Acta Chiropterologica, 9(2): 423–435, 2007
PL ISSN 1508-1109

Mist netting bias, species accumulation curves, and the rediscovery of two bats on Montserrat (Lesser Antilles)

ROXANNE J. LARSEN[1, 5], KAREN A. BOEGLER[1], HUGH H. GENOWAYS[2], WILL P. MASEFIELD[3], RONAN A. KIRSCH[4], and SCOTT C. PEDERSEN[1]

[1]*Department of Biology, South Dakota State University, Brookings, SD 57007, USA*
[2]*University of Nebraska State Museum, University of Nebraska, Lincoln, NE 68588, USA*
[3]*Durrell Wildlife Conservation Trust, Trinity, Jersey, JE3 5BP, United Kingdom*
[4]*Muséum National d'Histoire Naturelle, Département Systématique, Paris Cedex 05, France*
[5]*Present address: Department of Biological Sciences, Texas Tech University, Lubbock, TX 79409, USA*
E-mail: roxy.larsen@ttu.edu

Mist nets are commonly used to survey bat populations and to estimate bat biodiversity, but several studies have found that mist net capture data and methods are biased due to a number of factors, including size and placement of nets, and the frequency at which investigators check their nets. Despite the wealth of literature and anecdotal reports, few investigators have quantified the interactions of bats with mist nets directly. We employed night vision camcorders to monitor bat behavior when bats encountered a mist net and then utilized these data to re-evaluate years of survey data collected on Montserrat, Lesser Antilles. We recorded 2,523 bat passes during 43.3 hours of videotaping in July 2005 and June 2006. Observations conducted on successive nights provide evidence of avoidance-learning behavior in bats. When a mist net was present, 5.4% of bats in the airspace came into contact with the net giving an overall capture rate of 3.2% (range 0–10.3%). Mist nets are not accurately sampling bats that utilize flyways on Montserrat and such fieldwork thereby generates potentially misleading data. Biodiversity assessments and conservation guidelines based on short-term mist net surveys alone are not sufficient or reliable in regards to bats. A pragmatic solution to reduce mist net bias is to repeatedly sample a target region, utilize a variety of netting sites, use variable net sets, and carefully analyze species accumulation curves.

Key words: mist net bias, species accumulation curve, Lesser Antilles, rediscovery, *Chiroderma improvisum*, *Sturnira thomasi*

INTRODUCTION

Mist netting is a common method used to capture bats (Kunz and Kurta, 1988; Gardner *et al*., 1989; Kunz *et al*., 1996; Lang *et al*., 2004). Some investigators have utilized bat capture rates as a proxy for fluctuations in bat populations (Pedersen *et al*., 1996), but such efforts may be misleading, as several studies have found that mist net capture data are biased due to a myriad of issues that include survey effort, type of net, the surrounding habitat, weather, and the avoidance and echolocation abilities of bats (Kunz and Anthony, 1977; Francis, 1989; Kunz *et al*., 1996; Remsen and Good, 1996; Kuenzi and Morrison, 1998; Simmons and Voss, 1998; Lang *et al*., 2004).

Mist net capture data are biased due to several factors that involve the net itself or the bat species being netted. The match between animal/head size, mesh size, denier, and construction of the deployed net directly affects the efficiency of the net (Jenni and Leuenberger, 1996). However, as nets have become more standardized, researchers' techniques frequently vary in relation to the amount of play in each shelf, the tension of the net, or the frequency of clearing the net of captured animals. Additionally, the detection and perception of the net by a bat are greatly affected by habitat complexity and structure, frequency of precipitation, wind, and ambient light levels (Francis, 1989; Remsen and Good, 1996).

Studies in peninsular Malaysia, Borneo (Sabah), French Guiana, and Panama have commented on the method of capture, the need for the placement of mist nets at different heights (Francis, 1989, 1994; Simmons and Voss, 1998), surveys over several years (Kalko *et al.*, 1996), or estimating species abundance via captures in the net (Simmons and Voss, 1998). Several studies also have documented that capture rates of both insectivores and frugivores decrease when there is a full moon or bright moonlight (LaVal, 1970; Morrison, 1978; Kunz *et al.*, 1996; Simmons and Voss, 1998; Lang *et al.*, 2004). Capture rates also are confounded by the variation among species, in regards to their differential agility, wing loading, mode and power of echolocation calls, characteristic foraging pattern/altitude, and the facultative use of their other senses: vision and olfaction (Kunz and Anthony, 1977; Francis, 1989; Berry *et al.*, 2004). Investigators have documented decreased capture success on nights of repeated mist netting at a single site (Gram and Faaborg, 1997; Simmons and Voss, 1998), which has been credited to a learned avoidance response by the bats to the net (LaVal, 1970; Kunz and Brock, 1975; Kunz and Kurta, 1988; Kunz *et al.*, 1996; Gannon and Willig, 1998; Kuenzi and Morrison, 1998).

Despite the aforementioned literature and anecdotal reports, few investigators document bat/net interactions directly. Despite our own extensive survey efforts throughout the Caribbean (Genoways *et al.*, 1998, 2001, 2005, In press; Pedersen *et al.*, 1996, 2003, 2005, 2006, 2007; Pedersen, 2001; Larsen and Pedersen, 2002; Larsen *et al.*, 2006), we too have neglected this critical aspect of bat survey work. However, two studies in the last few years used infrared lights and video cameras to specifically record bat interactions with the net (Lang *et al.*, 2004; MacCarthy *et al.*, 2006) and the efforts of Lang *et al.* (2004) provided the incentive for employing a similar technique in an attempt to re-evaluate the last ten years of our own mist net data collected on Montserrat.

The first goal in our study was to determine if the number of bats caught in a mist netted airspace was an accurate estimate of the numbers of bats using that particular flyway. Therefore, we documented the interactions of bats at mist nets using video equipment and infrared lights. The second goal was to determine if there was evidence for a learning curve regarding the position of a new obstacle (such as a mist net) in the flyway, which lead us to quantify behavioral responses made by bats approaching the mist nets on successive nights. As a caveat, mist netting is inherently biased when used as a simple index of bat activity and not a count of individual bats (most bats are not marked under normal mist netting conditions). Therefore, individual bats may be captured more than once during a night, as well as pass in the airspace multiple times. A final question regarding the rareness of species was introduced when the data indicated very low capture rates for a few species. The rarity of two phyllostomids and the importance of mist netting effort will be discussed.

Materials and Methods

The island of Montserrat (Lesser Antilles) was chosen because of its simple bat fauna (6 frugivores, 3 insectivores, and 1 carnivore) as well as 13 documented surveys spanning 29 years on this island. Four study sites in 2005 (Mango Hill, Hope Springs, Sappit River, and Soldier Ghaut) and two study sites in 2006 (Mango Hill and Cassava Ghaut) were selected from the group of approximately 40 sites sampled during past survey years (Fig. 1). Hurricane Emily and two minor eruptions of the Soufrière Hills volcano interrupted fieldwork in 2005, and the volcano erupted again two weeks prior to survey in 2006. This 2006 eruption sent boulders, mud, volcanic ash, and toxic gases down into our field sites at Hope Springs and Sappit River, effectively sterilizing both watercourses and defoliating both sites. The Cassava Ghaut site was included in 2006 to compensate for the loss of two of the 2005 sites. An additional natural influence mentioned previously was moonlight; however, it did not appear to affect the use of flyways by the bats, as the canopy covered these airspaces and the nets were not illuminated by moonlight.

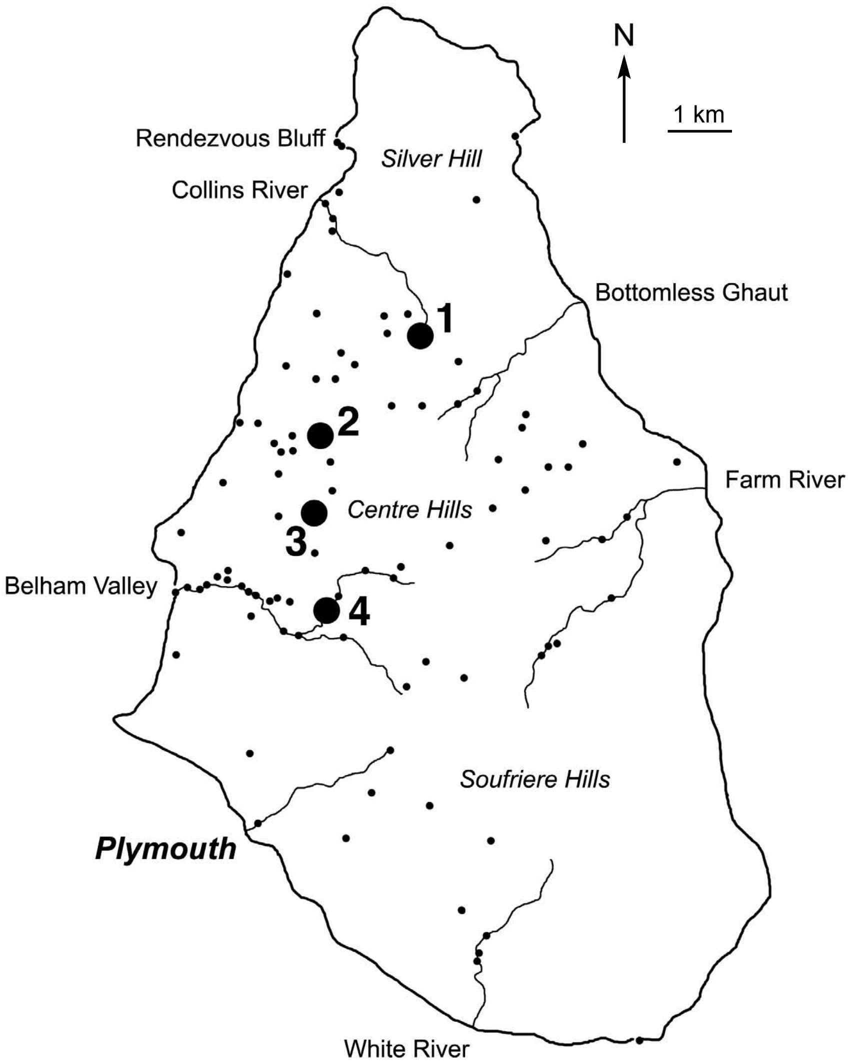

Fig. 1. Map of Montserrat, West Indies; mist netting sites from 1994, 1997–2007 are indicated by small black dots; four videotaped sites are indicated by large black dots: 1 — Mango Hill (16°46’40.0”N, 62°11’43.0”W), 2 — Cassava Ghaut (16°45’48”N, 62°13’12”W), 3 — Hope Springs (16°45’06”N, 62°12’44”W), 4 — Sappit River (16°44’25”N, 62°12’28”W)

Four of the original six filming sites were chosen for analysis as they had the most complete datasets (Mango Hill 2006, Hope Springs, Sappit River, Cassava Ghaut: Fig. 1). As such, the final design of the study consisted of four consecutive nights at each of four sites. The first night served as a control to quantify how many bats fly through an empty airspace on a given night. On subsequent nights, a single mist net (AVINET, Inc., black nylon, 4-shelf, 6 or 9 m wide, 2.6 m high, 38 mm mesh) was present. The length of the mist net was dictated by the width of the flyway, but then consistently set on each successive night. There was never more than 2 m of open space between the top of each net and the overhanging foliage. The flyways on each of the four nights were videotaped for 2.5 hours (on average) beginning just before sunset, as this period of time was found to be the most active time frame for bats on this island (Larsen and Pedersen, 2002). The interaction between bats and the mist net were analyzed during playback of the videotape footage the next day.

Flyways were illuminated using two Dalton Wildlife Engineering infrared lights (Model IRlamp6 40-degree beam) powered by 12-volt car batteries (Fig. 2). We used Sony Night-Shot camcorders (Models #CCDTRV87 and #CCD-TRV138 and Hi-8 videotape). The infrared lights were positioned on either side of the mist net to illuminate bats approaching from each side, and one camcorder was set perpendicular to the net approximately 5m away in 2005 (Camera 1: Fig. 2). In 2006, we added an additional Night-Shot camera that was placed parallel to the net to record bat activity at the net surface (Camera 2: Fig. 2). It provided another angle from which to view the net and to ensure that the numbers of bats filmed by the other camera were being counted accurately.

In 2006, we also used the 'Batcam' to facilitate the visual tracking of individual bats as they circled about the net (Batcam: Fig. 2). The Batcam consisted of a Watec camera (WAT-902H2), a Rainbow S16mm lens, a Wildlife Engineering Model IRlamp6 20 degree beam angle infrared light, and an Accelevision 7 inch wide TFT-LCD color monitor (LCDP7W) all mounted coaxially on a bracket that could be handheld or mounted on a tripod. All of this equipment was run from a 12-volt car battery. This large-screen, night-vision video camera greatly reduced eyestrain and allowed for continual observation of the mist net. It also provided a wider visual field in which to track the various activities of individual bats beyond the range of the stationary video cameras.

Ad hoc filming events were performed to determine if equipment was working properly. These data were not included in the final analysis, but were noted for future study. In 2006, we wrapped two cotton bed sheets tightly around 5 vertical meters of a tree trunk adjacent to the net to test if flying bats could be more easily observed against the white sheet (sensu Hirsch *et al*., 2003). There was nothing visually aberrant about the tree — no cavities, abundant insects, leaking sap, vines, etc. However, at least one bat exhibited a great deal of interest in these cotton sheets and flew up and down the trunk (20+ cycles) and landed on the sheets numerous times. Because our objective was to obtain data on mist net bias, and the lighter background offered only minor improvement during filming, we did not use sheets at other locations, as they seemed to impose a bias of their own.

Additionally, the marking of bats was not conducted because when they are captured and marked, most bats would have an aversion to the netting site. The stress of handling would have added another variable into this simple study and it has been shown that bats may not appear in the flyway for several days after the initial capture (LaVal, 1970; Kunz and Brock, 1975; Kunz and Kurta, 1988; Kunz *et al*., 1996; Gannon and Willig, 1998; Kuenzi and Morrison, 1998).

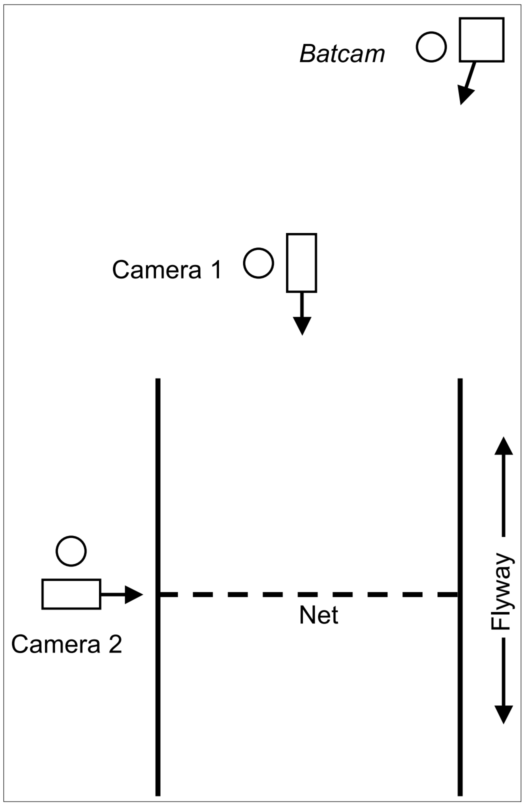

FIG. 2. General plan of cameras, nets, and lighting

The majority of bats on Montserrat are of the family Phyllostomidae, which do not emit loud echolocation signals (Fenton *et al*., 1992) and the structure of their signals is less discernable between species (Kalko *et al*., 1996). However, we did attempt to record echolocation signals at each net, but these efforts were terminated when it was clear we could not record clean signals due to excessive background noise from insects.

Lastly, Sony TCM-200DV tape recorders were used to dictate comments concerning bat behavior, activity, and time checks. While observing bat/net interactions through the Batcam it also allowed us to check for errors in counting or behaviors that may not have been recorded by the stationary cameras. The integral clocks in each camcorder and a digital watch used by the observer were synchronized to facilitate record keeping and data analysis when the various tapes were played back the following day. One tape was reviewed and counted several times to establish a counting error rate (≈ 1%). Subsequently, all tapes were analyzed by one person (RJL).

The numbers of bats approaching the net or using the flyway in the absence of the net were tallied and the behavioral responses of each bat to the net were recorded and classified into five categories: 1) circled or reversed their direction of flight; 2) flew over the net; 3) flew under or to either side of the net; 4) were caught and manually removed from the net; or 5) bounced off the net and flew away (Table 1). This information was compiled and entered into a Microsoft Excel spreadsheet. A nonparametric Kruskal-Wallis One-Way ANOVA was applied to determine differences among net nights. Simple linear regression was applied to determine if there was a relationship between bat passes/hour over net nights (SYSTAT, 2004).

Results

In 2005, we recorded 1,970 bat passes on 25.3 hours of videotape. In 2006, 553 bat passes were recorded on 18 hours of videotape, giving a total of 2,523 bat passes captured on 43.3 hours of videotape during the project. These raw numbers include the additional filming events for equipment testing previously mentioned. However, these data were reduced to the four sample sites (1,847 total bat passes observed on 20.3 hours of video in 2005, and 535 bats passes observed on 16 hours of video in 2006). A total of 2,382 bat passes were observed at all four sample sites on all nights (Table 1).

When a mist net was present, 112 of the 2,069 observed bats came into contact with the net (5.4%) and 66 of these were captured (3.2%; range 0–10.3%). Most bats that approached the net and were not captured would circle/reverse direction (47.5%), whereas others flew over the top of the net (38.9%), flew under or around the net (8.2%), or bounced off the net and flew away (2.2 % — Table 1).

These data are reported as the number of bat passes through the filming area per hour. Fewer bats on average were observed flying within the filmed target area on control nights than on nights when a net was blocking the flyway. Bats may have flown back into the target area several times to further investigate the mist net and may have been counted two or more times. During control evenings, we recorded an average of 28.6 (range of 2.6–83.7) bat passes/hour on nights without a net. In the presence of a mist net, we recorded 70.0 (range 13.0–338.7) bat passes/hour; however, bat activity and bat captures decreased on subsequent nights (Table 1).

Three of the four sites exhibited a similar trend, showing that activity decreased on subsequent nights when a mist net was present. However, the Sappit River site had been a highly productive site throughout the years and exhibited higher bat activity than the other three sites. Simple linear regression showed almost significant decrease in activity on sequential nights (r^2 = 0.30, n = 11, P = 0.08 — Fig. 3). The slope of this relationship may be unduly affected by the first night of the Sappit site, but the general trend that bat activity around a novel obstacle decreases over time was apparent. The Kruskal-Wallis One-Way ANOVA of bat passes/hour over net night also confirmed a decrease in activity between subsequent netting nights. The sums of ranks

TABLE 1. Summary of bat activity at four mist net locations

Location	Date of Filming	Over	Under & Around	Circle/Reverse	Bounce	Caught	Total	Bats/Hour	% Caught
Mango Hill	6/10/06						35	17.5 (no net)	no net
	6/11/06*	19	29	31	6	2	87	43.5	2.3
	6/12/06	55	21	41	4	4	125	63.5	3.1
	6/13/06	8	8	8	2	3	29	14.5	10.3
Cassava Ghaut	6/14/06						21	10.5 (no net)	no net
	6/16/06	90	49	33	4	5	181	90.5	2.8
	6/17/06	11	5	7	7	1	31	15.5	3.2
	6/18/06	9	9	8	0	0	26	13.0	0.0
Hope Springs	7/09/05						6	2.6 (no net)	no net
	7/10/05	64	7	121	0	3	195	65.0	1.5
	7/11/05	24	4	64	0	8	100	33.3	8.0
	7/12/05	15	0	40	0	4	59	19.7	6.8
Sappit	7/16/05						251	83.7 (no net)	no net
	7/17/05	412	16	555	12	22	1017	338.7	2.2
	7/18/05	98	22	74	11	14	219	73.0	6.4
Totals		805	170	982	46	66	2382	–	–
Percent of Total		38.9	8.2	47.5	2.2	3.2		–	–
Averages								70.0	4.2

* — indicates the date of a full moon, all other filming events ended before or started after a full moon

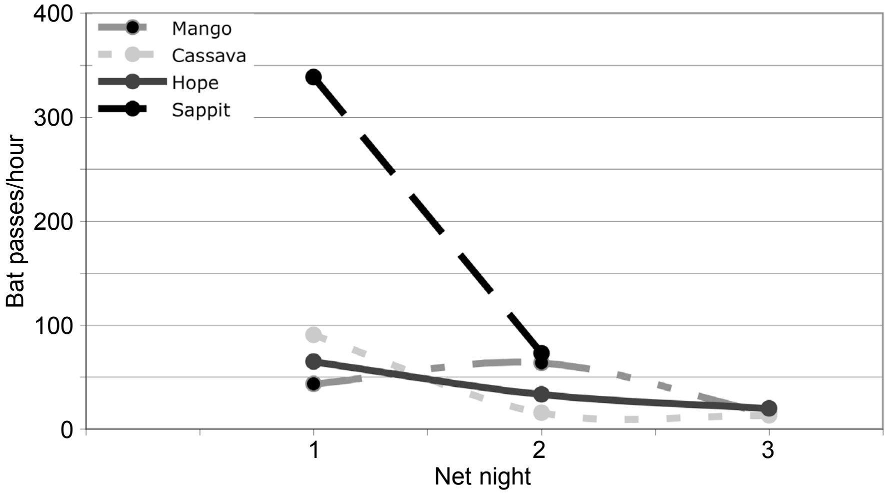

FIG. 3. Bat passes per hour over net nights at each site on Montserrat

for each of the net nights were 35.00 (first net night), 24.00 (second), and 7.00 (third; $P < 0.05$).

We also derived a simple accumulation curve with sampling effort (NN = net night) and yearly inventory numbers as an index to demonstrate the inadequacy of mist nets to consistently capture all species reported from this island in most survey years. This model was used to evaluate bat survey efficiency over many years and demonstrated that when mist netting effort was increased, the 10 known species on the island could be captured (Fig. 4, see 2005).

DISCUSSION

Our data support previous studies that report decreases in capture success on consecutive nights of mist netting and have observed bats flying in large circles on either side of the net and often re-entering the filming area from other directions (Gram and Faaborg, 1997; Simmons and Voss, 1998). Dobson *et al*. (2001) also found that circling behavior was a common response by bats to harp traps. Circling behavior by bats can lead observers to overestimate the number of individuals flying through the airspace, but we attribute this increase in bat activity to the inquisitive response by the bats to the appearance of a new obstacle (mist net) in their environment. Bats then decide whether or not to use that flight path again the next night – this has been classified as learning behavior by several other studies (LaVal, 1970; Kunz and Brock, 1975; Kunz and Kurta, 1988; Kunz *et al*., 1996; Gannon and Willig, 1998; Kuenzi and Morrison, 1998). Obviously, these inferences are speculative, but closer evaluation of bat behaviors in a laboratory setting would help us better understand these inquisitive behaviors and the nature of what appears to be a learning curve.

Mist netting along trails, paths, or pools of water remains a standard protocol for many investigators despite observations that show that a fair number of species are missed or under-represented because they simply do not fly near to or are able to avoid ground-level mist nets. This stratification of flight corridors has been well documented (Francis, 1994; Kunz *et al*., 1996; Simmons and Voss, 1998; O'Farrell and Gannon, 1999). A few studies have specifically used 'high-net sets' or canopy netting to survey bats that operate throughout the forest

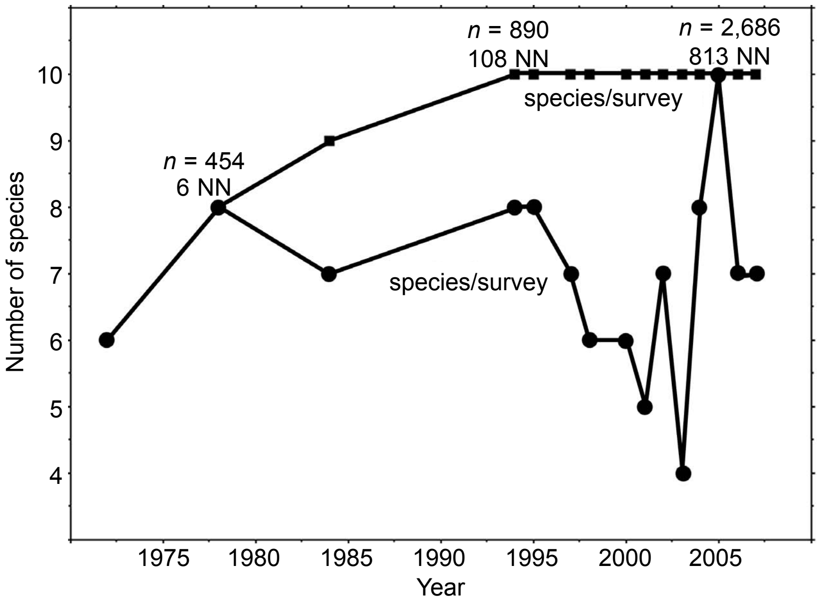

FIG. 4. Accumulation curve for Montserrat from 1978 to 2007. NN: Net-Nights = effort expended; *n* = bats captured

canopy (Gardner *et al.*, 1989; Francis, 1994); however, Simmons and Voss (1998) found that ground-level mist nets captured the majority of the frugivorous and gleaning phyllostomids, leaving relatively few species to be collected through the use of elevated mist nets and/or roost searches (e.g., high flying aerial insectivores). In particular, they found that 78% of the total captures and 83% of the known species were taken in ground level mist nets, while the others were taken from elevated nets or collected from roosts (Simmons and Voss, 1998). They also found that 22% of the known species at their field site were frugivores, yet these same species accounted for 63% of the total mist net captures at all heights.

As such, ground-level netting would appear to remain a pragmatic approach for performing a simple survey of a particular area — especially where phyllostomids are concerned (Francis, 1989; Simmons and Voss, 1998; O'Farrell and Gannon, 1999). Indeed, on Montserrat (where six of the 10 species are phyllostomids) all 10 species have been mist netted, while high net sets, roost searches, and acoustic sampling have not identified additional species.

Use of a single method that captures only 3.2% of the bats passing through an airspace does not give a picture of the true diversity of the sampled area. Bats that hit the net, bounced off, or were caught in the mist net (5.4%) were a very small percentage of the total bat activity near, over, or around the mist net. These data compare well with reports by others using harp traps or mist nets (2.6% — Dobson *et al.*, 2001; 4% — Berry *et al.*, 2004; ≈ 4% — Lang *et al.*, 2004; 3.1% — Larsen *et al.*, 2005, 2006). Due to these low rates, mist nets and harp traps are not accurately sampling bats that utilize flyways and thereby generate inaccurate or misleading data with respect to population structure, and raise the issue of the presence/absence of bats that easily detect and avoid mist nets. Capture data collected on the island of Montserrat throughout the last two decades were re-evaluated and showed that certain bat species were caught more frequently in mist nets (e.g., *Artibeus jamaicensis*). These species may have been more abundant, but the location of mist nets may have influenced capture success due to changes in food availability from site to site or our own bias for picking sites.

Given our results that show only 3.2% of bats passing through a given flyway are captured and the recent interest in rapid biodiversity assessment protocols, it is nad've to think that a short-term survey effort using mist nets would provide adequate inventory data (Simmons and Voss, 1998; Ellison *et al*., 2003; Conservation International, 2007). We acknowledge that many of our own short surveys throughout the Lesser Antilles fall into this category and we recognize that our data are indicative rather than comprehensive (also demonstrated by data from the islands of Antigua, Barbuda, Nevis, St. Kitts, St. Barthelemy, St. Martin, Saba, and St. Eustatius). Known limitations of mist net surveys can be compensated for, in part, by repetitive sampling efforts over several years, with careful analyses of species accumulation curves (e.g., Montserrat, Fig. 4; Simmons and Voss, 1998), which allow us to analyze the completeness and amount of effort for each survey year. Fleming *et al*. (1972) and Kalko *et al*. (1996) also used this method to evaluate bat survey data.

As such, we can only assume that data from 13 surveys spanning 29 years on Montserrat are indicative of the 10 species found on the island. This fauna includes one piscivore (*Noctilio leporinus*), one omnivore (*Brachyphylla cavernarum*), one nectivore (*Monophyllus plethodon*), four frugivores (*A. jamaicensis, Ardops nichollsi*, *Chiroderma improvisum*, *Sturnira thomasi*), and three insectivorous species (*Natalus stramineus*, *Tadarida brasiliensis*, *Molossus molossus*), representing four families — Noctilionidae, Phyllostomidae, Natalidae, and Molossidae. Of these, two species are rarely encountered — *C. improvisum* and *S. thomasi*.

What do we mean by the term 'rare' with respect to what we now understand about mist net bias? Is rarity a factor that merely reflects the constant movements of a vagile organism in response to the destruction of key habitat and foraging areas? Do rarely encountered species naturally occur in low numbers? Or do 'rare' species occur in large numbers, but forage in places mist nets are not set (e.g. high in canopy, above canopy)? Maybe they do not use open pools to drink, or roost where surveys are not normally conducted (e.g., tree cavities, high cliff faces)? Does rarity imply the decline of a species, or simply reflect the animals' abilities to avoid mist nets and humans? As cases in point, the 'rediscovery' of *C. improvisum* Baker and Genoways, 1976 and *S. thomasi vulcanensis* Genoways, 1998 on Montserrat in 2005 were of great interest to us.

Chiroderma improvisum is limited in its distribution to Montserrat and neighboring Guadeloupe. Despite continuing surveys on Montserrat, *C. improvisum* was not captured during the period 1985–2004 and was thought to have been extirpated in association with extensive habitat destruction by recent hurricane and volcanic activity. However, Will Masefield (Durrell Wildlife Conservation Trust), James Daly, and John Martin (Montserrat Forestry Department) caught and released a single female *C. improvisum* on Montserrat 12 July 2005. This lactating female was only the third example of this species captured on Montserrat and only the sixth example ever collected in the Lesser Antilles (Table 2).

The holotype of *S. thomasi vulcanensis* (UNSM 20062) was a pregnant female captured by Pedersen on 14 May 1994. The site of the capture was obliterated by volcanic activity in 1997 and the species had not been re-captured during surveys performed in 1997–2004 and was believed to have been extirpated along with *Chiroderma*. However, Pedersen mist netted a lactating female among banana plants in Bottomless Ghaut, Montserrat, in July 2005 and netted another lactating female at this same place in July 2006. As the name suggests, Bottomless Ghaut is a remote, deep ravine that supports a wealth of native plants and vertebrates and would seem to be a refugium immune to storm and volcanic damage.

Concerns over the presumed extirpation of these two bats were unwarranted, but only in hindsight. The results of our study should be a warning about drawing premature conclusions about the presence/absence of rare species and about rapid biodiversity surveys in general. Simmons and Voss (1998) suggested several steps that could maximize the efficacy of short-duration surveys and ground-level netting — employ large numbers of nets, shift net locations every night, open nets before it is fully dark, and sample in the first three lunar quarters to avoid issues with lunar phobia. Acoustic sampling, video analysis, and thermal imaging are additional technological alternatives to basic mist netting, and should be considered for use in combination with mist netting to provide more accurate and unbiased survey information (Fenton, 1997).

We suggest that another pragmatic solution to compensate for mist net bias would be to simply extend the number and duration of survey efforts over several years. Montserrat is a prime example of the efficacy of this approach. If investigators had performed a single blind survey of Montserrat during the years 1994–2004 they would have reported only 5–8 species as being present, not the 10 that we believe to be there. Indeed, until 2005 we had never caught more than eight species of bats on Montserrat in any single survey year (Fig. 4). In 2005, the number of mist netting nights, mist nets set, and available staff was beyond any other year and the outcome of that massive effort, resulted in the capture of the 10 known species on the island. Therefore, species accumulation curves are

TABLE 2. Mist net capture records of rare bats on Montserrat and Guadeloupe. As of 2007 — Montserrat: 2,845 captures in 827 net-nights; Guadeloupe: 674 captures (data from 1974 and 2000)

Island	*n*	Year of capture	Source of information
Chiroderma improvisum			
Guadeloupe	1	1974	Baker and Genoways (1976); Baker *et al*. (1978)
Guadeloupe	1	2000	D. Masson, C. Masson, M. Breuil, and A. Breuil (unpubl. data); R. Kirsch, R., G. Beuneux, and T. Stoeckle (unpubl. data)
Guadeloupe	1	2007	authors' unpubl. data
Montserrat	1	1978	Jones and Baker (1979)
Montserrat	1	1984	Pierson *et al*. (1986)
Montserrat	1	2005	S. C. Pedersen, R. J. Larsen, K. A. Boegler, and W. P. Masefield (unpubl. data)
Sturnira thomasi			
Guadeloupe	4	1974	Genoways and Jones (1975); Jones and Phillips (1976); Baker *et al*. (1978); Genoways *et al*. (1998)
Guadeloupe	5	2000	D. Masson, C. Masson, M. Breuil, and A. Breuil (unpubl. data); R. Kirsch, R., G. Beuneux, and T. Stoeckle (unpubl. data)
Montserrat	1	1994	Pedersen *et al*. (1996); Genoways (1998)
Montserrat	1	2005	S. C. Pedersen, R. J. Larsen, K. A. Boegler, and W. P. Masefield (unpubl. data)
Montserrat	1	2006	S. C. Pedersen, R. J. Larsen, K. A. Boegler, and W. P. Masefield (unpubl. data)

essential tools for assessing inventory completeness and should be graphed against suitable measures of sampling effort (e.g., numbers of captures) (Simmons and Voss, 1998). For Montserrat, our species accumulation curve peaked in the vicinity of 1,000 captures and 100 NN — values that are similar for many islands in the immediate region: Saint Kitts, Nevis, Antigua, and Saint Martin (Pedersen *et al*., 2003, 2005, 2006; Genoways *et al*., In press). Without long-duration/multi-year survey efforts, biodiversity estimates and conservation guidelines can only be approximations at best and almost certainly underestimate the true faunal diversity of an island.

Acknowledgements

Material and curatorial support were provided by the Mary B. Totten Trust (SCP), Bentley Research Award (SDSU), Durrell Wildlife Conservation Trust (UK), and the Division of Zoology of the University of Nebraska State Museum. We appreciated the general support provided by the Montserrat Department of Forestry and the Montserrat National Trust, and a formal thank you goes to Gerard Gray, Tony Hill, and Claude Gerald (MATE/MAHLE) for permission to collect bats on Montserrat (1994–2007). The courtesy and good humor extended to us by Estate owners on Montserrat were greatly appreciated — we extend a very warm and special thanks to Bryan Hollender (Waterworks Estate) for his continued support of our efforts (1994–2006). We must thank many people for their contributions over the years, but will limit the list to those directly involved in the mist net bias project: Phillemon Murrain (Montserrat National Trust), Kris Cudmore, and Joe Kolba (SDSU). We are indebt to Delphine Rist and Béatrice Ibéné on Guadeloupe. A formal thank you goes to the Préfet de Guadeloupe and the Guadeloupe National Park Director who delivered authorizations to capture and handle protected species on Guadeloupe — that work was part of a conservation education project developed under the UNESCO 'Man and Biosphere' program.

Literature Cited

Baker, R. J., and H. H. Genoways. 1976. A new species of *Chiroderma* from Guadeloupe, West Indies (Chiroptera: Phyllostomatidae). Occasional Papers of the Museum of Texas Tech University, 39: 1–9.

Baker, R. J., H. H. Genoways, and J. C. Patton. 1978. Bats of Guadeloupe. Occasional Papers of the Museum of Texas Tech University, 50: 1–16.

Berry, N., W. O'Connor, M. W. Holderied, and G. Jones. 2004. Detection and avoidance of harp traps by echolocating bats. Acta Chiropterologica, 6: 335–346.

Conservation International. 2007. Rapid Assessment Program. 10 July 2007 <http://web.conservation.org/xp/CIWEB/programs/rap/>

Dobson, K., L. Lumsden, and J. Nelson. 2001. To catch a bat with a harp trap. Bat Research News, 42: 53.

Ellison, L. E., T. J. O'Shea, M. A. Bogan, A. L. Everette, and D. M. Schneider. 2003. Existing data on colonies of bats in the United States: summary and analysis of the United States Geologic-al Survey's population database. Pp. 13–19, *in* Monitoring trends in bat populations of the United States and territories: problems and prospects (T. J. O'Shea and M. A. Bogan, eds.). U. S. Geological Survey Information and Technology Report, USGS/BRD/ITR-2003-0003.

Fenton, M. B. 1997. Science and the conservation of bats. Journal of Mammalogy, 78: 1–14.

Fenton, M. B., L. Acharya, D. Audet, M. B. C. Hickey, C. Merriman, M. K. Obrist, D. M. Syme, and B. Adkins. 1992. Phyllostomid bats (Chiroptera: Phyllostomidae) as indicators of habitat destruction in the Neotropics. Biotropica, 24: 440–446.

Fleming, T. H., E. T. Hooper, and D. E. Wilson. 1972. Three Central American bat communities: structure, reproductive cycles, and movement patterns. Ecology, 53: 555–569.

Francis, C. M. 1989. A comparison of mist nets and two designs of harp traps for capturing bats. Journal of Mammalogy, 70: 865–870.

Francis, C. M. 1994. Vertical stratification of fruit bats (Pteropodidae) in lowland dipterocarp rainforest in Malaysia. Journal of Tropical Ecology, 10: 523–530.

Gannon, M. R., and M. R. Willig. 1998. Long-term monitoring protocol for bats: lessons from the Luquillo Experimental Forest. Pp. *in* Forest diversity in North, Central, and South America, and the Caribbean: research and monitoring (F. Dallmeier and J. Comiskey, eds.). Man and Biosphere Series, 21: 271–291.

Gardner, J. E., J. D. Garner, and J. E. Hofmann. 1989. A portable mist netting system for capturing bats with emphasis on *Myotis sodalis* (Indiana bat). Bat Research News, 30: 1–8.

GENOWAYS, H. H. 1998. Two new species of bats of the genus *Sturnira* from the Lesser Antilles, West Indies. Occasional Papers of the Museum of Texas Tech University, 176: 1–7.

GENOWAYS, H. H., and J. K. JONES, JR. 1975. Additional records of the stenodermine bat, *Sturnira thomasi,* from the Lesser Antillean island of Guadeloupe. Journal of Mammalogy, 56: 924–925.

GENOWAYS, H. H., C. J. PHILLIPS, and R. J. BAKER. 1998. Bats of the Antillean island of Grenada: a new zoogeographic perspective. Occasional Papers of the Museum of Texas Tech University, 177: 1–28.

GENOWAYS, H. H., R. M. TIMM, R. J. BAKER, C. J. PHILLIPS, and D. A. SCHLITTER. 2001. Bats of the West Indian island of Dominica: natural history, areography, and trophic structure. Special Publications of the Museum of Texas Tech University, 43: 1–43.

GENOWAYS, H. H., R. J. BAKER, J. W. BICKHAM, and C. J. PHILLIPS. 2005. Bats of Jamaica. Special Publications of the Museum of Texas Tech University, 48: 1–155.

GENOWAYS, H. H., S. C. PEDERSEN, P. A. LARSEN, G. G. KWIECINSKI, and J. J. HUEBSCHMAN. In press. Bats of Saint Martin, French West Indies/Sint Maarten, Netherlands Antilles. Mastozoologia Neotropical.

GRAM, W. K., and J. FAABORG. 1997. The distribution of Neotropical migrant birds wintering in the El Cielo Biosphere Reserve, Tamaulipas, Mexico. The Condor, 99: 658–670.

HIRSH D. E., M. BETKE, S. CRAMPTON, J. HORN, and T. H. KUNZ. 2003. Censusing Brazilian free-tailed bats using infrared thermal imaging and computer vision methods. Bat Research News, 44: 143.

JENNI, L., and M. LEUENBERGER. 1996. Capture efficiency of mist nets with comments on their role in the assessment of passerine habitat use. Journal of Field Ornithology, 67: 263–274.

JONES, J. K., JR., and R. J. BAKER. 1979. Notes on a collection of bats from Montserrat, Lesser Antilles. Occasional Papers of the Museum of Texas Tech University, 60: 1–6.

JONES, J. K., JR., and C. J. PHILLIPS. 1976. Bats of the genus *Sturnira* in the Lesser Antilles. Occasional Papers of the Museum of Texas Tech University, 40: 1–16.

KALKO, E. K. V., C. O. HANDLEY, JR., and D. HANDLEY. 1996. Organization, diversity, and long-term dynamics of a neotropical bat community. Pp. 503–553, *in* Long-term studies of vertebrate communities (M. L. MOODY and J. A. SMALLWOOD, eds.). Academic Press, San Diego, CA, xix + 597 pp.

KUENZI, A. J., and M. L. MORRISON. 1998. Detection of bats by mist-nets and ultrasonic sensors. Wildlife Society Bulletin, 26: 307–311.

KUNZ, T. H., and E. L. P. ANTHONY. 1977. On the efficiency of the Tuttle bat trap. Journal of Mammalogy, 58: 309–315.

KUNZ, T. H., and C. E. BROCK. 1975. A comparison of mist nets and ultrasonic detectors for monitoring flight activity of bats. Journal of Mammalogy, 56: 907–911.

KUNZ, T. H., and A. KURTA. 1988. Capture methods and holding devices. Pp. 1–29, *in* Ecological and behavioral methods for the study of bats (T. H. KUNZ, ed.). Smithsonian Institution Press, Washington D.C., xxii + 533 pp.

KUNZ, T. H., C. R. TIDEMANN, and G. C. RICHARDS. 1996. Small volant mammals. Pp. 122–146, *in* Measuring and monitoring biological diversity: standard methods for mammals (D. E. WILSON, F. R. COLE, J. D. NICHOLS, R. RUDRAN, and M. S. FOSTER, eds.). Smithsonian Institution Press, Washington D.C., xxvii + 409 pp.

LANG, A. B., C. D. WEISE, E. K. V. KALKO, and H. ROEMER. 2004. The bias of bat netting. Bat Research News, 45: 235–236.

LARSEN, P. A., and S. C. PEDERSEN. 2002. Capture rates of four species of fruitbats on Montserrat. Bat Research News, 43: 162.

LARSEN, P. A., H. H. GENOWAYS, and S. C. PEDERSEN. 2006. New records of bats from Saint Barthélemy, French West Indies. Mammalia, 70: 321–325.

LARSEN, R. J., K. A. BOEGLER, and S. C. PEDERSEN. 2005. Mist net bias on Montserrat. Bat Research News, 46: 191.

LARSEN, R. J., K. A. BOEGLER, J. C. KOLBA, K. W. CUDMORE, and S. C. PEDERSEN. 2006. Montserrat: Mist-netting bias and accumulation curves. Bat Research News, 47: 121.

LAVAL, R. K. 1970. Banding returns and activity periods of some Costa Rican bats. Southwestern Naturalist, 15: 1–10.

MACCARTHY, K. A., T. C. CARTER, B. J. STEFFEN, and G. A. FELDHAMER. 2006. Efficacy of mist-net protocol for Indiana bats: a video analysis. Northeastern Naturalist, 13: 25–28.

MORRISON, D. W. 1978. Lunar phobia in a Neotropical fruit bat (*Artibeus jamaicensis*). Animal Behaviour, 26: 852–855.

O'FARRELL, M. J., and W. L. GANNON. 1999. A comparison of acoustic versus capture techniques for the inventory of bats. Journal of Mammalogy, 80: 24–30.

PEDERSEN, S. C. 2001. The impact of volcanic eruptions on the bat populations of Montserrat, BWI. American Zoologist, 40: 1167A.

PEDERSEN, S. C., H. H. GENOWAYS, and P. W. FREEMAN. 1996. Notes on the bats from Montserrat (Lesser Antilles), with comments concerning the effects of Hurricane Hugo. Caribbean Journal of Science, 32: 206–213.

PEDERSEN, S. C., H. H. GENOWAYS, M. N. MORTON, J. JOHNSON, and S. E. COURTS. 2003. Bats of Nevis, northern Lesser Antilles. Acta Chiropterologica, 5: 251–267.

PEDERSEN, S. C., H. H. GENOWAYS, M. N. MORTON, G. G. KWIECINSKI, and S. E. COURTS. 2005. Bats of St. Kitts (St. Christopher), northern Lesser Antilles, with comments regarding capture rates of Neotropical bats. Caribbean Journal of Science, 41: 744–760.

PEDERSEN, S. C., H. H. GENOWAYS, M. N. MORTON, V. J. SWIER, P. A. LARSEN, K. C. LINDSAY, R. A. ADAMS, and J. D. APPINO. 2006. Bats of Antigua, northern Lesser Antilles. Occasional Papers of the Museum of Texas Tech University, 249: 1–18.

PEDERSEN, S. C., P. A. LARSEN, H. H. GENOWAYS, M. N. MORTON, and K. C. LINDSAY. 2007. Bats of Barbuda, Northern Lesser Antilles. Occasional Papers of the Museum of Texas Tech University, 271: 1–20.

PIERSON, E. D., W. E. RAINEY, R. M. WARNER, and C. C. WHITE-WARNER. 1986. First record of *Monophyllus* from Montserrat, West Indies. Mammalia, 50: 269–271.

REMSEN, J. V., JR., and D. A. GOOD. 1996. Misuse of data from mist-net captures to assess relative abundance in bird populations. The Auk, 113: 381–398.

SIMMONS, N. B., and R. S. VOSS. 1998. The mammals of Paracou, French Guiana, a Neotropical lowland rainforest fauna. Part 1, Bats. Bulletin of the American Museum of Natural History, 237: 1–218.

SYSTAT. 2004. Systat version 11. SYSTAT Software Inc., Richmond, CA.

Received 12 July 2007, accepted 15 November 2007