; P: *Pyrus* sp.; Ca: *Crataegus azarolus*; C: *Citrus* sp.; Wf: *Washingtonia filifera*; A: Arthropods; L: Leaves; Ui: Unidentified items.

and Turkey (Albayrak et al. 2008) although *Morus* sp., *M. azedarach* and *C. siliqua* are important in both these countries, in the former *Ficus* sp. represents the main *R. aegyptiacus* food item (Korine et al. 1999). In Turkey *Ficus elastica* is eaten from the end of October to the beginning of December, while *M. azedarach* is consumed all year round (Albayrak et al. 2008). Figs (*Ficus spp.*) may represent an important source of calcium for lactating females, although no sex-related variation in fig consumption has been recorded in South Africa (Barclay and Jacobs 2011).

Overall, this bat proved to be an opportunistic forager (see Sánchez 2006): its staple food differed according to site and season. Important food categories differed between Mammari and Pissouri, probably as a result of different local availability of food plants. However, our data also suggest that *R. aegyptiacus* may cover long distances to reach locally abundant food sources. For instance, to reach the closest *A. andrachne* trees (fairly important at least for the Pissouri colony), bats from Mammari and Pissouri may have covered ca. 13 and 20 km respectively (Nicolau 2009). Similar distances are travelled in other parts of its geographical range. For instance, in Israel *R. aegyptiacus* travels 12-15 km per night (Makin 1990; Tsoar et al. 2010). This behaviour makes it possible to exploit largely scattered, patchy foraging sites (Lučan et al. 2010).

The seasonality we recorded matches plant phenology on Cyprus and also reflects the degree of persistence of ripe fruits on plants. It partly resembles the seasonal pattern noticed in Israel (Korine et al. 1999) and Turkey (Albayrak et al. 2008). In both Israel and Cyprus (Korine et al. 1999; this study), *M. azedarach*, *C. siliqua* and *A. andrachne* represent the main winter food, whereas *Morus* sp. was mainly present in late spring in Israel, and in summer on Cyprus. Unlike the Israeli case study, we also found *A. andrachne* in late summer, when fruits are about to ripen. In Turkey (Albayrak et al. 2008) the year-round importance of *M. azedarach* is due to its peculiar phenology: fruits start ripening in spring and persist on trees in winter; in autumn, trees loose the foliage, making fruits more conspicuous to bats (Albayrak et al. 2008). The importance of *C. siliqua* for the Cypriot population of *R. aegyptiacus* in winter and early spring is also documented by Benda et al. (2007), who highlighted the importance of this plant as food for this bat. In the Mediterranean, *R. aegyptiacus* and *C. siliqua* constitute a single integrated synchorologic unit - possibly set up under a scenario of marked seasonality, as in the latest Caenozoic – which allowed bats to survive in the cold season. *R. aegyptiacus* would have thus been able to colonize only geographical regions first reached by carob trees (Galil et al. 1976; Benda et al. 2007).

By radiotelemetry, Lučan et al. (2010) found that in mid-summer, flowers of *Agave americana* were frequently eaten, whereas those of eucalyptus trees were eaten in late winter. Our analysis, which focused on fruits, may have overlooked these items. Unlike Lucan et al. (2010), we also did not find *Myrtus communis* fruits, despite their seeds are easily identified in mammal droppings (e.g. Aronne and Russo 1997). In Lučan et al. (2010)'s study, late winter diet also included a palm tree, albeit of a species (*Phoenix dactylifera*) different from that (*W. filifera*) we recorded. As in our study, however, figs (*F. carica*), Persian lilac (*M. azedarach*), mandarines and lemons were also food plants. These differences are likely the result of the different methods of analysis adopted.

Our study confirmed the importance of alien plant species in the diet of this bat (Korine et al. 1999; Albayrak et al. 2008; Lucan et al. 2010) and pointed out that the impact of *R. aegyptiacus* on economically valuable plants was negligible. Voigt et al. (2011) found that another fruit bat, *Epomophorus wahlbergi*, frequently feeds on *M. azedarach* in South Africa and acts as a major seed disperser for this plant. The role of *R. aegyptiacus* in dispersing seeds of *M. azedarach* and more generally of alien species is so far unknown.

In our study, *R. aegyptiacus* largely fed on wild fruits and escaped ornamental plants. Five out of 11 plant species found in the diet are commercially grown for fruit crops on Cyprus; of these *Morus* sp. and *E. japonica* were only important in the bats' diet at one site. The occurrence in the diet of other commercially grown plants such as *Citrus*, *Ficus* and *Pyrus* was negligible, so the impact of bat foraging on such cultivations was likely small. This is an important aspect which constitutes a strong argument to mitigate conflicts with farmers.

Our study, as well as that by Lucan et al. (2010), identifies plant species that may be easily grown and planted around main roosts to support colonies and, where relevant, buffer cultivations to further mitigate or prevent the impact of foraging bats. Moreover, the nutritional value of fruits (Korine et al. 1996) represents another aspect to be taken into account when providing food plants important to support this population. Appropriate management of food resources may be a key strategy to help invert the current population decline, but other factors should be addressed such as controlling the use of biocides and preventing the deliberate killing of this important bat population.

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