ELSEVIER

Biological Conservation 88 (1999) 301–306

BIOLOGICAL CONSERVATION

Is the Egyptian fruit-bat *Rousettus aegyptiacus* a pest in Israel? An analysis of the bat's diet and implications for its conservation

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Received 19 March 1998; received in revised form 12 October 1998; accepted 16 October 1998

Abstract

The Egyptian fruit-bat *Rousettus aegyptiacus* is regarded as a pest for agriculture. However, no quantitative data on its diet have been collected in Israel or in other Mediterranean areas, and control measures in the past reduced populations of insectivorous bats in Israel. We therefore studied the relative importance of native versus commercially cultivated fruit plants by analysis of bat faeces. Droppings were collected during 1993–1995 in two roost-sites in the Carmel National Park. Results show that the bat feeds mainly on fruits but leaves and pollen are also eaten. Leaf eating was observed mainly during winter, when bats may face times of severe decrease in fruit availability and quality. Only four fruit species (15%) of the bat's diet are commercially grown and only two of these in the research area. Therefore the definition of the fruit-bat as a major agricultural pest should be re-examined. Two effective methods for controlling damage caused by bats are discussed.

Keywords: Fruit-bats; *Rousettus aegyptiacus*; Diet; Seed dispersal; Crop damage; Frugivory

1. Introduction

The Egyptian fruit-bat *Rousettus aegyptiacus* is the only megachiropteran among 32 bat species in Israel. It is the most common bat and may be found in cities, national parks and nature reserves. In Israel this bat is considered as an agricultural pest (Moran and Keidar, 1993) and large colonies were persecuted and exterminated by the authorities in the early 1950s, by fumigating caves that contained them. This resulted in a drastic decrease in populations of insectivorous bats that shared the same roosts (Makin and Mendelssohn, 1987). These actions ended in 1987–1988, but nevertheless, fruit-bats are still considered as major agricultural pests and large scale destruction of fruit-bat colonies may be considered again for population management.

However, the definition of these bats as pests should be based on a thorough investigation of the bat's natural diet, as well as on the extent of the actual damage to fruit crops (see also Mickleburgh et al., 1992). Such detailed information does not exist, and all the present assessments of damage or food choice in the field are based on casual observations, and partially on a study conducted in 1976 (Galil et al., 1976). However, that study did not describe the working methods, the sites of observations or the data collection methods. Moreover, in adjacent Mediterranean countries, where a similar conflict is reported between fruit-bats and man, the available information is also based on casual observations (Egypt: Madkour, 1977; Lebanon: Lewis and Harrison, 1962; Ahattla, 1977; Cyprus: Spitzenberger and Bauer, 1979).

The first objective of the present study, therefore, was to determine the diet of *R. aegyptiacus* in the Mediterranean area. The research site was a national park that is partially surrounded by agricultural areas. Since the fruit-bat can fly long distances during its nightly activity (Makin, 1990), we assumed that by methodically sampling the bats' faeces in the day-roosts, we could obtain information about annual or seasonal damage caused to commercial fruits, and to evaluate its extent.

Using a national park as the research site also enabled us to examine the bats' contribution to the seed dispersal of wild fruits and to determine the role of native versus introduced and cultivated fruit plants in the bat's diet.

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0006-3207/99/$—see front matter
PII: S0006-3207(98)00126-8

2. Methods

2.1. Study sites

The research was carried out in two natural caves (Rakefet and Nachash caves) located on Mount Carmel National Park (32°40N;35°05E) in the north-western part of Israel. In the valleys surrounding the park, there are different agricultural plantations in which fruit crops are grown, such as bananas, loquat and persimmon. The two caves were 7 km apart. They serve as day-roosts and are occupied by thousands of fruit-bats all year round (Korine, pers. obs.).

2.2. Faeces collection and analysis

Faecal material was collected monthly (in the last week of each month) from December 1993 to November 1995. Samples were collected by placing plastic sheets (1×1 m) in three different locations in each cave, for 48 h. From each sheet, three samples of each colour-type dropping were collected, wrapped in aluminum foil and freeze-stored for later identification. Food items were identified by light microscopy, after preparing an index of known fruits for comparison. This index included all 11 fruit species suspected of being part of the fruit-bats' diet, both wild and commercially grown. Comparisons were also made with faeces of captive bats fed on known single fruit diets (wild, introduced and 22 of the cultivated species assumed to be eaten by the fruit-bats in Israel).

The occurrence of food items in the faeces was calculated according to Thomas (1988). On each collection sheet, different coloured droppings were defined, each representing a different dietary component and the different colour patches were counted. Of the total number of patches, the percentage of each colour (% droppings containing each plant species) was calculated for each month of collection. This technique allows the comparison of different sample sizes (n) taken at different times. The advantage of this method is that all food items are treated equally. However, this method is only qualitative, as each dropping is treated in the same manner, without regard to its diameter or mass.

3. Results

A clear pattern of the number of droppings was found in both caves during the research period. The number of droppings was highest during winter (December–February) 1993–1994, declined through spring and summer, increased in autumn and peaked again during winter 1995 (Fig. 1).

The diet of the fruit-bats, in both caves and during the 2 years of the study, consisted only of plants in the form of fruits, leaves and pollen. No evidence of insect remains was found in the droppings (see Table 1). Overall, 14 plant species were identified, belonging to three types of food: fruits (14 species, 88%), pollen (one species of *Lantana*, 6%) and leaves (*Ficus religiosa*, 6%) (Table 1).

Twelve species are introduced, of which four are also grown commercially in Israel (persimmon *Diospyros kaki*, loquat *Eriobotrya japonica*, fig *F. carica*, and date *Phoenix dactylifera*) (Table 1). However, in the specific research area figs and dates are not grown commercially. The only two native fruit species were carob *Ceratonia siliqua* and arbutus *Arbutus andrachne*.

Table 1
Classification of fruit species identified in the faeces of the Egyptian fruit-bat in the Rakefet and Nachash caves

Fruit species	Common name	Family	Status
Ceratonia siliqua	Carob	Caesalpiniaceae	NA,IN
Diospyros kaki	Persimmon	Ebenaceae	IN, CO
Arbutus andrachne	Arbutus	Ericaceae	NA
Melia azedarach	Lilac	Meliaceae	IN
Ficus carica	Commercial fig	Moraceae	IN,CO[b]
Ficus microcarpa	Fig	Moraceae	IN
Ficus religiosa	Ornamental fig	Moraceae	IN
Ficus rubiginosa	Fig	Moraceae	IN
Ficus sycomorus	Sycamore	Moraceae	IN
Morus nigra	Mulberry	Moraceae	IN
Eugenia uniflora[a]	Pytanga	Myrtaceae	IN
Phoenix dactylifera	Date	Palmaceae	NA, IN,CO[b]
Eriobotrya japonica	Loquat	Rosaceae	IN, CO
Lantana sp.	Lantana	Verbenaceae	IN

[a] Only in Nachash cave.
[b] Not grown in the research area.
NA, native species; IN, introduced species; CO, commercially grown species.

3.1. Diet composition in the Rakefet and Nachash caves during 1994 and 1995

In general, the distribution and abundance of the food sources in both caves during the 2 years were similar. The fruit-bats' monthly diet composition range in Rakefet and Nachash caves in 1994 and 1995 is presented in Table 2.

The diet from December to March consisted of five species of fruit, mainly carob and lilac. These fruits are also eaten at the end of autumn (November), but in a smaller proportion. Other fruits consumed during winter are arbutus, persimmon and figs (*F. microcarpa*).

During spring, the bats' diet consisted mainly of loquat (mostly in April) and mulberry (mostly in May). In both caves, the lowest number of fruit species in the diet was during March and April 1994 for Nachash and Rakefet caves, respectively. In both caves, April 1995 coincided with least variety in the diet and only four fruit species were represented. The number of available species increased from the end of spring (May) to nine in Nachash cave and 10 species in Rakefet cave, throughout the summer and early autumn, mostly species of figs. The commercial fig (*F. carica*) was eaten mainly in July and August in both years. *F. Microcarpa* was eaten almost all year round but mainly during summer. Altogether, *Ficus* species constituted 36% of the bat diet. Leaf eating was observed mainly in winter, contributing 9–17% during December–February diets in 1994 and 1995 for Rakefet and Nachash caves. Leaf eating was also observed at the beginning of spring and towards the end of autumn, but its contribution to the diet then was smaller, compared to winter and early spring.

In both caves, pollen eating was observed mainly during summer but continued up to the beginning of winter. Its contribution to the diet was generally small (0–12%).

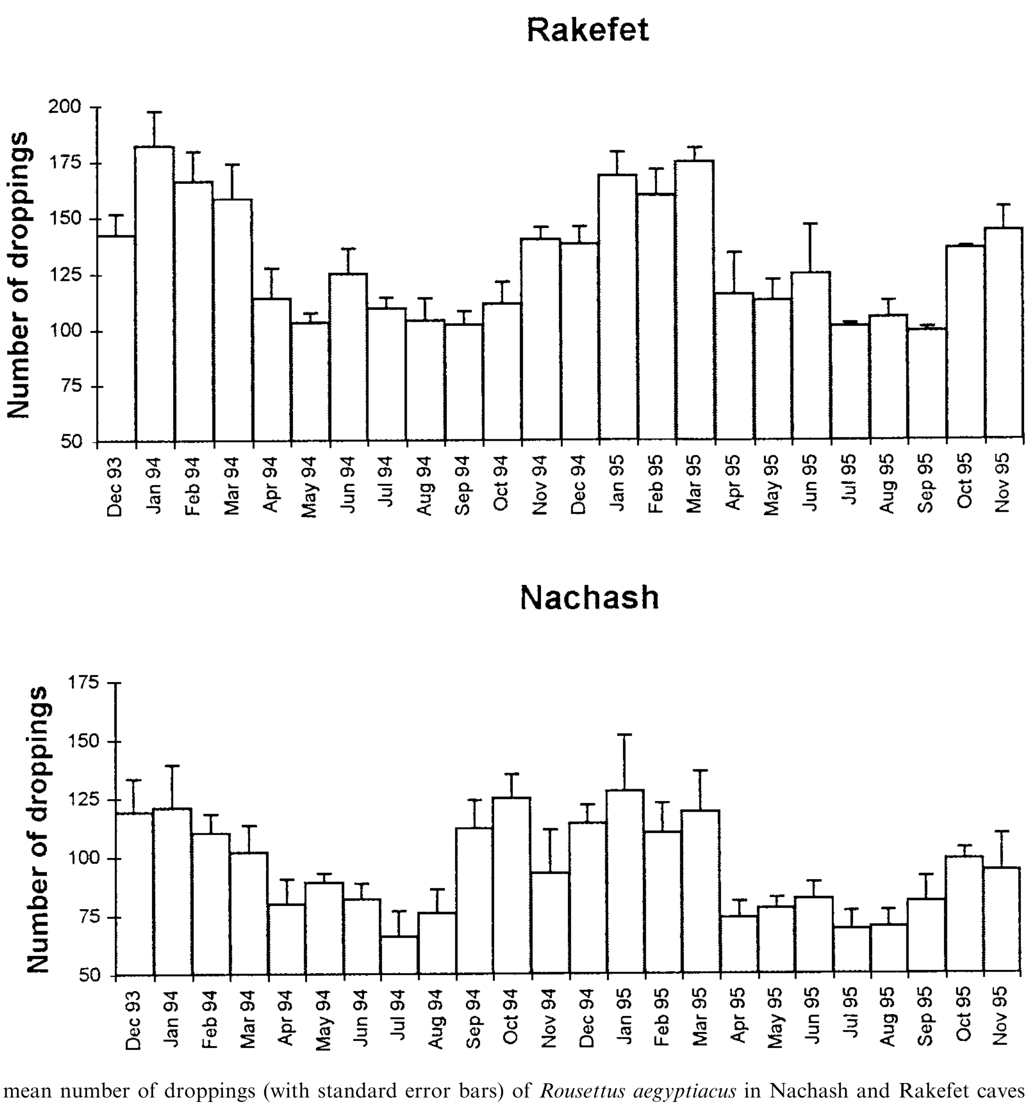

Fig. 1. Monthly mean number of droppings (with standard error bars) of *Rousettus aegyptiacus* in Nachash and Rakefet caves during 1994 and 1995. Samples collected from three 1 m^2 sheets during 48 h each month.

Table 2
Range of food items (in %) found in the faecal analysis of *Rousettus aegyptiacus* in Rakefet and Nachash caves during December 1933 to November 1995

Plant species	Winter			Spring			Summer			Autumn		
	December	January	February	March	April	May	June	July	August	September	October	November
Ceratonia siliquaa[a]	31–43	30–42	30–44	19–39	–	–	–	–	–	–	–	10–22
Melia azedarach[a]	33–36	37–49	28–43	25–39	–	–	–	–	–	–	–	14–26
Arbutus andrachne[a]	–	2–5	1–5	–	–	–	–	–	–	–	–	–
Ficus religiosa[b]	11–17	9–16	13–15	14–19	0–10	0–4	–	–	–	–	0–6	6–10
Diospyros kaki[a]	7–8	3–7	5–9	0–3	–	–	–	–	–	–	0–6	4–8
Lantana sp[c]	0–3	0–3	–	–	–	0–6	6–12	0–8	0–5	0–4	0–7	1–4
Eriobotrya japonica[a]	–	–	–	6–9	44–56	11–21	–	–	–	–	–	–
Morus nigra[a]	–	–	–	–	23–39	37–39	8–17	0–15	–	–	–	–
Eugenia uniflora[a]	–	–	–	–	0–3	0–4	–	–	–	–	–	–
Ficus sycomorus[a]	–	–	–	–	0–2	9–21	3–11	2–16	2–12	0–9	–	–
Ficus carica[a]	–	–	–	–	–	–	3–7	41–56	30–46	15–36	4–8	–
Ficus religiosa[a]	–	–	–	–	–	–	0–24	0–17	5–10	9–21	9–29	0–22
Ficus microcarpa[a]	3–13	0–2	3–9	0–26	0–26	19–26	32–44	15–26	22–31	27–45	29–47	8–28
Ficus rubiginosa[a]	–	–	–	–	0–3	–	10–21	0–13	4–11	3–6	19–30	0–18
Phoenix dactylifera[a]	–	–	–	–	–	–	–	–	0–14	7–18	4–11	7–9

[a] Fruits.
[b] Leaves.
[c] Pollen.

4. Discussion

The results of the present study show that the *R. aegyptiacus* feeds mainly on fruits (87%), while leaves and pollen constitute the remaining 13%. In this respect, its diet is similar to other megachiropteran bats (Marshall and Macwilliam, 1982; Marshall, 1983, 1985; Parry-Jones and Augee, 1991; Funakoshi et al., 1993; Bhat, 1994). As the bats can fly an average of 12–15 km during the nightly activity (Makin, 1990), fruits may be eaten all year round over a wide range of the Carmel National Park and its surroundings.

The monthly distribution of fruits collected in both caves shows that two main seasons can be defined. During winter (December–February) and beginning of spring (March–April), only five species of fruit were eaten, and of these, only carob and lilac are abundant and constitute 80% of the bats' diet. The other three species (arbutus, persimmon and *F. microcarpa*) are eaten to a much smaller extent. From the end of spring (April–May) to the end of autumn (November), there are more species of fruit available for the bats (9–10 species) and there is no clear preference in the diet. These two periods correspond with the Mediterranean climate that is characterized by a relatively short winter and long summer. The results are also consistent with the cyclic changes of the bats' body mass throughout the year. Makin (1990) showed that during winter there is a decrease in body mass, followed by an increase during spring and summer, reaching a peak in October, when food availability is greatest.

Owing to the distinct seasons, there is synchrony in fruit-ripening. The change in the relative abundance of each fruit species in the fruit-bat's diet, from month to month, and from year to year, reflects this synchrony and may also reflect yearly changes in fruit crop sizes. This is particularly obvious for arbutus, loquat, mulberry and fig (*F. carica*). Exceptions are *F. religiosa* and *F. microcarpa*, which fruit asynchronously, and can therefore, be available to the bats almost all year round. In other Mediterranean countries, *R. aegyptiacus* was reported to feed on date, fig, carob and mulberry, as well as other food sources, which is consistent with the results of the present study (Atalla, 1977; Madkour, 1977; Spitzenberger and Bauer, 1979).

The number of droppings in both caves in the present study showed a clear pattern that may indicate more activity of bats in the caves during winter. Several explanations may account for this. Although it is possible that more individuals of fruit-bats are inhabiting the caves, this is unlikely in Mediterranean habitats, as fruit-bats do not migrate and populations from different caves show a high fidelity to the roost site (Makin, 1990). Populations increase when young are born, at the beginning of both spring and autumn (Makin, 1990; Korine et al., 1994). It is also possible that fruit sources are closer to the caves during winter than during other seasons and so bats move less between caves and feeding sites. However, the most likely explanation is that fruit-bats use the caves as a temporary shelter (beside being a roost) during winter more intensively then in other seasons. In any case, for practical conservation, caves populated by fruit-bats should be less visited during winter.

The present results show that the genus *Ficus* constitutes the largest portion of the bat's diet. This is consistent with the preference of other fruit-eating bats, both in old-world tropical areas (Marshall, 1985; Fujita, 1991; Bhat, 1994), and in new world tropical areas (Morrison, 1978; Charles-Dominique, 1986; Fleming, 1993; Kalko et al., 1996). Interestingly, Galil et al. (1976) postulated that the Egyptian fruit-bat actually invaded the Mediterranean area only after man started using *F. sycomorus* as a cultivated plant.

Recent studies on the diet of fruit-eating bats have shown that leaf eating is a common phenomenon and that bats consume the leaves of a range of plant species (Lowry, 1989; Parry-Jones and Augee, 1991; Funakoshi et al., 1993; Zortea and Mendes, 1993; Bhat, 1994; Kunz and Diaz, 1995). Several possible explanations have been suggested for this (see Kunz and Ingalls, 1994). Fruits are characterized by a low nitrogen content (e.g. Izhaki, 1993), and it has been postulated that leaves may supplement nitrogen requirements (Kunz and Ingalls, 1994). However, recent studies on nitrogen budgets have shown that fruits can fully supply the nitrogen requirements of Old world and New world fruit-eating bats (Law, 1992; Delorme and Thomas, 1996; Korine et al., 1996). Nevertheless, although the leaves of only one plant species were consumed, their contribution to the diet of *R. aegyptiacus* is relatively high, which suggests that leaf eating in Mediterranean areas may supplement nitrogen demands at times of a nadir in fruit availability and quality; it was previously found that the nitrogen content of *F. religiosa* leaves was as much as 39–75% higher than that of all the other fruits observed in this study (Korine, 1996). Our findings are supported by those of Lewis and Harrison (1962) who found that the stomach contents of *R. aegyptiacus* in Lebanon in January contained large quantities of *F. religiosa* leaves.

4.1. Seed dispersal

Although the carob only represents 30–40% of the fruit-bat's diet over the whole year, it is the second most important component during winter and therefore, the bat's contribution to carob seed dispersal may be significant. The bat's contribution to the dispersal of arbutus seeds is probably secondary, as this fruit is only a minor component of the bat's diet (2–5%). However, *R. aegyptiacus*, may also disperse seeds of semi-cultivated plants. Indeed, seedlings and trees of *F. carica* and *M. nigra* are often found in the surroundings of many caves that host fruit-bat populations (D. Makin and Korine, pers. obs.).

4.2. Is the fruit-bat a serious pest for commercial fruits in Israel?

Only four species of fruit (28%) that were eaten by the bats in the research area are commercially grown in Israel. Of these, cultivated figs and dates are not commercially grown in the study area whilst the occurrence of persimmon in the bat's diet is relatively small (up to 9%). The high occurrence of loquat in the bat's diet in both caves (up to 56%) does not necessarily mean that loquat fruits were picked from commercial crops since this plant is also grown in many private gardens.

Yet, fruit crops can be effectively protected. Two main methods have been applied in Israel for crop protection and fruit-bat management. Commercial crops are protected with nets that prevent bats, as well as birds, from consuming and/or indirectly damaging fruit tissue by test bites. Such a method, although highly effective and non-destructive, is expensive and difficult to maintain, but because of the long life of the structures, it may be cost-effective. A second method has been applied since 1990–1991, in which mist nets are placed in commercial crops during feeding activity for 3 nights and netted bats are killed. Such a method, although destructive, time consuming and requiring that non-target animals will be released, is less expensive and may be effective, since fruit-bats avoid re-visiting the netting sites (Korine, pers. obs.). However, long term studies should be carried out to reinforce the site-avoidance observations. A third method used by farmers in the northern part of Israel is a sonic animal scarer. This is the most inexpensive and least time consuming method. However, since it is a relatively new method, its long-term effectiveness is still unclear. Crop protection and management of fruit-bats with mist nets have proved effective both in Australia (Fleming and Robinson, 1987) and in the Maldive Islands [Dolbeer et al. (1988), but see Mickleburgh et al. (1992) for criticisms of this method and general discussion about a range of techniques used for fruit-bat management].

Other observations in Israel indicate that bats consume commercial fruits such as pears, apples, mandarins, pomegranate and litchi (Galil et al., 1976; Moran and Keidar, 1993). There are several reasons for the differences between the present results and these reports, in terms of the amount of commercial fruit damaged. Some species, such as litchi, are not grown in the study area. Food digestion and passage through the bat's alimentary system is fast, and therefore the droppings that accumulate on top of the faecal traps may only represent the food eaten towards the end of the night activity. It is therefore possible that this method does not provide a complete picture of the bat's diet. Furthermore, to identify each dropping, nine samples representing a specific colour or type of dropping, were taken to the laboratory (three from each trap). However, in most cases there were more patches of the same colour that were not sampled, and could theoretically represent a different and unidentified fruit. Although the number of commercial fruit species in the above mentioned reports is relatively high, both reports were based on occasional observations, without quantitative assessment of the damage. It is possible that at least for some of the fruits, the damage is small (as may be the case for the persimmon in the present study). Therefore, the definition of *R. aegyptiacus* as a serious pest should be re-examined, at least in the study area. We suggest that an extensive analysis of fruit-bat's diet, as presented in this study, combined with the methods for crop protection and fruit-bat management described above should help to resolve the conflict between fruit farmers and fruit-bats. Such a combination may also be helpful in other areas, such as Australia, India and South Africa (Jacobsen and Du Plessis, 1976; Advani, 1982; Fleming and Robinson, 1987; and see also Mickleburgh et al., 1992) where similar conflicts have been reported.

Acknowledgements

The authors thank Dorit Korine for her valuable help in the field. This study was supported by a joint research grant of the Technion and the University of Haifa.

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