

# Surveying bats for conservation: the status of cave-dwelling bats on Curaçao from 1993 to 2003

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## Keywords

bat caves; bat census; bat monitoring; bat population fluctuation; bat species compatibility; bat roost disturbance; bat survey; survey regularity.

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Received 16 August 2005; resubmitted 31 August 2005; accepted 10 November 2005

doi:10.1111/j.1469-1795.2005.00012.x

## Abstract

In view of their ecological importance and the abundance of threats on a developing Caribbean island, we surveyed the bats of Curaçao, Netherlands Antilles, and examined changes in the populations of seven threatened species over a decade, using previously published data as a baseline for comparison. The most important caves for bats (in terms of species representation and reproduction) were visited yearly, and monthly in 2001. *Noctilio leporinus* still occurs on the island, but does not appear to be numerous (six observed in 2003). We captured *Myotis nesopolus nesopolus*, but its roosting sites remain unknown. *Leptonycteris curasoae curasoae* numbers varied greatly, even within a year, and it may travel to and from other islands and Venezuela. Overall, however, the population of this species on Curaçao seems to be declining (1000 in 1993 and 625 in 2003); the disappearance of this pollinator could have severe consequences for the Curaçao ecosystem. *Mormoops megalophylla intermedia* is declining as well; in 2003, we counted 403 individuals including 75 pups, from 500 to 600 adults in the 10 previous years, representing a 25–30% decline in 1 year. We estimated the population of *Natalus tumidirostris* to be 890 in 2003. We also found a group of 60 *Pteronotus davyi* in Kueba di Ratón in 2003. *Glossophaga longirostris elongata* (1417 individuals counted) is the only species for which our data indicate relative stability over 10 years; *L. curasoae* and *Mor. megalophylla* are declining and other species must be monitored closely. Most caves are disturbed; four major caves require attention for the conservation of the most fragile species. Without immediate attention, *Mor. megalophylla*, in particular, risks imminent extinction. Despite problems associated with bat counts on Curaçao, it is clear that regular surveys are crucial to understand bat populations and their fluctuations in caves, and to allow management responses to declines, particularly for areas undergoing rapid urbanization.

## Introduction

Environmental legislation for the semi-arid island of Curaçao, Netherlands Antilles, is still in its infancy. Rampant urban development and lack of protection are likely to result in the extinction of native species. We examined the bats of Curaçao because they constitute the largest group of native mammals on the island, and the ecological importance of at least the nectar-feeding bats, which are associated with columnar cacti in a keystone mutualism, has been demonstrated (Petit, 1995). Without these bats, the natural ecosystem of Curaçao would collapse. In 1992 and 1993, we conducted the first extensive surveys of bats on Curaçao (Petit, 1996). Here, we present the results of regular surveys since then up to September 2003.

Curaçao is located 70 km north of Venezuela, and has a surface area of only 444 km<sup>2</sup>, excluding inland waters. Curaçao's mean yearly rainfall between 1971 and 2000 was

553.4 mm (source: Bureau of Meteorology, Mahuma). The official human population was 129 944 on 1 January 2003 (source: H. Martina, Central Bureau of Statistics, Curaçao).

Threats to bats and their roosts have received little attention, in spite of the importance of bats to the island. For example, the two nectar-feeding species (*Leptonycteris curasoae curasoae* Miller and *Glossophaga longirostris elongata* Miller) pollinate several plant species, including columnar cacti, which provide essential resources for wildlife when most of the other fleshy fruit-bearing vegetation is dormant during the dry season (Petit, 1995).

Urban development continues and an increasing surface area of cactus scrub is cleared each year. New homes are being constructed even where development is not allowed by the land use plan of 1995 (Curaçao's first; Eilandgebied Curaçao, 1995), with no consequences for builders and owners. The island's government is attempting to increase tourism activities on Curaçao, and a few businesses are now

**Table 1** Bat species expected to occur (H) (from Husson, 1960) and occurring (O) on Curaçao, endemic to the island as determined by Miller (1900; M) and confirmed by Genoways & Williams (1979; G), with total numbers from the 2003 survey and conservation status on the island using IUCN criteria (IUCN, 2001, 2003)<sup>a</sup>

Species	Family	Occurrence	2003 numbers	Recommended status
<i>Artibeus jamaicensis</i>	Phyllostomidae	H	–	RE (or NA, was vagrant)
<i>Glossophaga longirostris elongata</i> MG	Phyllostomidae	HO	1417	LC
<i>Leptonycteris curasoae curasoae</i> M	Phyllostomidae	HO	625	CE
<i>Molossus molossus pygmaeus</i> M	Molossidae	H	–	RE
<i>Mormoops megalophylla intermedia</i> MG	Mormoopidae	HO	403	CE
<i>Pteronotus davyi</i>	Mormoopidae	O	60	EN
<i>Myotis nesopolus nesopolus</i> MG	Vespertilionidae	HO	?	DD
<i>Natalus tumidirostris</i> MG	Natalidae	HO	890	DD
<i>Noctilio leporinus</i>	Noctilionidae	HO	6	CE

<sup>a</sup>RE, regionally extinct; NA, not applicable (IUCN, 2003); LC, least concern; CE, critically endangered; DD, data deficient; EN, endangered. Here we do not make assumptions about the possible recruitment of bats from other islands or the mainland; it is possible that *Leptonycteris* and *Noctilio* disperse to and from Curaçao.

conducting cave tours on the north coast, where most caves are located. The impact of such activities on bats and caves is unknown, but only groups of *Glossophaga longirostris*, if any, occur in the most frequently visited caves. Garbage and graffiti are found in caves; trampling and structural damage to cave features also result from human visitation.

In 1993, the date of the last major survey before the one we conducted in the present study, seven species of bats were found on Curaçao (Petit, 1996; Table 1); they seemed to occur in relatively low numbers compared with reports from early explorers (Van der Horst, 1924; see also Husson, 1960) and in view of the stains present on the ceiling of many caves. Reports from Husson (1960) mentioned that Grot van Hato (Hato cave) contained at least *Mormoops megalophylla intermedia* (Miller) and *G. longirostris*; it now contains only the latter species.

Considering the relatively low numbers of bats and appropriate roosting caves and the existence of uncontrolled threats, Petit (1996) suggested that all species be considered endangered or threatened (only *G. longirostris*) and recommended that special attention be placed on three very important caves. The cave system located in the Christoffel Park (Bosá caves) has been receiving some protection for the last few years; currently, only one cave containing very few bats may be visited by the public. An attempt was also made to close Kueba (cave) di Ratón and Kueba di Jetchi to the public but the design was inappropriate (see discussion).

From 1992 to 2003, we examined the bat populations of Curaçao yearly, except in 1999 and 2002; we conducted monthly surveys in 2001. The major census of 1993 appears in Petit (1996). Such comprehensive and medium-term bat surveys are rare, and natural variability of populations within roosting sites and over time is unknown for most bat species. This study, in addition to providing vital information about the status of bats on a Caribbean island, will assist in evaluating future movements of long-distance flyers such as *L. curasoae* among islands and Venezuela, confirms compatible bat assemblages within caves, as well as general

cave requirements, and aims to alert authorities to the great conservation needs of bats and dependent organisms on Curaçao.

## Materials and methods

### Survey locations

Two of us (L. P. and A. R.) conducted bat surveys in major caves (based on species representation and reproduction) from 1994 to 2001 (except 1999); in 2003 we visited additional known roosts. Few non-succulent native trees grow on Curaçao; most are inappropriate for roosting and bats were never observed emerging from trees, although certain bat species use them during the night. Consequently, our surveys focused on caves. Survey times depended on the availability of the researchers who volunteered for this long-term project, but attempts were made to confine census times close to October, as in Petit (1996). A census was also conducted monthly from October 2000 to November 2001 in selected caves, including the three caves of the Bosá system, Kueba di San Pedro, Kueba Bruha, Kueba di Diabel, Kueba di Jetchi, Kueba di Ratón, Kueba di Noordkant, Kueba di Koral Tabak and Kueba di Ronde Klip. These caves were chosen because they included the major caves used for reproduction, as well as caves located along the way between the major caves. The 'major' caves are the Bosá system, Kueba di Jetchi, Kueba di Ratón and Kueba di Noordkant; they are considered very important because they contain all bat species of Curaçao, excluding *Noctilio leporinus* (Linnaeus), and all populations of the other species, excluding *G. longirostris*.

*Noctilio leporinus*, a piscivorous and insectivorous species, is not represented in these caves; it roosts in separate rock crevices. All crevices accessible from the sea along the south coast from Piscadera Baai to Lagun were visited on 15 March and 6 May 1994. In 1994, a crevice near Daai-booi-baai was discovered to contain *Noctilio*. It was visited by one of us (L. P.) four times between 1994 and 2003.

In 2003, the survey of some of the most significant caves took place on 13 September; Grot van Hato, Kueba di Boca Grandi, Kueba di Diabel, Kueba Bruha, Kueba di San Pedro and Kueba Ascención were also included that day. We visited Kueba di Koral Tabak on 15 September and Kueba di Noordkant and Kueba di Ronde Klip on 16 September. The crevice near Daaiboobaai was examined on 17 September and additional locations were visited between 14 and 26 September.

The map of Curaçao (Fig. 1) indicates the location of the sites surveyed in 2003. These sites were the same as in 1993 (see Petit, 1996), except for Porto Marie 1 (bats not visible) and Kueba di Piedra Spaño, Kueba di Playa Mansalina, Riet's house (not surveyed), and additional sites surveyed in 2003 (see 'Results').

In 1994, one of us (A. R.) found that a small passage in Kueba di Noordkant opened onto a room containing a fairly large group of *Natalus tumidirostris* (Miller). A. R. also discovered another chamber in 2001. Numbers for this species are thus more accurate for the end of 2001 and in 2003 than reported previously. This Noordkant group is difficult to count because of the cave structure and the restlessness of the species; thus, counts from this cave must be viewed with more caution than others.

Another caveat concerns our counts of *Mor. megalophylla*. We probably included *Pteronotus davyi* individuals in the *Mormoops* count until May 2001, when we discovered that *P. davyi* individuals were using the same roost as did *Mor. megalophylla*.

Because of the importance of *Leptonycteris curasoae curasoae* as a cactus pollinator (Petit, 1995, 1998), its concentrated presence in only two caves (Petit, 1996), the dependence of its diet on cacti (Petit, 1997) and an indication that nectar-feeding bats are at carrying capacity in

relation to cactus resources (Petit & Pors, 1996), this species' population size was checked more frequently than that of other species. Thirty-eight visits made to Kueba di Jetchi or Kueba Bosà since the 1993 survey indicated the presence of 450 and 550 *L. curasoae* in these caves, respectively.

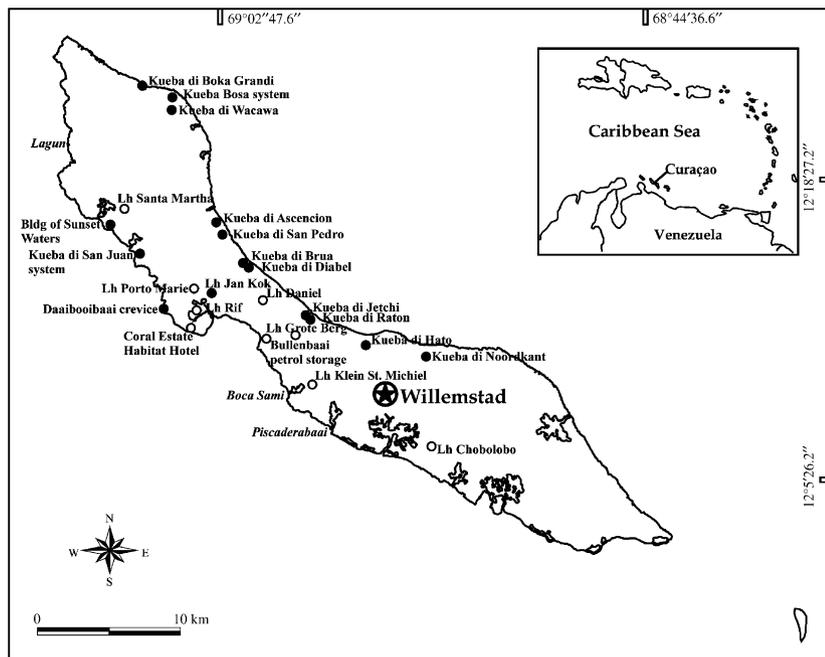
On 20 September 2003, we used a harp trap (Petit *et al.*, 1995) at 18:45 h to confirm the existence of *Myotis nesopolus nesopolus* (Miller) at Kueba di Jetchi. We removed the trap before *L. curasoae* emergence to avoid additional stress to individuals of this species.

## Survey methods

For the caves and buildings, two people estimated the number of bats of each species independently twice, one bat at a time, and then researchers agreed on the final number. The numbers estimated by both researchers were very close ( $\pm 10$  of total) except for a few instances. On those occasions, the number of bats in the cave was estimated a second time. Both researchers wore Willson<sup>®</sup> respirators (Survivair, Santa Ana, CA, USA) with T01P100 cartridges in the caves to reduce exposure to fungal spores.

Surveys always occurred in caves and buildings during the day, using flashlights. Many caves have several openings, which precludes emergence counts. In addition, several bat species share the same caves and may not be distinguished upon emergence. We focused on the major caves during the same day, to avoid double-counting bats that may have changed roosts. Unfortunately, Kueba di Noordkant, a major cave, is very difficult to survey on the same day because it takes half a day to access and survey it.

As in Petit (1996), overestimates were possible when bats escaped to undisturbed areas of caves with or without distinct chambers, and underestimates were also possible



**Figure 1** Map of Curaçao including sites surveyed in 2003. Closed circles represent sites containing bats.

for caves with small passages and areas not accessible to people. In addition, it is impossible to know all the buildings in which bats occur, and some small caves and crevices containing bats probably remain to be discovered or re-discovered. We did not visit the two caves at Eastpunt because of difficulties in accessing private property. In spite of these limitations, we believe that our surveys are as accurate as they can be, given our current knowledge of the Curaçao environment.

We used general IUCN criteria (IUCN, 2001, 2003) to assign a conservation status to each bat species, so as to assist government organizations on the island in establishing priorities for bat conservation. Interpretation of the criteria can be quite variable for bats, however. We considered maternity roosts to be essential locations of occurrence, for example, and the surface area of occurrence was not considered to be as important as the number of roosts.

### Measurement of *Pteronotus davyi*

On 2 September 2003, we captured 17 individuals of *P. davyi* (Gray) by holding a butterfly net to the ceiling of Kueba di Ratón. We recorded forearm length, mass and ear length (from base to tip) as data for this species had never been collected on Curaçao. We also examined forearm length and recorded body mass (data presented with standard deviations) of dried Venezuelan specimens located at the Museum of Natural History in Washington, DC, USA, to ensure that the species present on Curaçao matched the general characteristics of *P. davyi*.

## Results

The bat species expected to occur on Curaçao, based on Husson (1960), and those found in 2003 are presented in Table 1, along with our estimates of their conservation status based on IUCN criteria. Survey results are presented for each species individually.

### *Noctilio leporinus*

In March 1994, a crevice that contained 35 *No. leporinus* was discovered near Daaibooibaai. In May of that year, a cave near Santa Cruz contained 10 *No. leporinus*. One of us (L. P.) visited the crevice c. 1 month after Hurricane Lenny in December 1999 (no bats), on 23 February 2000 (bats present but not counted) and in September 2000 (14 bats were counted). Six *No. leporinus* occupied the crevice on 17 September 2003. The individuals photographed during the 2003 survey were males with large testes, indicating they may be reproductively active at this time. L. P. also witnessed the emergence of four *No. leporinus* on 22 January 1998 from a location under the Willemstad bridge; he observed no bat at this location during a later visit (date not recorded).

### *Myotis nesopolus*

As in 1993 (Petit, 1996), we did not find a large roost of *Myotis nesopolus nesopolus*. Thirteen individuals of this species were captured between 1991 and 1993, most of them flying into caves occupied by other species (Petit, 1996). We have not run a regular capture programme since 1994, but on 20 September 2003 we captured two individuals at the entrance of Kueba di Jetchi. One male had a forearm length of 30 mm, and the other individual escaped. Five small bats were noted among *P. davyi* in Kueba di Ratón on 13 September 2003 that may have been *Myotis*, but we were unable to confirm its presence in the cave. We captured two *Myotis* at Klein Hofje sewage plant (females with forearm length of 30 mm) on 26 September 2003, and two more were detained in the trap long enough for identification. The bats were flying into a group of bushes and trees that they seemed to use for resting. We confirmed that this species started foraging earlier than did the other insectivorous species (18:40 h; their foraging activities coincided with that of swallows for a time) echolocating at frequencies around 30 kHz, and that many were present at Klein Hofje. Another species (echolocating at around 60 kHz) arrived at 19:00 h, followed 10 min later by a less abundant species (echolocating at around 90 kHz). *Myotis* numbers at the plant seemed to decrease an hour later.

### *Artibeus jamaicensis* and *Molossus molossus*

We did not observe *A. jamaicensis* (Leach) and *Molossus molossus pygmaeus* (Miller) as would have been expected following Husson (1960). Both species may be extinct on Curaçao, although our search effort focused mostly on cave-dwelling bats and *A. jamaicensis* and *Mol. molossus* can take advantage of other dwellings, such as vegetation and buildings (*Mol. molossus*).

### *Natalus tumidirostris* and *Pteronotus davyi*

Some notable discoveries of the last 10 years include larger populations of *P. davyi* and *Na. tumidirostris* than known previously (Tables 1 and 3; see Petit, 1996). Both species roost with *Mormoops megalophylla intermedia* but *Na. tumidirostris* also occurs alone in two chambers of Kueba di Noordkant. In 2003, we counted 890 *Na. tumidirostris* and 60 *P. davyi* on Curaçao (Table 1).

Confirmation of the identity of *P. davyi* followed the capture and measurement of several individuals. Seventeen individuals of *P. davyi* captured in September 2003 included 11 adult females, five adult males and one juvenile male. The mean body mass for females was 9.9 g ( $\pm 1.4$  g) and 9.3 g ( $\pm 0.4$  g) for adult males. The mean forearm length for females was 46.2 mm ( $\pm 1.71$  mm) and 46.0 mm ( $\pm 0.52$  mm) for adult males. Ear length averaged 14.2 mm ( $\pm 1.34$  mm) in females and 14.0 mm ( $\pm 0.49$  mm) in adult males. The young male weighed 8.0 g; his forearm length was 45.3 mm and his ear length was 14.8 mm. These measurements are comparable with those of the Venezuelan

specimens housed in the National Museum of Natural History Washington, DC, USA. The mean female mass was 9.4 g ( $\pm 0.91$  g;  $n = 16$ ) and 9.2 g ( $\pm 0.64$  g;  $n = 14$ ) for males; the mean female forearm was 47.2 mm ( $\pm 1.01$  mm;  $n = 17$ ) and 46.3 ( $\pm 0.86$  mm;  $n = 14$ ) for males. The results suggest that the species present on Curaçao is likely to be *P. davyi* and not a new species.

### ***Mormoops megalophylla***

Compared with 500–600 over a decade, we found only 403 *Mormoops megalophylla intermedia* on Curaçao in 2003 (Table 1), 75 of which were pups in Kueba di Ratón (30 carried by their mother). No pups were present in Kueba Bosá II.

### ***Leptonycteris curasoae***

*Leptonycteris curasoae curasoae* numbers are also relatively low (Tables 1 and 2; Fig. 2). Most individuals were found in Kueba Bosá III and Kueba di Jetchi, but a few, including pups, were discovered in Kueba di Noordkant in July 2001 (Table 3). Numbers were quite variable and we noted the absence of this species in Kueba di Jetchi on three instances (Table 4), although we do not know whether they were present at Kueba di Noordkant during that time.

### ***Glossophaga longirostris***

Data for *Glossophaga longirostris elongata* for some of the major caves are presented in Table 2. In additional searches, we also found the following: Kueba Ascención 37, Kueba di Boca Grandi (Christoffel Park) 15, Grot van Hato 110 (all on 13 September 2003); Kueba di San Juàn I 1, Kueba di San Juàn II 72, Kueba di San Juàn III 10 (17 September 2003); storage building of Sunset Waters (formerly Coral Cliff Hotel) 55 (19 September 2003); Landhuis Jan Kok 36 (18 September 2003); Porto Marie house (14 September 2003); smell only but bats were not visible; Landhuis Brievengat 102 from emergence count (24 September 2003); and Kueba di Wacawa 35 (26 September 2003). The following did not contain any bats: rock building of Landhuis Santa Martha (26 September 2003; bat smell), Landhuis Klein St. Michiel (owner's report), Bullenbaai petrol storage, Coral Estate Habitat Hotel, Landhuis Grote Berg (owner's report), Landhuis Rif, Landhuis Chobolobo (employee's report), and Landhuis Daniel (employee's report). We were unable to access Kueba di Playa Hulu, said to contain a small group of bats. The total number of individuals counted in 2003 is thus 1417 (Table 1).

### **Monthly surveys**

Monthly surveys in 2003 suggest that bat numbers at one cave are relatively variable (Table 3; Fig. 3), even within a single year. Unlike other places (Fleming & Nassar, 2002), there is no indication that one cave on Curaçao is used uniquely as a maternity roost for any species, although we noted the importance of the Bosá system, Kueba di Jetchi

and Kueba di Ratón during lactation. Specifically, we have never found *Mor. megalophylla* pups in places other than Kueba di Ratón. These caves, however, are used by males as well as females.

## **Discussion**

Apart from one species, all bats of Curaçao are endangered or information is lacking on their status. Two species have experienced a serious decline in a short amount of time; the population of one of them (*L. curasoae*) shows variability among years and even months, but the other (*Mor. megalophylla*) declined abruptly from a relatively stable population over a decade.

### ***Noctilio leporinus***

We counted only six *No. leporinus* in the Daaibooibaai crevice in 2003. Since its discovery in 1994, the crevice has contained between zero (after Hurricane Lenny in 1999) and 35 individuals (in 1994). Other than a small group seen exiting a crevice under the Willemstad bridge in 1998, we are unaware of other roosting locations for *No. leporinus* on Curaçao. This species is unlikely to be abundant on the island because fishing bats are not commonly observed, although people often do not realize that they are looking at bats and not birds. We did observe individuals foraging alone or in groups of two or three on 20 and 25 September 2003 at Boca Sami. According to the owner of a local restaurant near the water, these bats forage frequently where the light attracts minnows. Some people had thrown bread to the fish and a *No. leporinus* picked up three pieces before dropping them; it is possible that floating garbage, which is common around Curaçao, reduces the effectiveness of this bat's foraging strategy. This possibility should be examined. *Noctilio leporinus* is a large bat (50–90 g; Brooke, 1994) and a strong flyer; it may be able to travel to and from locations away from Curaçao.

### ***Myotis nesopolus***

We were unable to determine the status of *Myotis nesopolus nesopolus*, although we captured several individuals in 2003 and in the past (see Petit, 1996); we also observed many bats foraging at Klein Hofje sewage treatment plant. This species probably roosts in Kueba di Ratón and Kueba di Jetchi and perhaps in other caves. Radio-tracking may be the only way to find out more about *My. nesopolus* on Curacao, although the bat is too small for common transmitters.

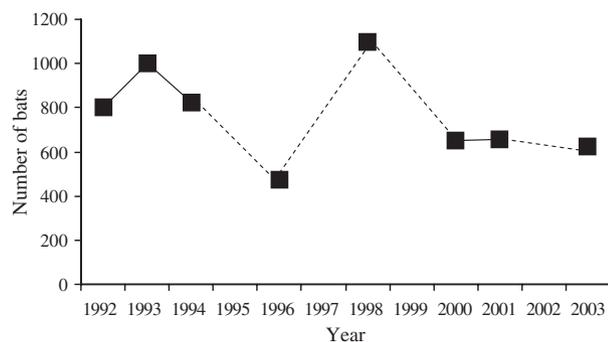
### ***Artibeus jamaicensis* and *Molossus molossus***

We have no evidence that *A. jamaicensis* and *Molossus molossus pygmaeus* still occur on the island. The only record of *A. jamaicensis* on Curaçao consists of two individuals that were shot in 1947 at Klein Santa Martha and may have been vagrants (Husson, 1960). All *Mol. molossus* specimens were collected in houses in the Netherlands Antilles

**Table 2** Bat survey data for some of the major caves from 1992 to 2003<sup>a</sup>

Location	Genus	Sept/Oct 92	Oct 93	Oct 94	Oct 95	Mar 96	Nov 96	Apr 97	Feb 98	Oct 98	Nov 01	Sept 03
Kueba Bosá I	<i>Glossophaga</i>	0	3	0	—	0	1	0	0	0	6	0
Kueba Bosá II	<i>Glossophaga</i>	20	0	2	—	0	30	6	0	0	10	3
	<i>Mormoops</i>	100	20	65	—	120	35	90	130	70	60	83
	<i>Natalus</i>	0?	35	2	—	10	4	6	2	1	10	3
Kueba Bosá	<i>Glossophaga</i>	300	250	160	—	155	200	300	115	235	230	300
III	<i>Leptonycteris</i>	500	550	300	—	300	400	250	300	500	330	350
	<i>Mormoops</i>	0	0	0	—	0	0	0	120	0	0	0
	<i>Natalus</i>	0	0	0	—	0	0	0	0	0	10	7
Kueba di San Pedro	<i>Glossophaga</i>	—	—	105	150	—	50	—	40	60	80	70
Kueba Brua	<i>Glossophaga</i>	—	—	50	180	—	105	—	60	120	70	75
Kueba di Diabel	<i>Glossophaga</i>	40	20	30	Bees	—	20	—	2	30	10	45
Kueba di Jetchi	<i>Glossophaga</i>	60	50	80	—	75	110	80	110	130	160	120
Kueba di Ratón	<i>Leptonycteris</i>	300	450	500	—	60	75	Many	700	600	325	275
	<i>Glossophaga</i>	25	20	15	—	10	13	—	15	20	5	11
	<i>Mormoops</i>	550*	550*	600*	—	450*	550*	—	300*	600*	500	325
	<i>Natalus</i>	0	10	11	—	7	0	—	7	0	5	20
	<i>Pteronotus</i>	With	75	60								
		<i>Mormoops</i>										
Kueba di Noordkant	<i>Glossophaga</i>	200	150	35	40	—	100	—	115	80	15	100
	<i>Leptonycteris</i>	0	0	25	0	—	0	—	20	0	0	0
	<i>Natalus</i>	6	12	275	30	400	15	300	235	70	540	860
Kueba di Koral Tabak	<i>Glossophaga</i>	65	65	65	83	—	110	—	1	75	85	80
Kueba di Ronde Klip	<i>Glossophaga</i>	50	51	70	125	—	110	—	135	115	110	140
Total	<i>Glossophaga</i>	(760)	(609)	612	(578)	(240)	849	(386)	593	910	781	944
Total	<i>Leptonycteris</i>	800	1000	825	NA	(360)	475	NA	1020	1100	655	625
Total	<i>Mormoops</i>	650*	570*	675*	NA	570*	585*	(90)	550*	670*	560	403
Total	<i>Natalus</i>	(6)	(57)	(450)	(30)	(417)	(19)	(306)	(244)	(71)	565	890
Total	<i>Pteronotus</i>	NA	75	60								

<sup>a</sup>Data for 1992 and 1993 are from Petit (1996). Missing values indicate that the location was not surveyed at the date indicated. 'Bees' means that the cave was not visited because of bee infestation. *Pteronotus* were only noted as a separate species in Kueba di Ratón from 2001; because they were mixed with *Mormoops*, the *Mormoops* numbers incorporate *Pteronotus* before 2001 (indicated by \*). Data collected at times other than in the September–November period appear in italics. In 1994 and 2001, *Natalus* chambers were discovered in Kueba di Noordkant. Total number for *Glossophaga* is incomplete (see text). Missing values or incomplete information during the surveys is indicated by 'NA' or parentheses in the totals.



**Figure 2** *Leptonycteris curasoae* population size from 1992 to 2003. The dotted lines join squares in between which yearly data are missing.

(Husson, 1960). The increasingly low occupancy of houses by bats, because of renovation, new designs or active exclusion of bats, makes it unlikely that this species persists on Curaçao. The date of the last record for the species remains

unclear, but it is possibly 1940, with no record after Husson (1960).

### *Natalus tumidirostris*

Fortunately, numbers of *Na. tumidirostris* are much greater than the 1993 survey indicated (Petit, 1996) owing in large part to the discovery of additional chambers in Kueba di Noordkant. In 2003, we estimated the total population to be 890. Counts of *Na. tumidirostris* in Kueba di Noordkant are estimates that would improve in accuracy if exits from the roost chamber could be temporarily blocked during surveys. *Na. tumidirostris* pups were observed only in Kueba di Noordkant, indicating that this cave is of great importance for this species.

### *Pteronotus davyi*

One individual *P. davyi* was captured in the past, and we discovered the first group in 2003. On the day of the survey,

**Table 3** Monthly bat survey data for the major caves, from October 2000 to November 2001<sup>a</sup>

Location	Genus	Oct 00	Nov 00	Dec– Jan 00	Jan– Feb 01	Mar 01	Mar– Apr 01	May 01	Jun 01	Jul 01	Aug– Sep 01	Sep– Oct 01	Nov 01
Kueba Bosá I	<i>Glossophaga</i>	0	0	0	3	0	–	–	0	0	0	0	6
	<i>Natalus</i>	0	0	0	0	1	–	–	0	4	1	0	0
Kueba Bosá II	<i>Glossophaga</i>	0	11	12	4	12	1	0	5	20 + 6	8	17	10
	<i>Mormoops</i>	40	60	65	140	220	185	180	180	95	100	55	60
	<i>Natalus</i>	0	4	0	0	2	4	1	4	3	2	4	10
Kueba Bosá III	<i>Glossophaga</i>	220	210	250	225	300	230	130	180	200 + ?	275	300	230
	<i>Leptonycteris</i>	350	350	350	220	245	280	300	230 + 100	240 + 160	275	350	330
	<i>Mormoops</i>	0	0	0	0	0	0	0	25	70	30	135	0
Kueba di San Pedro	<i>Natalus</i>	10	6	3	3	2	6	40	5	3	20	10	10
	<i>Glossophaga</i>	120	125	110	55	85	70	55	60	75 + 19	90	80	80
Kueba di Brua	<i>Glossophaga</i>	70	120	95	30	90	85	65	75	65 + 25	145	140	70
Kueba di Diabel	<i>Glossophaga</i>	50	2	20	7	30	15	8	30	25 + 5	80	45	10
Kueba di Jetchi	<i>Glossophaga</i>	150	135	145	135	135	95	90	100	125 + 55	165	220	160
	<i>Leptonycteris</i>	300	450	400	350	20	400	200	200 + 100	200 + 100	400	350	325
Kueba di Ratón	<i>Glossophaga</i>	15	10	5	7	10	5	2	10	10 + 1	20	11	5
	<i>Mormoops</i>	600*	750*	650*	550*	380*	450*	350*	275	250	320 + 10	370 + 285	250 + 250
	<i>Natalus</i>	1	1	0	10	45	20	40	25	35	20	22	5
	<i>Pteronotus</i>	?	?	?	?	?	?	Some	75	80	80	80	75
Kueba di Noordkant	<i>Glossophaga</i>	165	145	270	–	250	255	380	140	5	20	20	15
	<i>Leptonycteris</i>	0	0	0	–	0	0	0	0	50 + 12	0	40	0
	<i>Mormoops</i>	0	0	0	–	0	0	6	0	25	2	0	0
Kueba di Koral Tabak	<i>Natalus</i>	240	45	415	–	480	540	1040	450	865	617	685	490 + 50
	<i>Glossophaga</i>	105	80	80	50	25	80	55	40	55 + 44	130	105	85
Kueba di Ronde Klip	<i>Glossophaga</i>	60	85	20	40	120	95	115	100	115 + 23	130	125	110
Total	<i>Glossophaga</i>	955	923	1007	–	1057	(931)	(900)	740	695 + 178	1063	1063	781
Total	<i>Leptonycteris</i>	650	800	750	–	265	680	500	430 + 200	490 + 272	675	740	655
Total	<i>Mormoops</i>	640*	810*	715*	–	600*	635*	536*	480	440	452 + 10	560 + 285	310 + 250
Total	<i>Natalus</i>	251	52	418	–	530	(570)	(1120)	484	910	660	721	515 + 50
Total	<i>Pteronotus</i>	?	?	?	?	?	?	?	75	80	80	80	75

<sup>a</sup>Numbers starting with '+' indicate young. Missing values indicate that the survey was not conducted at that time for that location. Asterisks show *Mormoops* numbers that may incorporate *Pteronotus* numbers. Numbers in parentheses are incomplete data.

**Table 4** Presence of *Leptonycteris curasoae curasoae* in Kueba di Jetchi and Kueba Bosá III between 1992 and 2003<sup>a</sup>

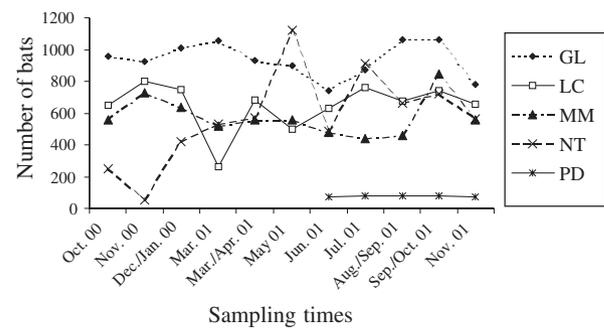
Date	Kueba di Jetchi	Kueba Bosá
28/01/1992	—	200
7/09/1992	300	—
9/11/1992	—	500
10/93	450 Petit (1996)	550 Petit (1996)
12/10/1994	300	500
12/04/1995	0	—
25/06/1995	Large group with pups	—
21/03/1996	60	300
4/07/1996	Large group with pups	—
6/11/96	75	400 (counted on slides)
4/04/1997	Large group with big pups	—
4/10/1997	—	250
29/01/1998	700 (counted with scan)	300
26/02/1998	0	—
26/03/1998	Large group/ mating activity	—
27/04/1998	0	—
22/10/1998	600	500
27/10/2000	300	350
27/11/2000	450	350
27/12/2000	400	350
31/01/2001	350	220
2/03/2001	20	245 (unusual part of the cave)
29/03/2001	400	280
4/05/2001	200 (some pregnant)	300
8/06/2001	200 (many pregnant and many with small pups)	230 (many pregnant and many with small and larger pups)
4/07/2001	200 adults and 100 mostly large pups	240 adults (some still pregnant) and 160 mostly large pups
05/02	Pregnant and with small pups	—
13/09/03	275	350

<sup>a</sup>Groups containing pups were not always counted to minimize disturbance of the bats.

the group size was initially estimated at 65, including five pups, but we now believe the five smaller bats were *My. nesopolus* because none of the females examined on 2 September appeared to be pregnant or lactating. We also captured an independent juvenile male on that day, indicating it is unlikely that *P. davyi* has pups in September. We do not believe that this species roosts elsewhere because it has ‘hot cave’ requirements, as do *L. curasoae* and *Mor. megalophylla* (Fleming & Nassar, 2002).

***Mormoops megalophylla***

Unlike *P. davyi*, *Mormoops megalophylla intermedia* have declined in numbers since the 1993 census. We may have



**Figure 3** Bat population sizes (including pups) during the 2001 monthly census (see Table 3 for locations). Eighty individuals of *Mormoops megalophylla* (MM) were removed from the data in Table 3 because we assumed the *Pteronotus davyi* (PD) population, which had originally been counted with MM, remained constant. All data available for *Natalus tumidirostris* (NT) and *Glossophaga longirostris* (GL) were added, because the missing data in Table 3 are likely to have low values. Note that February is missing because of lack of data for Kueba di Noordkant, not all GL roosts are represented, and NT counts are not very reliable (see text). GL lactates from June to September and *Leptonycteris curasoae* (LC) from June to August (Petit, 1997).

included *P. davyi* in the *Mor. megalophylla* count until May 2001 because they share the same chamber in Kueba di Ratón. Our confusion of the two species may be attributed to the low-intensity lights we used in an effort to minimize bat disturbance. However, *Mor. megalophylla* pups remain mostly hairless until they are quite large and are in fact rather easy to distinguish from other species, even in dim light. If we assume that the *Mor. megalophylla* population was 500–600 for 10 years, the drop to 400 indicates a 25–30% loss in population in one year; the number could be higher if pup mortality is high. On 2 September 2003, pups were not present in the cave, but on 13 September 2003 we found 75 pups, 30 of which were being carried by their mother. Unfortunately, *Mor. megalophylla* pups tend to drop from the ceiling when disturbed, so we believe it is necessary to stop visiting the cave between August and December. This species has strict roosting requirements and the known roosts must be made a high priority for protection. *Mormoops megalophylla* is one of the species most at risk on the island. The low number of 403 individuals, including 75 pups, strongly suggests that *Mor. megalophylla* must be actively protected; we believe the best protection for this species is to maintain its roosting sites completely undisturbed.

Inappropriate cave gating may have contributed significantly to the dramatic decrease in the *Mor. megalophylla* population between the last two surveys, and possibly the decline in *L. curasoae* as well. Kueba di Jetchi and Kueba di Ratón, on the North Coast, were partially gated in 2003. Unfortunately, the gates at both caves had vertically arranged bars, except at the very top; bats need gates with horizontal rather than vertical bars (Tuttle, 1977) and not all species tolerate bat gates (Kennedy, in press). Also, we

unscrewed the bars to enter the caves for the surveys, demonstrating that anyone can access the caves. We recommended the immediate removal of existing gates. Additional funding must be sought to redesign and construct new gates. Fencing should prevent access to the cave from the ground below the terrace and not at the cave entrance. In addition, signs explaining the reason for closing the cave should be placed near the gates, so that potential visitors can understand the consequences of cave disturbance and not be frustrated by the gate.

Research on the feeding ecology of *Mor. megalophylla* on Curaçao is also important. Currently, we know nothing about the availability of food and competitive interactions with other species on the island.

### ***Leptonycteris curasoae***

Like *Mor. megalophylla*, *Leptonycteris curasoae curasoae* numbers decreased in the survey decade, although variation for *L. curasoae* is high, if not comparable with variation in Mexican populations (e.g. 5000–75 000 at Chamela Bay, Ceballos *et al.*, 1997). From 1992 to 1994, we recorded numbers between 800 and 1000; the population size was around 650 during the last three surveys (Fig. 2), representing a decrease of 25–30%. However, *L. curasoae* can fly long distances (Sahley, Horner & Fleming, 1993; Horner, Fleming & Sahley, 1998) and it is possible that some individuals may fly to the nearby island of Bonaire, where A. Rojer (unpubl. data) found an unexpectedly large population of 1535 on 5 and 6 December 2000. It is interesting that in three instances when few *L. curasoae* were in Kueba di Jetchi (March and November 1996, and March 2001, Table 4), numbers had not increased in Kueba Bosá, suggesting that the bats either use a different cave or travel off the island occasionally, possibly for mating, feeding and dispersal of young.

It is possible that columnar cactus populations have decreased enough as a result of land clearing that *L. curasoae*, whose diet consists mainly of cactus products (91% of diet samples contained cactus products and 43% contained cactus products exclusively; Petit, 1997), is not able to sustain its population size. In July, the 'bottleneck' month when resources are most limiting in relation to energetic requirements, one *L. curasoae* required at least 12.5 ha of cactus scrub at 10.4 cacti ha<sup>-1</sup> for food in 1993 (Petit & Pors, 1996). Extensive urban development has resulted in the clearing of much cactus scrub, and cactus density on Curaçao is probably lower currently than in 1993. We have evidence that *G. longirostris* and *L. curasoae* do not have the same effectiveness as pollinators of cacti (Petit, 1998); the unique role of *L. curasoae* as a pollinator should be emphasized in plans for its conservation.

### ***Glossophaga longirostris***

*Glossophaga longirostris elongata* seems to be the most resistant of all bat species to disturbance, as concluded by Petit (1996). Its diet also consists principally of columnar

cactus products (86% of diet samples contained cactus products and 43% contained nothing but cactus products; Petit, 1997). *Glossophaga longirostris* uses a diversity of roost types including buildings and relatively open caves. It may occur in very small groups as well as large ones and it is a successful species on Curaçao, considering the high frequency of disturbances. Its ability to withstand disturbance may not be as useful to *Glossophaga longirostris* on Bonaire, Netherlands Antilles, where it is less numerous than *L. curasoae* (A. Rojer, unpubl. data).

### **Dwelling disturbances**

*Pteronotus davyi*, *Mor. megalophylla* and *L. curasoae* have strict 'hot cave' roosting requirements (Bonaccorso *et al.*, 1992; Arends, Bonaccorso & Genoud, 1995). Few caves provide these conditions on Curaçao, but the Grot van Hato did contain *Mor. megalophylla* before it was turned into a tourist attraction featuring lights, a pond and fans (it is interesting that the population of *G. longirostris* in this cave has increased from 23 in 1993 to 110 in 2003). The conservation of Kueba di Jetchi, Kueba di Ratón and the Bosá system is thus crucial. It is also possible that large numbers of bats are necessary to keep the temperature optimal (Arends *et al.*, 1995) and losing part of the population may have a cascade effect on the rest of the population.

In her field notes, one of us (A. R.) recorded various disturbances while surveying caves, which included visitors, trash, graffiti, voodoo (bruha), fire, owls, pigeons, cats, snakes, rats and bees. Cave disturbance may be extremely detrimental to bats (McCracken, 1989). An extension to the airport to accommodate an American military base included bomb-blasting of the same geological terrace that contains Kueba di Jetchi and Kueba di Ratón (end of 2002–2003). Considering the proximity of these two caves to the airport, it is possible that noise and vibrations disturbed the bats. Any such devastating activity, if it cannot be prevented, should be strictly controlled and take place at times of the year when pups are not present.

Fortunately, harm to the bats of Curaçao does not seem to be intentional and even their elimination from buildings is not normally motivated by fear or hatred. The manager of Landhuis Jan Kok told us she had been relatively successful in excluding most *G. longirostris* after they had become quite abundant in the house. Cleaning (possibly inducing disturbance) and aloe were used to chase the bats away. G. van Buurt, of the agriculture department, indicated that he occasionally received phone calls to chase bats from buildings, and that he recommended placing aloe and wind chimes with glass bells in the roosts when the bats were out, because it seemed to work. Although Curaçaoans do not seem to accept bats in their houses, in general, they do not appear to kill them and most people do not fear them. It is possible that the recent arrival of many immigrants could change this trend. Education remains a priority for all.

The Institute for Caribbean Research and Management of Biodiversity, formerly Caribbean Marine Institute (CAR-MABI) has been involved in education programmes for

school children since 1996, taking over from STINAPA, another government organization that started these programmes in 1986. CARMABI also produces documentaries, including a recent one on bats, and arranges for regular press releases. Staff have also approached some of the tour operators conducting bat visits, mostly in Kueba di Diabel and Kueba Bruha. The guided tours are relatively respectful of bats and it may be possible to set up a formal training programme for all tour operators involved with cave visits. CARMABI's education activities seem rather successful and it would be worth measuring and monitoring this success with appropriate performance indicators (e.g. O'Brien & Pease, 2004).

## Conclusions

The status of bats on Curaçao in 2003 was of greater concern than in 1993 for two bat species: *Mormoops megalophylla intermedia* and *Leptonycteris curasoae curasoae*. The status of *Myotis nesopolus nesopolus* is still unknown, and small groups of *P. davyi* and *No. leporinus* occur on the island, but we have found only one roosting site for each species. It is unlikely that bats other than *L. curasoae* and *No. leporinus* fly between islands and between Curaçao and Venezuela. Two cave chambers containing *Na. tumidirostris* have been discovered in the last decade and so it is difficult to estimate the change in its population during this period. There is still no evidence of *A. jamaicensis* and *Molossus molossus pygmaeus*, and our data suggest that earlier records are those of accidental vagrants (*A. jamaicensis*), the species is regionally extinct (*Mol. molossus*) or our surveys missed the species. *Glossophaga longirostris elongata* was the only species that our data indicated was maintaining and possibly expanding slightly its population.

The bat populations tended to fluctuate within caves and among years and even months, sometimes considerably, but the vital importance of Kueba di Ratón, Kueba di Jetchi, the Bosá system and Kueba di Noordkant, considered 'hot' caves because of their relatively high temperature, remains clear. All caves containing bats should be protected, and only Kueba di Diabel and Kueba Bruha should be available for carefully planned and monitored tourism activities, although health issues associated with cave visits should be examined thoroughly. Cave disturbance appears to be a significant threat, but in view of the complexity and risks of cave gating (Kennedy, 2004, in press), we recommend that gating be performed away from the entrance of the keystone caves, at the base of the geological terrace of interest. We also suggest that a monitoring programme be established for owls (*Tyto alba*) on Curaçao and that their impact on bats be evaluated. Urban development has increased considerably in the last 10 years and we fear that crucial resources, particularly columnar cacti, are being destroyed to an extent such that two nectar-feeding bat species may not be viable in the near future. A new cactus survey should be undertaken and the remaining cacti should be protected. In addition, the feeding ecology and social behaviour in all bat species need

to be examined. In spite of the difficulty of achieving accurate bat surveys in an environment such as Curaçao, this study shows that the regular survey of bats is very important to understand population status and conservation needs.

## Acknowledgements

We thank Frankito Zimmerman, Kees van Dongen, Gilbert Cristina, Michelle da Costa Gomez and Adolphe Debrot for their assistance with field work, and Terry Reardon, Amy L. Russell and anonymous colleagues for reviewing the manuscript. Alfred Gardner kindly facilitated the work at the Museum of Natural History, Washington, DC. S. Petit's travel to Curaçao was made possible by a grant from the Ian Potter Foundation and a Professional Experience Program grant from the University of South Australia. Her stay on Curaçao was facilitated by CARMABI, the Institute for Caribbean Research and Management of Biodiversity. This paper is a contribution from the Program of Biodiversity, Environmental and Park Management of the School of Natural and Built Environments, University of South Australia.

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