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ECOLOGY AND BEHAVIOR OF KITTI'S HOG-NOSED BAT *(CRASEONYCTERIS THONGLONGYAI)* IN WESTERN THAILAND

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ABSTRACT

The ecology and behavior of a colony of *Craseonycteris thonglongyai* was studied during November, 1984 to May, 1986. *Craseonycteris* was found to have two short foraging periods, one around dawn and another at dusk. The mean duration of activity was 18 min in the morning and 30 min in the evening. The bats used specific flyways to reach their foraging areas which were less than 1 km from the cave. The numbers of bats using each flyway changed daily and seasonally. The foraging periods of the bats also varied seasonally. *Craseonycteris* appeared very sensitive to changes in environmental conditions; low temperature and heavy rains inhibited foraging activity.

Recommendations and guidelines are given concerning minimizing disturbance to the roosting caves and foraging areas, future research, and the establishment of a long term population monitoring program and an education center.

INTRODUCTION

Kitti's Hog-nosed bat *(Craseonycteris thonglongyai)* was discovered in 1973 by Kitti Thonglongya, in a cave near Sai Yok Waterfall, Kanchanaburi Province, western Thailand (Figs. 1 and 2). At that time he collected 52 bats from the cave (THONGLONGYA, 1973). In the month following discovery of the bat, Kitti Thonglongya explored about 50 more caves along the Khwae Noi River (River Khwae) but no more bats were found.

On the basis of the unique characteristics of this bat, J.E. HILL (1974) described *Craseonycteris thonglongyai* as a new species in its own family, Craseonycteridae. The family has taxonomic affinities with the Rhinopomatidae and Emballonuridae. *Craseonycteris* is also the world's smallest known mammal, with a body mass of only about 2 g (HILL, 1974).

In 1980, 500 km^2 of forest in the Sai Yok area were declared as Sai Yok National Park (ROYAL FOREST DEPARTMENT, 1980). Many tourists came to see the world's smallest mammal in Sai Yok Cave after it was promoted by the park officials.

In 1981, J.D. Pye checked in Sai Yok cave with an ultrasonic bat detector (PYE, 1981), but found only one *Craseonycteris*. However, he found about 200 bats of this species in Wang Phra Cave, outside the park (Fig. 2). In November 1981, R. Stebbings and M.D. Tuttle found that the bat had disappeared from Sai Yok Cave and that only 50 bats, instead of the 200

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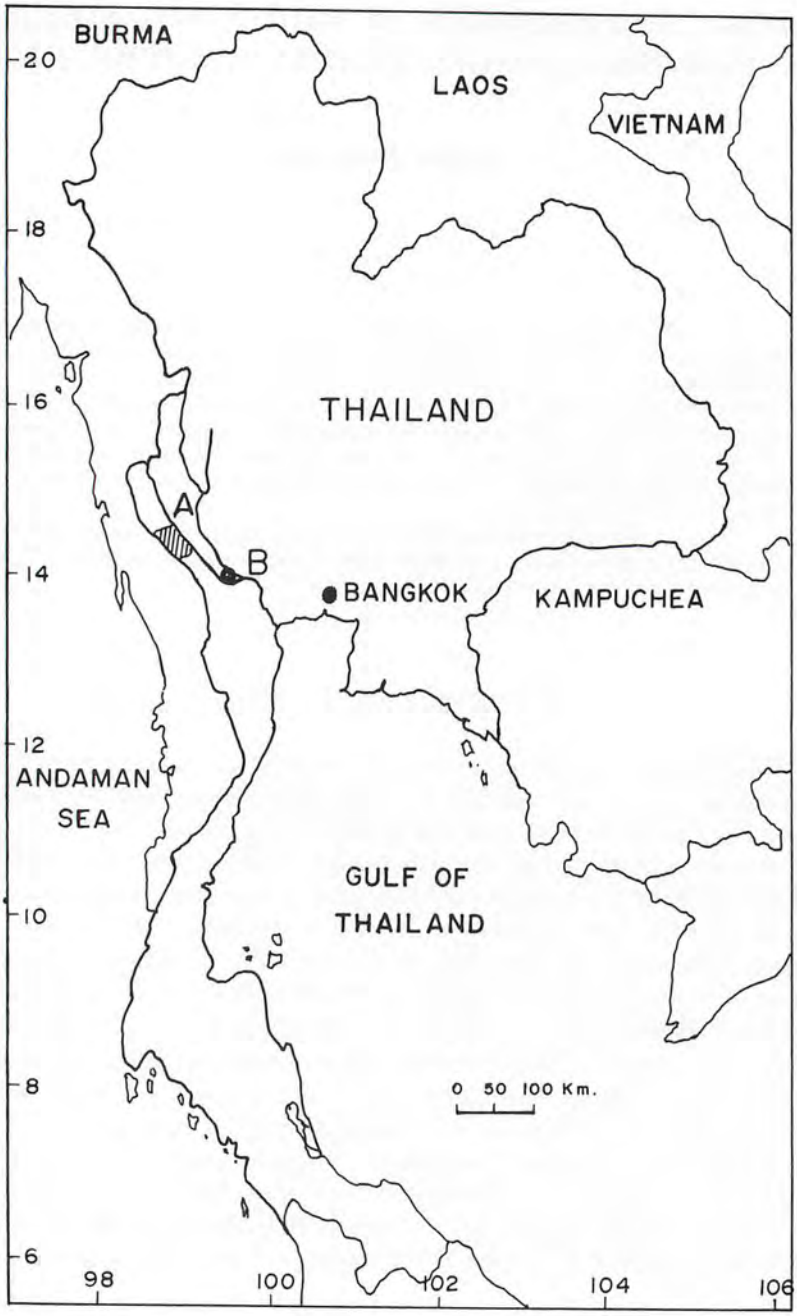

Figure 1. A, Sai Yok National Park in western Thailand. B, Study site at cave 30.

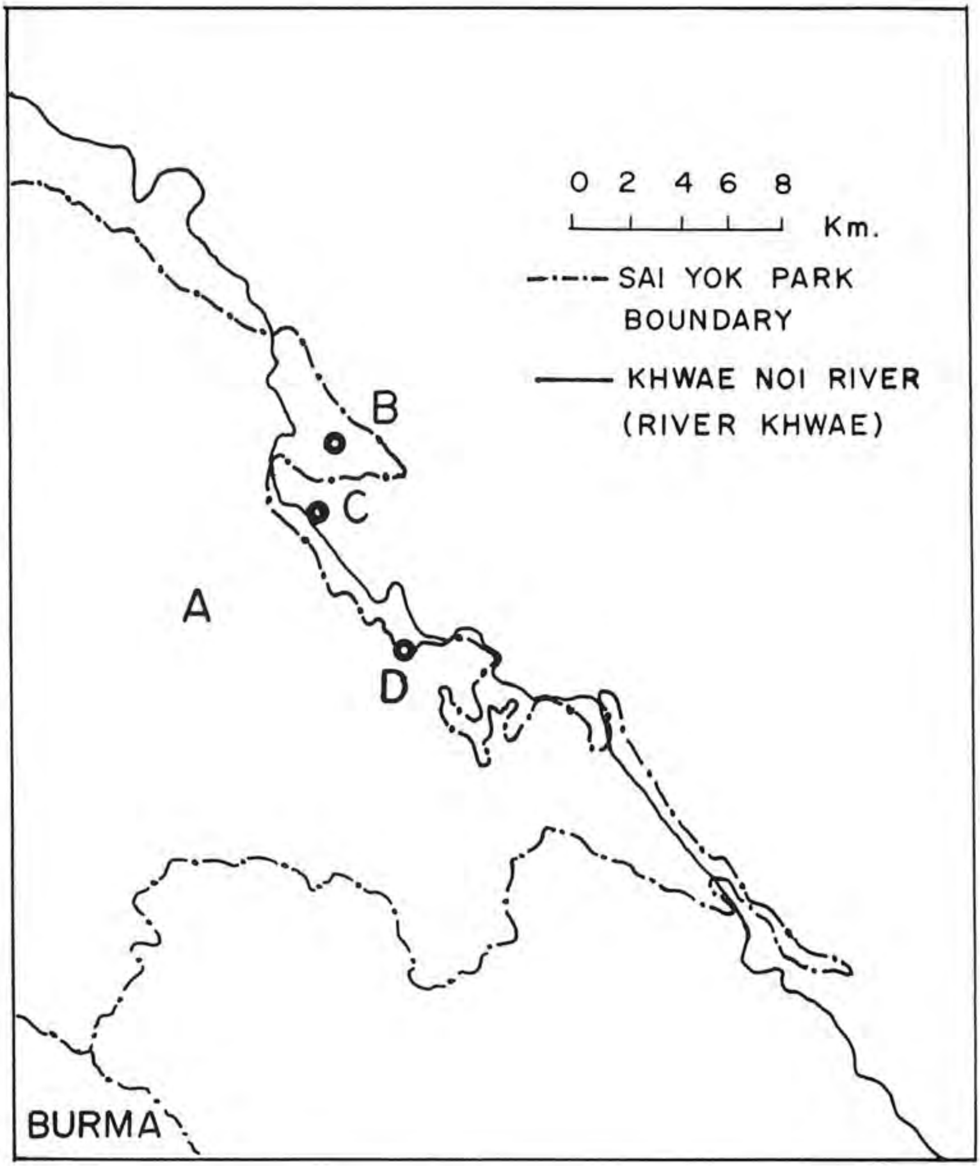

Figure 2. Map showing : A, Sai Yok National Park; B, Sai Yok cave; C, Wang Pra cave; D, Study site in dry evergreen forest at cave 1.

previously estimated by Pye, still remained at Wang Phra Cave (STEBBINGS & TUTTLE, 1982). In January 1982, J.A.T. Hall found no bats at Sai Yok cave and confirmed the count of 50 *Craseonycteris* at Wang Phra cave. Two new *Craseonycteris* caves were discovered by Hall, one outside the eastern boundary of the park, and another in the southern part of the park (HALL, 1982).

The objectives of my study were to (1) establish the activity cycle, foraging pattern and home range of *Craseonycteris* in selected study caves; and (2) examine the effects of environmental conditions (air temperature, relative humidity and light intensity) on foraging behavior. This study of behavior and ecology was undertaken to evaluate and perhaps improve the bat's chances for survival in the face of frequent human disturbance.

STUDY AREA

The site selected is in the dry deciduous forest in Sai Yok District, Kanchanaburi Province, western Thailand, about 10 km east of the town of Sai Yok (Fig. 3). The cave ('cave 30') is located in a hill at 240 m elevation at 99° 13.9' E, 14° 7.7' N. It has two entrances : one used by *Hipposideros bicolor* and another by *Craseonycteris*. The area around the cave is rocky with clay soil. Primary forest is found on the hill, but the remaining forest on the slope is secondary growth with grasses (Figs.4 and 5). The canopy was dominated by *Shorea siamensis* Miq. Other species present included *Bridelia retusa* Spreng., *Terminalia chebula* Retz., *Xylia xylocarpa* Taub.var. *kerrii* (Craib) Niels., *Careya sphaerica* Roxb., *Eugenia cumini* Druce, *Dalbergia cultrata* Grah. ex Benth., *Lanna coromandelica* Merr. and *Schleichera oleosa* Merr. The understorey and canopy were open enough to allow direct observation of *Craseonycteris* activity.

Human settlers have invaded the forest on the hill since 1983. The villagers were clearing the forest for charcoal, leaving behind only grasses and shrubs. Some additional observations of foraging behavior were made at cave 1 at the edge of Sai Yok National park, near dry evergreen forest (map, Fig. 2).

Climate at the study site

Western Thailand has three seasons. Monthly changes in temperature, humidity and rainfall are shown in Fig. 6.

Winter begins in late November and ends in early February. Most of the days are sunny and cloudless. Rain falls occasionally lasting one or two days, and then the weather becomes cooler. Dew and mist are heavy in early morning and evening. During the study the average minimum temperature and humidity in the morning were 18° C and 82%, respectively (n=28 days).

Summer begins in late February and ends in late April. Most days are cloudless and become very hot and dry in the afternoon. During the study the average maximum temperature in the afternoon was 40°C; the relative humidity was 35% (n=28). The difference between morning and evening temperatures was about 15° C.

The rainy season extends from late April to early November. Most days are cloudy, and rain falls almost every day, usually in the afternoon. Storms bring heavy rain for a week or more in September and October. Average maximum temperature during the rainy season

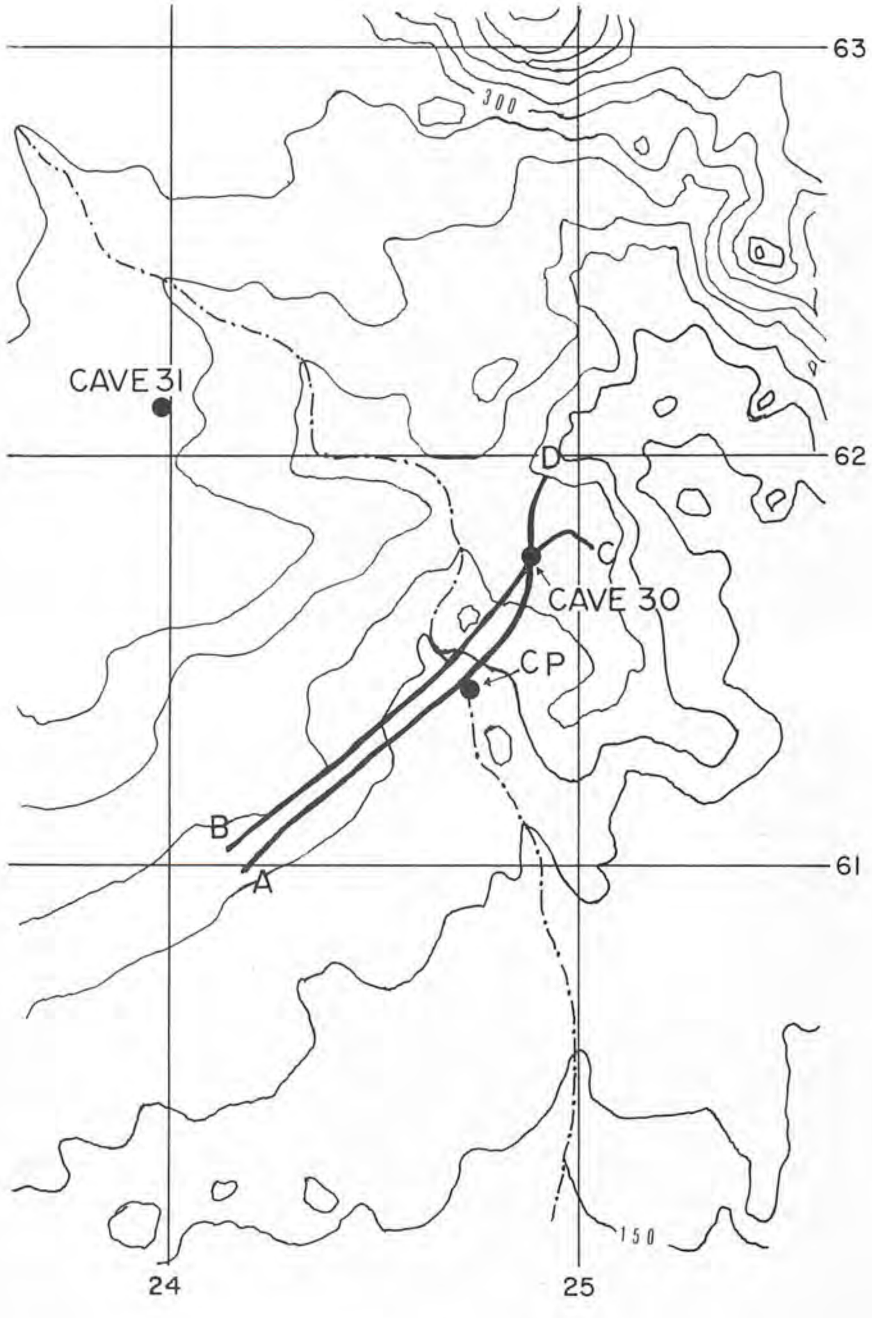

Figure 3. Study site at cave 30. A,B,C,D = flyways; CP = check–point 125 m from cave entrance. Map redrawn from 1 : 50,000 sheet 4837 III, Amphoe Sai Yok, edition 2–RTSD. Numbered grid lines are 1 km apart.

Figure 4. Forest near cave 30 in summer (dry season).

Figure 5. Forest near cave 30 in rainy season.

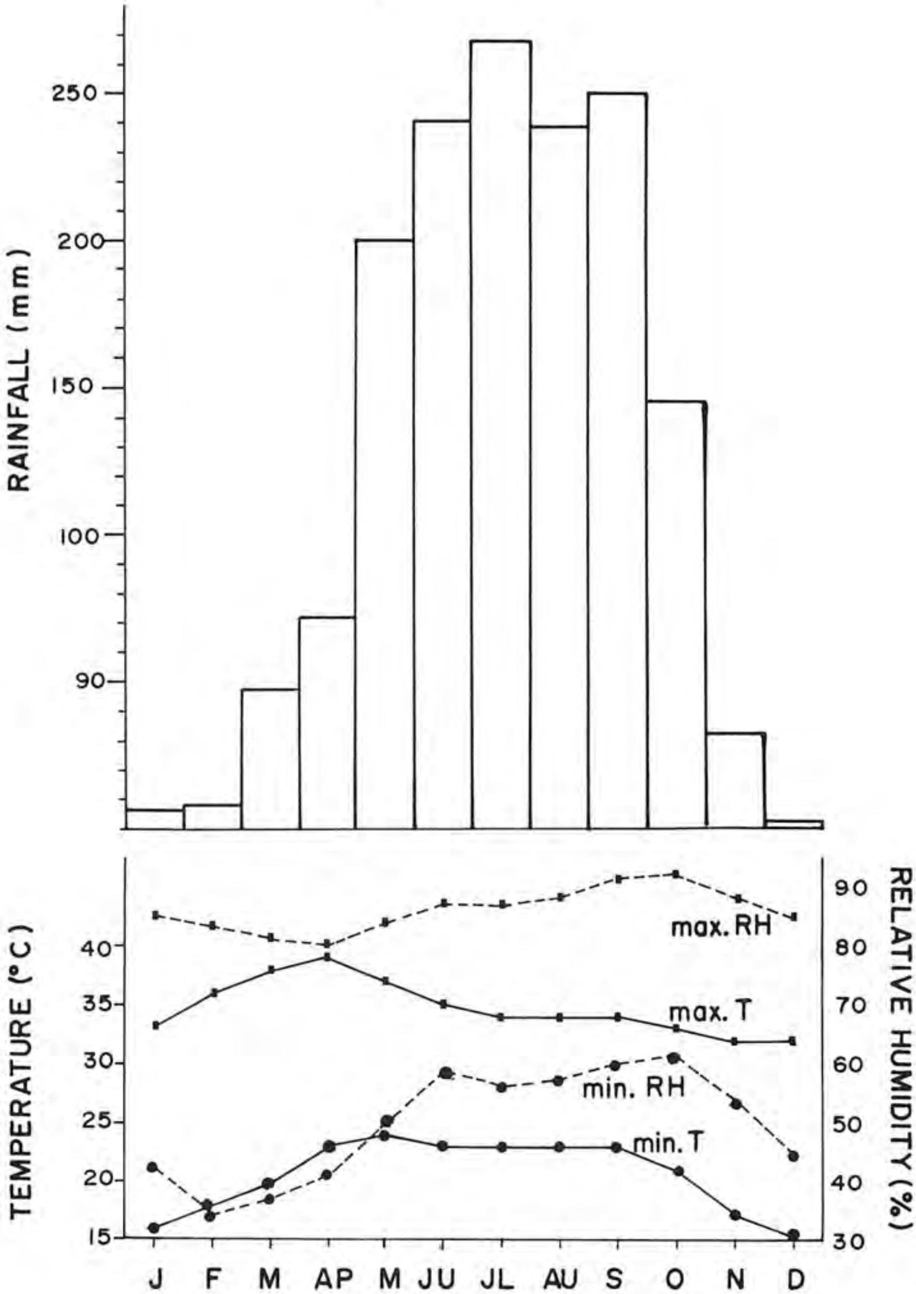

Figure 6. Above: Average monthly rainfall (Royal Irrigation Dept., Lum Sum station, Sai Yok, 1971–1980). Below: Average maximum and minimum monthly temperature and relative humidity (Royal Meteorological Dept., Kanchanaburi Station, 1971–1980).

was 30° C. The maximum temperature in the afternoon was about 5° C higher than the minimum temperature in the morning. During the day the average relative humidity was 90% (n=28).

METHODS

Trail cutting and transects to find foraging area

Transect trails 500 m. in length were cut around the cave (Fig.3) in order to patrol about the cave to detect foraging activity. After the general daily pattern of activity was determined these trails were walked with a bat detector starting just before the bats began emerging from the cave. Any *Craseonycteris* sound detected along the trail was marked on the map.

Checkpoints were selected to observe *Craseonycteris* activity and record environmental conditions. A point on a *Craseonycteris* "flyway" at 125 m from the cave was selected as a checkpoint (Fig. 3). Data from the 125 m checkpoint were recorded in 1986, on 28 days over three seasons, as follows: 12 days in winter: Jan. 20–27 and Feb. 4–7; 7 days in summer: Feb. 19–20 and March. 6–8 and 27–28; and 9 days in the rainy season: April 24 and May 14–20 and 27.

Recording environmental conditions

Air temperature (°C), relative humidity (%) and light intensity were recorded during the active period of *Craseonycteris*. A Nikkei wet–dry bulb thermometer was hung on a pole at 1.5 m from ground while recording *Craseonycteris* activity.

A Nikon EM camera with 200 mm f/4 Nikkor lens was used as a light meter to record times of twilight and darkness. Before sunrise and after sunset continuous f–stop readings were made with the ASA setting at 1600, with camera pointed at the brightest part of the sky. Because the activity period occurred partly during darkness, it was not possible to measure the light intensity during most of the active period. The time of "darkness" was defined as the time at which the needle in the viewfinder did not register any light with the aperture wide open shutter speed set at 1 sec. and ASA set at 1600. Time of "twilight" was then defined as the time at which the meter needle lined up in the middle with the aperture opened up 6 f-stops (or equivalent shutter speed settings). Times of activity are also recorded as times before sunrise and after sunset. Local sunrise and sunset time were obtained from tables prepared by the Royal Thai Navy.

Recording **Craseonycteris** *activity*

A QMC Mini Bat Detector set at 75 kHz was used to monitor *Craseonycteris* activity. Local time of activity was read from a digital wrist watch. The time and activity were recorded into a Sony WA–5000 tape recorder.

Measuring flight speed of **Craseonycteris**

Two poles were put in the ground along a *Craseonycteris* flyway, 8 m apart. An observer stood beside each pole. When a *Craseonycteris* passed the first pole, the first observer shouted a number. When the same bat passed the second pole, the *second* observer shouted the same number. The shouts of the observers were recorded into a Sony WA–5000 tape recorder. Using the difference in time of shouting between the two observers, it was possible to estimate the average flight speed of *Craseonycteris*.

Data analysis

Data were analyzed with SPSS (Statistical Package for Social Sciences) at Mahidol University Computer Center. When preliminary screening showed that values for each variable were normally distributed, parametric tests for correlation were used.

RESULTS

Activity Periods

Craseonycteris has two brief activity periods, one in the morning and one in the evening (Fig. 7). The bats start to circle at the cave entrance about one minute before leaving. At about 10 minutes after sunset, they leave the cave and circle over the entrance. About one minute later the bats spread out and rapidly disappear from around the entrance. They separate into small groups, each group using a flyway to a feeding area (Fig. 3). The bats feed for about 30 minutes in the evening, then return to the cave where they remain until about 40 minutes before sunrise, when they exit and forage again for about 18 minutes.

The periods of morning and evening activity varied seasonally (Fig. 7 and Tables 1 and 2). In winter, morning flight activity was rather late, starting about 30 minutes before sunrise, and finishing about 16 minutes before sunrise. Flight activity started much earlier in summer than in winter, at about 48 minutes before sunrise, and finished later at about 11 minutes before sunrise. The morning foraging period was longest in summer (March–April). In the rainy season morning activity lasted from about 40 minutes to 7 minutes before sunrise.

The onset of evening flight activity was earliest in summer and latest in winter. The finish of flight activity was earliest in winter and latest in the rainy season. Evening activity is shortest in winter and longest in the summer.

Over all seasons, about 57% of daily activity occurred in the evening and 43% in the morning.

Relation between activity and air temperature

There is evidence that temperature affects the foraging behavior of *Craseonycteris*. Bats were not active when morning temperatures were lower than about 19° C during Jan. 20–30, 1986 and again during Mar. 5–8, 1986. The number of *Craseonycteris* foraging in the morning was significantly correlated with air temperature when data for winter and rainy seasons were pooled ($r = 0.66$, $P < 0.01$, $N = 28$) (Fig. 8), but there was no significant correlation within any of the three seasons alone (Table 3).

Relation between activity period and relative humidity

The length of the evening activity period of *Craseonycteris* showed a positive correlation with relative humidity with seasons pooled, but no significant correlation within season (Fig. 9 and Table 4). Evening activity period of *Craseonycteris* was correlated with

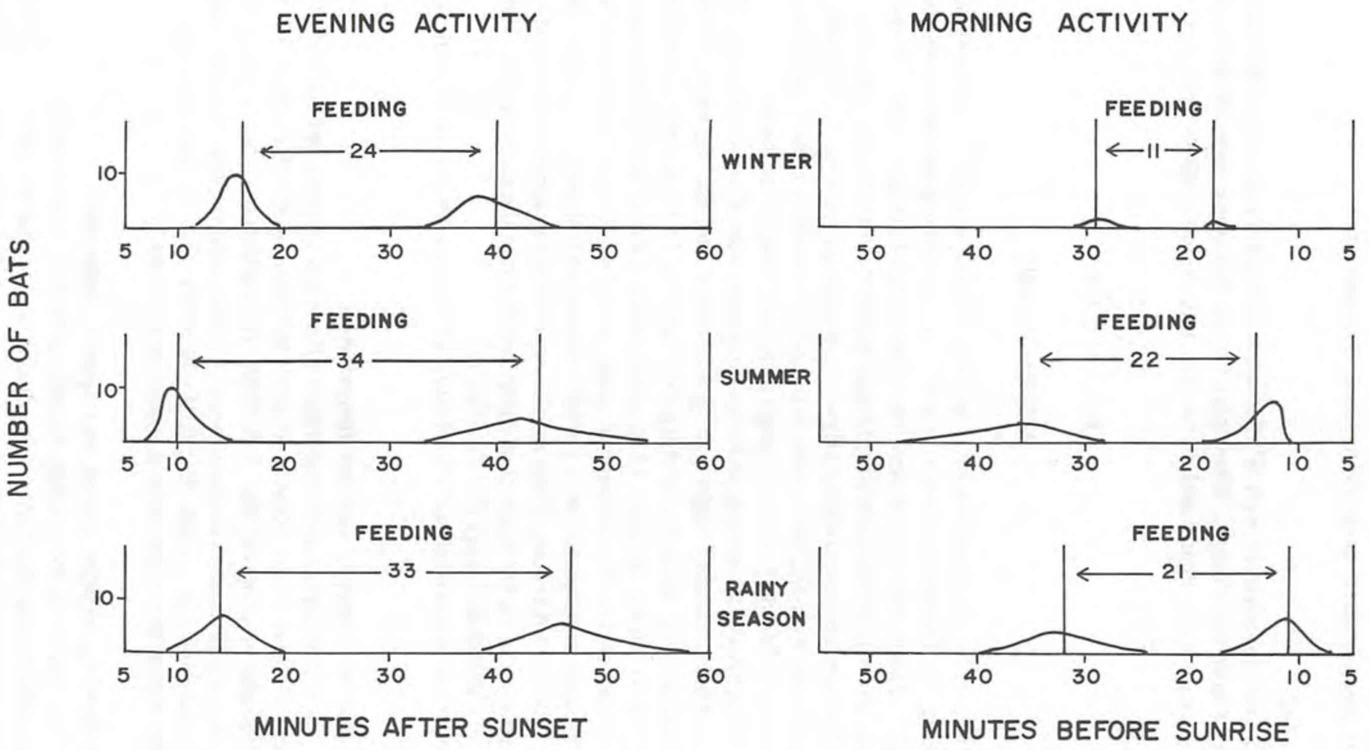

Figure 7. Schematic representation of distribution of activity of *Craseonycteris* in winter, summer and rainy season. Left, evening activity; right, morning activity.

Table 1. Mean values for morning activity during three seasons.

Morning activity	Season		
	Winter (N=12)	Summer (N=7)	Rainy Season (N=9)
No. bats out	1	21	25
No. bats in	1	28	29
Time first bat out*	31	48	40
Time first bat in*	18	19	17
Time last bat out*	25	28	24
Time last bat in*	16	11	17
First out to last in**	17	39	31
Time peak No. out*	29	35	33
Time peak No. in*	18	12	11
Peak–peak period**	15	23	23
Temperature (C)	18	19	23
Humidity (%)	82	63	85

* : Minutes before sunrise.
** : Minutes.

Table 2. Mean values for evening activity during three seasons.

Evening activity	Season		
	Winter (N=12)	Summer (N=7)	Rainy Season (N=9)
No. bats out	33	29	35
No. bats in	27	26	30
Time first bat out*	12	7	9
Time first bat in*	33	33	39
Time last bat out*	19	15	20
Time last bat in*	46	54	58
First out to last in**	33	47	50
Time peak No. out*	15	9	14
Time peak No. in*	38	42	46
Peak–peak period**	23	34	33
Temperature (C)	27	29	26
Humidity (%)	47	38	74

* : Minutes after sunset.
** : Minutes.

Table 3. Correlation coefficients between activity period and temperature within season.

Season	Morning	Evening
Winter	0.87 (n = 3)	0.19 (n = 11)
Summer	–0.20 (n=6)	0.25 (n = 6)
Rainy Season	0.92** (n = 7)	0.17 (n = 7)

* = P<0.05; ** = p<0.01; *** = p<0.001

Table 4. Correlation coefficients between length of activity period and relative humidity within season.

Season	Morning	Evening
Winter	–0.98 (n=3)	0.16 (n = 11)
Summer	–0.03 (n=6)	0.59 (n = 6)
Rainy Season	–0.87** (n=7)	0.29 (n = 9)

* = P<0.05; ** = p<0.01; *** = p<0.001

both relative humidity (negatively) and season (longest in summer) but a significant negative correlation with relative humidity within season exists only for the rainy season ($r=-0.87$, $P < 0.01$, $n = 7$) (Table 4; Fig. 10).

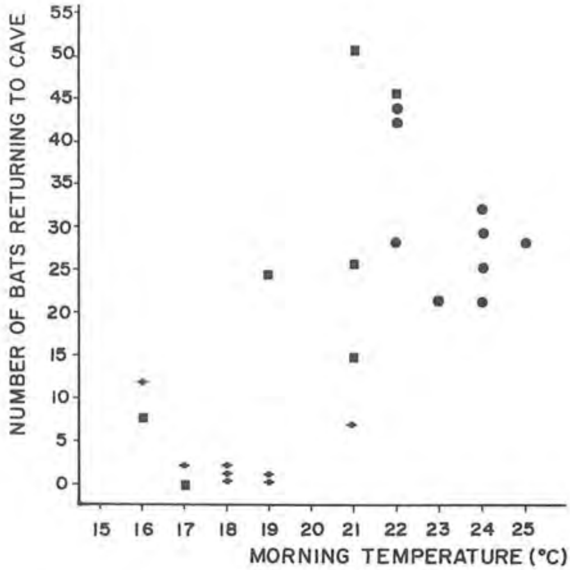

Figure 8. Scatter diagram of number of bats in the feeding area in relation to morning air temperature (r=0.66, P<0.01, n=28). +'s, winter; squares, summer; circles, rainy season.

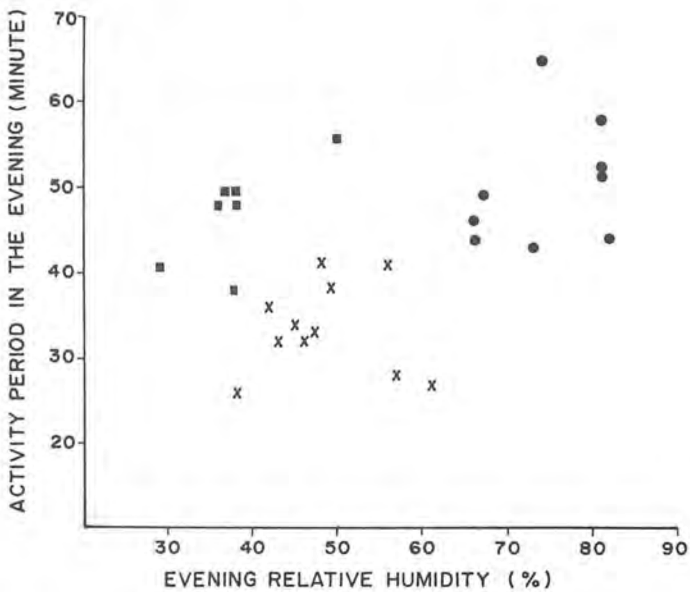

Figure 9. Scatter diagram of length of evening activity period (min.) in relation to relative humidity in the evening. (r=0.045, P<0.05, N=27). X's, winter; squares, summer; circles, rainy season.

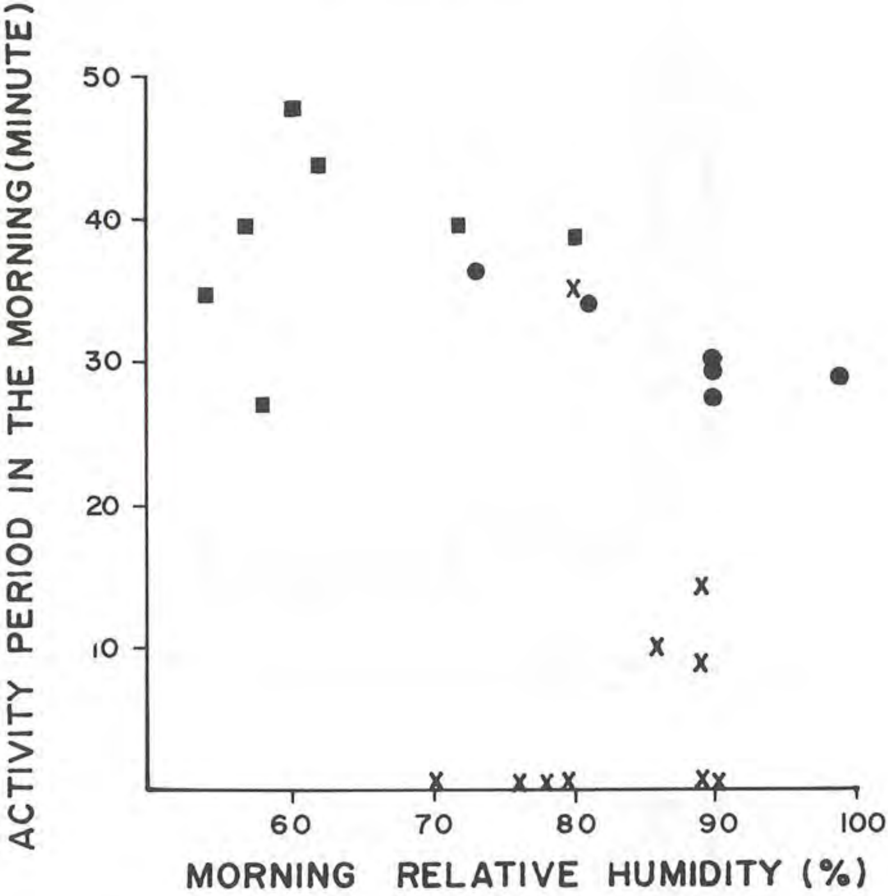

Figure 10. Scatter diagram of length of morning activity period (min.) in relation to relative humidity in morning ($r=-0.67$, $P<0.01$, $N=25$). X's, winter; squares, summer; circles, rainy season.

Light intensity

Correlation coefficients between light intensity and activity of *Craseonycteris* are shown in Table 5. There was a significant correlation between light intensity and both the onset and finish of *Craseonycteris* activity in the evening for the rainy season only; for the summer, only the onset of activity was correlated. There was an overall correlation between light intensity and the finish of activity in the morning. In general, however, correlations with light intensity are weak; the bats tended to leave and return to the cave at fixed times regardless of sky conditions. Correlations between activity and sunrise and sunset are relatively strong (Table 6) especially over all seasons. Within seasons there is probably insufficient variability to yield strong correlations.

Table 5. Correlation coefficients between light intensity and *Craseonycteris* activity, in the evening (above) and in the morning (below).

Season	Activity[1]					
	TFOUT	TFIN	TLOUT	TLIN	TPOUT	TPIN
			Evening light intensity			
All seasons (n=27)	0.28	0.06	–0.006	-0.09	0.1	–0.008
Winter (n=12)	0.00	0.09	0.13	0.05	–0.4	0.07
Summer (n=6)	0.96**	0.09	0.32	–0.07	0.86*	0.64
Rain (n=9)	–0.42	0.02	–0.60	–0.16*	–0.68*	–0.60*
			Morning light intensity			
All seasons (n=16)	–0.04	0.58**	0.19	0.51*	0.01	0.41
Winter (n=3)	–0.75	–0.73	0.95	0.95	–0.63	–0.59
Summer (n=6)	–0.04	0.51	0.19	0.39	-0.05	0.77*
Rain (n=7)	–0.03	0.70*	–0.02	0.82*	0.31	0.45

* P<0.05, ** P<0.01, *** P<0.001

[1] Definitions: TFOUT = Time first bat leaves cave (passed checkpoint) ;
TFIN = Time first bat returns to cave ;
TLOUT = Time last bat leaves cave ;
TLIN = Time last bat returns to cave ;
TPOUT = Time peak number of bats/min leave cave ;
TPIN = Time peak number of bats/min return to cave.

Table 6. Correlation coefficients between sunrise and sunset time and *Craseonycteris* activity, in the evening (above). and morning (below). See table 5 for definitions of activities.

Season	Activity					
	TFOUT	TFIN	TLOUT	TLIN	TPOUT	TPIN
			Sunset time			
All seasons (n=28)	0.93***	0.93***	0.51*	0.90***	0.92***	0.95***
Winter (n=12)	0.97***	0.60*	0.84***	0.64*	0.95***	0.60*
Summer (n=7)	–0.19	0.68*	0.29	0.28	–0.01	0.59
Rain (n=9)	0.59*	0.01	–0.43	–0.52	0.45	0.66*
			Sunrise time			
All seasons (n=19)	0.94***	0.97***	0.98***	0.98***	0.97***	0.98***
Winter (n=4)	0.89	0.30	0.28	–0.57	0.87	0.00
Summer (n=7)	0.80*	0.91**	0.83*	0.97***	0.78*	0.98**
Rain (n=8)	0.49	–0.18	0.28	0.43	0.19	0.63*

* $P<0.05$, ** $P<0.01$, *** $P<0.001$

Effect of unfavorable weather on activity

Craseonycteris stopped its activity during heavy rain and low temperature. Storms usually appeared in late afternoon in the rainy season. If a storm appeared during the active period of feeding, *Craseonycteris* would stop coming out of the cave. This happened once in the early evening of October 28, 1986. The storm began about 10 minutes before the active period, and rain continued after the storm. No bats appeared at checkpoint 125.

During January 20–30, 1986, when the temperature in the morning was lower than 19° C, no *Craseonycteris* come out for feeding. The number of bats coming out for feeding during mornings of the following days increased gradually as air temperatures become warmer. The number of bats coming out in the morning decreased again when the air temperature become lower than 19°C for 5 days during March 5–8, 1986.

Foraging Behavior

Flight paths

There were four bat routes from the entrance of cave 30 (Fig. 3) as follows:

Route A extended southwest from the cave. The check point was at 125 m from the cave along the route. I observed *Craseonycteris* from this check point in every season. An average of 33 bats used this route during the evening. The distance between the cave and the farthest feeding area was about 1 km. When *Craseonycteris* flew out for feeding, they usually kept within a narrow flight line on the route between the cave and foraging area up to 250 m from the cave. Beyond 250 m some of the bats separated from the main flyway. The width of the route was not more than 5 m. Some bats flew in a straight path to the farthest area. At the end of feeding period, the bats joined along the same route again to return to the roosting cave.

Route B was in the same direction as route A, but located about 70 m to the west. The numbers of bats using this route varied from about 5 up to 70 individuals.

Route C went to the northeast and turned to the east about 50 m from cave. About 10 bats used this route in the rainy season.

Route D went to the north. About 6 bats used this route in winter and summer, but the number increased up to 60 in the rainy season.

The numbers of bats using each route changed every day. On routes B, C and D, the numbers of bats varied much from season to season, but on route A, the number of bats did not change much with season. The average number of bats leaving in the evening along route A is shown in Table 2, and the number of bats returning to the cave in the morning is shown in Table 1.

In winter and summer no bats were seen on Route C; only about 6 bats were seen on route D and only about 10 on route B. But in the rainy season the numbers of bats on the routes B, C and D increased as follows: B, 63; C, 14 and D, 60 (bats on each route were counted in the morning of different days).

Foraging

The earliest bats to come out during each feeding bout usually occupied foraging areas farthest from the cave; later bats scattered and occupied foraging areas along the route.

Craseonycteris usually circled in a small patch of foraging area about 10 m in diameter. A bat would spend 1 or 2 minutes in one foraging location and then move to another place. They repeated this foraging behavior many times during the feeding bout. The bats often swooped up and down while circling. It was likely that they were catching insects, but I seldom heard a terminal buzz coinciding with the swooping action. Each individual had its own foraging area. Occasionally, when another bat got into an individual's foraging area it would be chased out. While flying back to the cave at the end of the feeding bout, some individuals would also stop to feed at certain points along the way back.

The pattern of flight was observed carefully at the 125–m checkpoint along Route A, both leaving and returning to the cave. Bats were often seen flying together in pairs. They did not fly smoothly and in a straight line along the flight path; they had an acrobatic and moth–like flight.

Flight speed of Craseonycteris

Flight speeds of *Craseonycteris* were measured when the bats flew from the cave to feeding areas and from the feeding areas back to the cave in the rainy season (May 17–19, 1986). The distribution of flight speed of 58 *Craseonycteris* is shown in Fig. 11. Flight speeds in the morning and in the evening were similar. Mean flight speed was 26.2 km/h (N=46, range 18–40) in the morning (measured while the bats were flying back to the cave) and 23.6 km/hr (N=12, range 16–28) in the evening (measured while the bats were flying from the cave).

Population Dynamics

Breeding and parental behavior

The breeding season of *Craseonycteris* began in the late dry season (late April). Each female gave birth to only one baby. The females gave birth to the young in their roost (Fig. 12).

Mothers left their babies in the roost when they flew out for feeding. Each mother carried her baby with her all the time while in the roost. When they were disturbed during inactive periods they flew away with their babies.

A pair of special organs appeared near the female's genital area in the breeding season. The baby clung to its mother by holding these organs in its mouth and placing its legs around its mother's neck (Fig. 13).

Evidence of migration

Craseonycteris in cave 1 disappeared from their usual roost in winter (Jan, 1985), but reappeared in summer (April, 1985) and stayed there through the rainy season. However, *Craseonycteris* were found throughout the year in cave 30.

Predators

Many possible predators were found near the *Craseonycteris* colony in cave 30. Five species of birds of prey were found as follows:

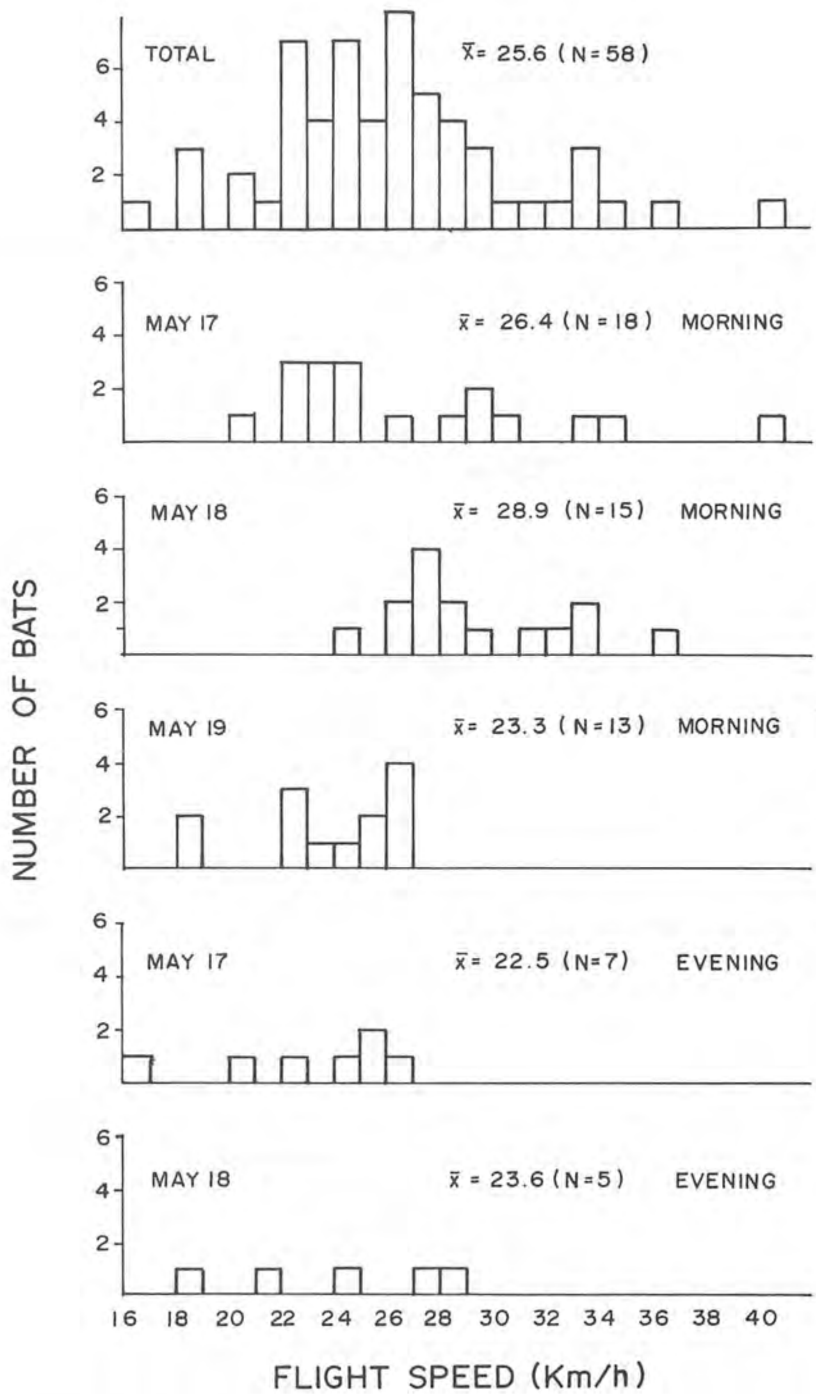

Figure 11. Distribution of flight speed of *Craseonycteris*.

1. Shikra, *Accipiter badius*
2. White–rumped Falconet, *Polihierax insignis*
3. Barred Owlet, *Glaucidium cuculoides*
4. Common Scops Owl, *Otus scops*
5. Chestnut–backed Shrike, *Lanius collurioides*

Many diurnal birds are still active during the active period of *Craseonycteris*. Ten individuals of the carnivorous bat, *Megaderma lyra*, were found in cave 31 with 50 *Craseonycteris* in 1985, and all *Craseonycteris* disappeared from the cave 11 months later. It is possible, but not certain, that the *Megaderma* preyed upon the *Craseonycteris*.

DISCUSSION

Ranging and Foraging

Why does *Craseonycteris* have flyways? Flyways have been reported in several species of bats (LEKAGUL & MCNEELY, 1977; VOUTE, 1972). Some bats are thought to use flyways to avoid predators (ERKERT, 1982). The major purpose of flyways in *Craseonycteris* may be to minimize the energy cost of foraging. Foraging in or along a familiar way may enable *Craseonycteris* to feed more efficiently in a shorter time than would be possible along an unfamiliar path. The flight behavior of *Craseonycteris* in the flyway showed that the bats were familiar with it. The flight interval between individuals or couples ranged from about 4 sec to more than 1 min. Those individuals not following other bats must be navigating independently.

Foraging confined to two short activity periods has never been reported in any other bat species. The bats go out at about 10 minutes after sunset, spend about 30 minutes feeding and go out again at about 40 minutes before sunrise and spend 18 minutes feeding. Most of other species of bats go out early after sunset and return to the cave just before sunrise (BELL, 1980; ERKERT, 1982; HILL & SMITH, 1984; KUNZ, 1974). Bats are most active at times when insects are abundant (RABINOWITZ, 1978). NYHOLM (1965) reported that *Myotis mystacinus* foraged all day because insects were more abundant during the day (lat. 60° 37'N). Normally insects have peak abundance in early evening and in early morning (RABINOWITZ, 1978). *Craseonycteris* selects these times of peak insect abundance to optimize its feeding.

The number of *Craseonycteris* appearing on the flyways was not constant from feeding bout to feeding bout. There are two possible explanations for these changes:

1) Torpor after the activity period. *Craseonycteris* may feed for one bout and then go into torpor and skip feeding for the next two or three feeding bouts. Each individual may have different success in finding insect prey in each feeding bout. This might be partly due to variation in abundance of insects from site to site and from night to night (BELL, 1980; RABINOWITZ, 1978; ROMOSER, 1981). Changes in numbers of *Craseonycteris* using route A were not related to either daily or seasonal temperature or humidity variations.

2) *Craseonycteris* may be able to communicate information to one another about the abundance of insects in different foraging areas, perhaps at the cave entrance or along the flyway. Exchanging information about food sources has been reported in bees and in some

Figure 12. Female *Craseonycteris* hanging in cave roost, in threatening posture. Baby is clinging on underside.

Figure 13. Picture showing special organs for carrying young in female *Craseonycteris* (2 finger–like projections on lower abdomen).

species of birds (BROWN, 1986; GROOT, 1980; KREBS & DAVIES, 1981). In Cliff Swallows *(Hirundo pyrrhonota)*, it has been reported that birds unsuccessful in finding food follow the successful birds in order to reach the food sources (BROWN, 1986).

Humidity and Temperature

The evening activity period of *Craseonycteris* was longer in seasons with high relative humidity than in the dry season but there was no significant correlation within seasons. The morning activity period, however, was longest in the season with lowest relative humidity in the foraging area. There are two possible reasons to explain the positive effect of relative humidity on bat activity in the evening and the inverse relation in the morning.

One might be that insects are more abundant during times of high relative humidity, if the temperature is appropriate. Temperature in the morning in the cold season may reduce insect activity even though humidity is very high. ROMOSER (1984) mentioned that extremely high or low relative humidity causes feeding, reproduction and development of insects to decrease.

Variation of relative humidity from day to day within each season might have only small effects on insect abundance, but large scale variation from season to season might produce significant effects. Insect abundance in the evening might be affected by relative humidity alone, but low temperature in the morning in winter might adversely affect insect abundance regardless of humidity. In summer and the rainy season, air temperature was warmer while relative humidity was still high.

Another explanation for the effect of relative humidity observed might be that in winter, high humidity coincides with low temperature in the morning, which may cause excessive loss of body heat. Loss of heat may force the bats to return to the cave earlier.

It is significant that *Craseonycteris* decreases its activity when air temperature is low (Fig. 8). NYHOLM (1965) also reported that *Myotis mystacinus* (lat. 60° 37'N) foraged during day time and stopped foraging at night due to low ambient temperature. Many bats forage for a shorter time in cold weather, and when the temperature falls below a certain threshold the bats stop foraging (O'FARREL & BRADLEY, 1970; LAUFENS, 1973). At a temperature lower than 19°C all *Craseonycteris* stop going out for feeding. A very small mammal requires a lot of energy to maintain its body temperature (GOLLEY, 1975; MCNAB, 1982). It is also significant that *Craseonycteris* uses the warmest part of the cave (dome ceiling shape) for roosting.

Light

Some weather conditions, for example cloudiness, mist and rain, cause the sky to become bright later in the morning and dark earlier in the evening. Light intensity changed somewhat from day to day but did not much affect the activity of the bats. Some activity was found to be significantly correlated with evening and morning light intensities, but the results are not clear and cannot be used to predict the timing of activity.

Activity apparently was affected by various different environmental factors in different seasons. Activity in the morning in winter was affected by low temperature. Activity in the morning and evening in the rainy season might be affected by storms or rain. Activity in the evening in summer might be affected by other variables. Although activity of *Craseonycteris* is probably controlled by an endogenous rhythm which is adjusted by sunrise time (ERKERT, 1982), its activity is also sensitive to changes in some environmental conditions.

Flight Speed

Flight speed was measured in the beginning of the rainy season (May 17–19, 1986) while most of the females already had babies with them. There was wide variation in the flight speeds of the bats. The total range of flight speed was 16 to 41 km/h and the mean speed was 25.6 km/h (N=58). The bats coming out to feed in the evening and those returning after feeding in the morning did not differ much in flight speed.

The volant young born the previous year might have slightly different flight speeds; however, the distribution of flight speed of all bats was not clearly bimodel.

Population Size and Conservation

Environmental conditions affecting survival of *Craseonycteris* are summarized below.

Forest habitat. Caves with *Craseonycteris* are known only in the dry evergreen or deciduous forests in the west of Thailand. Feeding areas of *Craseonycteris* are relatively small, within flying distances of 1 km from the cave. These two conditions confine *Craseonycteris* to caves in the vicinity of appropriate foraging habitat. If its specific caves and habitats are disturbed, it will be very difficult for *Craseonycteris* to find new roosts.

Unfavorable weather. There are two types of unfavorable weather which stop the activity of *Craseonycteris* : heavy rain and low temperature. Heavy rain, when a storm appeared at the onset of *Craseonycteris* activity, prevented the bats from following their usual flyway. They foraged within about 100 m around the cave for a few minutes and then returned to the cave soon after the rain started. These responses suggest that *Craseonycteris* may not be able to exist in the evergreen forests in the south of Thailand, because there is much more rain in the south.

Low temperature. At temperatures lower than 19°C in the morning during winter, no *Craseonycteris* came out for feeding. In the limestone ranges in northern Thailand the climate may be too cold for *Craseonycteris,* and the species may not be able to exist even if suitable forest habitat and caves are available.

The following behavioral characteristics may affect the survival and conservation of *Craseonycteris.*

Individual *Craseonycteris* roost separately from each other and are easily disturbed. The species has already disappeared from Sai Yok Cave (cave 19, Fig. 3) which is heavily visited by tourists in Sai Yok Park (although it was recently reported to have returned). Bats are widely spaced apart in the roost and hence at very low density. *Craseonycteris* has two brief foraging periods, and may be in torpor during the inactive period. Frequent disturbance of its roost may cause it to consume too much energy which cannot be made up during the brief foraging periods. *Craseonycteris* uses certain flyways to reach its foraging areas, and disturbance of these flyways by burning in the dry season or deforestation may effect the resources or feeding success of *Craseonycteris* and also adversely affect its energy balance.

Female *Craseonycteris* give birth to only one baby a year. If female *Craseonycteris* become torpid during long inactive periods, the gestation period might be prolonged. The volant young might require a longer time to reach adulthood. If the population becomes endangered through disturbance, it may need a long time to recover.

Although *Craseonycteris* may be the target of many predators, including *Megaderma* bats and several species of predatory birds, humans may be the worst predators. It has been eagerly sought after by scientific collectors and tourists, and local people have collected the bat for sale to visitors. Visitors have entered caves in excessive numbers to observe the bat. The bat may easily become extirpated from some caves if special management precautions are not taken. On the other hand, the fact that *Craseonycteris* exists in many small colonies, many rather inaccessible, may also work in its favor, as there hopefully will always be some caves free of disturbance.

The breeding season of *Craseonycteris* is in late summer (April–May). Burning of the forest occurs at this time every year in the dry season. Burning may affect the survival of young, as burning destroys the foraging area. The caves with *Craseonycteris* located near villages may be threatened.

CONSERVATION RECOMMENDATIONS

Destruction of feeding habitats of *Craseonycteris* may be one of the major causes of decline of the population, but disturbance by people, including scientists, has also been a major problem. Previously, local people never paid much attention to very small bats such as *Craseonycteris*. The larger size bats such as *Hipposideros armiger* or *Taphozous spp.* are targets of the local people for food on occasions when they are not successful in hunting other animals. Local people have collected *Craseonycteris* at Sai Yok because of the demand by visitors. I believe that the following recommendations, if carried out, will be able us to maintain the long-term survival of *Craseonycteris*.

1. Guidelines concerning further research involving *Craseonycteris* should be carefully set up.
2. Cave 30 is the best study site because it is very accessible and not visited by tourists. Any further research should be set up here under strict guidelines and supervision.
3. In order to follow the long term survival of *Craseonycteris*, it is most urgent to establish a long term monitoring program of populations both in undisturbed habitat and in destroyed or unprotected habitat.
4. Further surveys should be carried out in order to establish the exact distribution of *Craseonycteris*, especially in limestone areas to the north and north–east of the known *Craseonycteris* range.
5. A study of ecology of insects along each flyway and outside the flyways should be carried out at cave 30, in order to better understand the purpose of their feeding routes and effects of disturbance on them.
6. An education center with special exhibits on *Craseonycteris* should be set up at Sai Yok National Park headquarters for visitors.
7. Sai Yok Cave,in which *Craseonycteris* was discovered for the first time, should be fenced at about 100 m around the cave entrance. *Craseonycteris* has reportedly returned to Sai Yok Cave again. Visitors should be prohibited from entering any *Craseonycteris* caves in the park. Scientists and naturalists who wish to take pictures, etc., should enter only with permission of the Royal Forest Dept., and only with proper supervision.
8. No further museum collection of *Craseonycteris* should be permitted under any circumstances.

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