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Are bat mist nets ideal for capturing bats? From ultrathin to bird nets, a field test

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The use of mist nets is the most widespread technique to capture bats; however, no study has compared if the type of ground-level mist net used during sampling affects bat captures. We sampled bats using three different types of mist nets that varied in mesh (16, 18, and 20 mm) and denier/ply (45/1 and 75/2) sizes over 76 half-night surveys. We used 17–20 mist nets and checked them at intervals of 15–20 min. Capture rate for echolocating bats was higher in the two mist nets with the biggest denier/ply and smaller mesh sizes. "Ultrathin bat mist nets" showed the lowest capture rates (1.5 times less than "Regular bat mist nets"), whereas "Bird mist nets" had capture rates only 1.2 times smaller than "Regular bat mist nets." Our results showed that "Bird mist nets" can sample echolocating bats almost as well as "Regular bat mist nets," and that thinner mist nets may not be the best solution to capture bats that echolocate at high frequencies in this type of surveys. We highlight the importance of considering the efficiency, durability, and longevity of mist nets when choosing the ideal mist-net type for a bat survey.

Key words: bat, bird, denier/ply, mesh, mist nets

Bats are the second most diverse group of mammals in the world (Fenton and Simmons 2015) and are responsible for several key ecosystems services, such as pest suppression, pollination, and seed dispersal (Kunz et al. 2011). Despite their important roles, bats are still one of the least studied mammal groups in the world, mostly due to their nocturnal habits, fast flying speeds, and elusive behavior (Kingston 2016).

To tackle the challenges of studying bats, several techniques have been developed to make their sampling more feasible (Flaquer et al. 2007). Roost checks are one of the most commonly used methods in temperate regions, but they are limited to species that roost in caves or human-made structures (Tuttle et al. 2000; Lourenço and Palmeirim 2004). Ultrasound detectors are a good noninvasive method with incredible potential to study bats, and have gained visibility in the last decades (e.g., López-Baucells et al. 2019). However, this technique has several limitations, for example, a lower detectability for whispering or high frequency bats (e.g., Fenton et al. 1995; Schnitzler and Kalko 2001). Also, bats of the family Pteropodidae do not emit ultrasounds; thus, this technique is not adequate for their study (ACR 2019). The high cost of ultrasound detectors further hampers the accessibility of this approach. Arguably, trapping is the most widespread capture technique for bats, including harp-traps, mist nets, and other less conventional traps (Tuttle 1974; Waldien and Hayes 1999). This technique also allows researchers to collect morphological data and genetic samples from individuals, which is not possible when using noninvasive techniques. Although traps have been widely used, their effectiveness depends on the characteristics of the trapping sites, such as roost entrances or areas with vegetation or water where bats fly low. Studies have shown that harp-traps can cause less distress and be more efficient to capture insectivorous bats than mist nets (e.g., Francis 1989; Kingston 2013). However, due to the small size of harp-traps, only covering an area of ca. 2 m^2, their use mainly is restricted to roost entrances or natural flyways through which bats fly regularly. Although mist nets also present some strong sampling bias (Larsen et al. 2007), they usually are considered the best option due to being less expensive, more versatile (from 2 to 18 m lengths), lighter, and easier to carry (Genoways et al. 2020), making them more ubiquitous in a wider array of ecological studies (e.g., Ferreira et al. 2017; Nkrumah et al. 2017).

Mist nets can vary in size, height, material, mesh, and denier/ply sizes. Although several studies have compared bat mist nets with sub-canopy mist nets and harp-traps (Tidemann and Woodside 1978; Francis 1994; Fukui et al. 2001; Pech-Canche et al. 2011; Sedlock et al. 2011), ultrasound detectors (Kunz and Brock 1975; O'Farrell and Gannon 1999; Flaquer et al. 2007; MacSwiney et al. 2008; Silva and Bernard 2017), and different mist-net protocols and configurations (MacCarthy et al. 2006; Gilley and Kennedy 2010; Marques et al. 2013; Trevelin et al. 2017), no study has compared the bat assemblages captured with different types of mist nets. Some bird studies have compared different mesh sizes, showing that smaller meshes capture smaller and lighter birds (Heimerdinger and Leberman 1966; Pardieck and Waide 1992; Jenni et al. 1996; Piratelli 2003; Akinpelu 2013). Hence, understanding what type of mist net maximizes captures and species diversity is of paramount importance to obtain a better picture of bat communities in a specific study area.

Mist nets used to capture birds usually are thicker than bat mist nets, thus the conventional thinking is that they can more easily be detected by echolocating bats and therefore bat capture rates should be lower. Although no studies support this claim, it is based on the fact that echolocating bats can detect very small objects in the dark, with bats emitting at higher frequencies (shorter wavelength) able to detect smaller objects (Schnitzler and Kalko 2001). In recent years, thinner mist nets, such as monofilament or ultrathin nets, have been developed to try to improve capture rates of bats that echolocate at high frequencies. However, thinner nets are less robust because they have individual threads with low thickness (denier) and fewer threads overall (ply), and so can be less durable and repairable. Furthermore, even if more bats are caught by these mist nets, they may be able to escape more rapidly and thus fewer will be extracted by the researchers.

In this study, we aim to investigate the performance of three types of mist nets ("Regular bat mist net," "Ultrathin bat mist net," and "Bird mist net") in a half-night bat survey, where multiple mist nets are set in a forested environment and checked at regular intervals. More specifically, we wanted to understand: (i) whether bat capture rates change among the different types of mist nets; (ii) how body size and mass of those captured bats differ among the mist-net types; and (iii) how bat species diversity and assemblage composition varies with mist-net type. We hypothesize that "Ultrathin bat mist nets" (smaller denier/ply) will capture more bat species that emit at higher sound frequencies, due to their purported ability to detect thicker nets. Also, we hypothesized that frugivorous bats (family Pteropodidae) will be captured equally by all bat and bird mist nets because most species from that family do not echolocate. Finally, we hypothesized that mist nets with the higher mesh sizes will capture larger and heavier bats.

Materials and Methods

Study design.—We carried out the study in 38 cacao farms in Cameroon, Africa. Cacao farms were in seven different landscapes across Cameroon: Konye (eight farms), Bokito (two farms), Elat (two farms), Ngoumou (six farms), Ebolowa (eight farms), Ayos (eight farms), and Somalomo (four farms; Fig. 1). Farms had a varying degree of shade cover (from 20 to 90%) and understory density (from clear to relatively dense), always were > 1.5 ha, and separated by at least 500 m. In each farm, we used 17–20 ground-level mist nets in four seasons between January 2018 and February 2020. We visited each cacao farm from one to four times and only once per season, making a total of 76 sampling nights (i.e., sampling units).

For the duration of this study, we used three different types of mist nets in total, and two types in each season: "Ultrathin bat mist net" (length: 12 m; height: 3.2 m; mesh: 20 mm [measured as one side of the square]; denier/ply: 45/1: material: nylon; ECOTONE, Poland), "Regular bat mist net" (length: 12 m; height: 2.5 m; mesh: 16 mm; denier/ply: 75/2: material: polyester; ECOTONE), and "Bird mist net" (length: 12 m; height: 2.6 m; mesh: 18 mm; denier/ply: 75/2; material: nylon, Avinet, USA). Depending on the shape and size of the cacao farm, we placed mist nets in net lanes cleared by us in a "T," "L," or "+" layout, with mist nets always within the limits of the farm and not using or crossing existing trails, to maximize spatial homogeneity. Also, all mist nets were stored in a single bag, removed haphazardly, and set by order of removal. In January 2018 and 2019, we used 14–15 Ultrathin bat mist nets and 4–6 Bird mist nets per farm (30 farms and 36 sampling nights), while in August 2019 and January 2020, we used 10–15 Regular bat mist nets and 4–7 Bird mist nets (28 farms and 40 sampling nights). The number of mist nets depended on the farm's size and mist net's conditions, that is, when a bat mist net was broken or needed to be repaired it was replaced by a bird mist net. All Ultrathin bat mist nets had to be trashed after the second field campaign due to the presence of irreparable holes, while Bird mist nets were still usable after being repaired.

Bat sampling.—We sampled bats for 6 h from dusk until midnight and inspected mist nets at intervals of ca. 15 min during the first couple of hours of the night (more than 50% of total captures occurred during this period) and at intervals of ca. 20 min for the remaining hours of the night. We identified, measured, and recorded all captured bats. Species identification followed Rosevear (1965), Hayman and Hill (1971), Patterson and Webala (2012), and Happold and Happold (2013); taxonomy followed ACR (2019). Due to the difficulty of morphologically identifying small individuals from the genus *Nycteris*, *Pipistrellus*, and *Neoromicia* (similar-sized individuals without any clear distinctive morphological characteristics), we grouped them at the genus level and treated them as a single taxon. Also, some individuals from the genus *Hipposideros* were grouped into a nonidentified species due

Fig. 1.—Distribution of the 38 sampled cacao farms in Cameroon, Africa.

to clear differences in echolocation characteristics compared with the other species of this genus known for the area. We captured and handled bats in the field following guidelines approved by the American Society of Mammalogists (Sikes et al. 2011).

Data analysis.—We carried out all analyses in R v3.5.1 software (R Core Team 2020). We used Poisson generalized linear mixed models (GLMMs) to assess differences in captures of echolocating bats (insectivores) and nonecholocating bats (frugivores) between the three types of mist nets (*objective 1*). We assessed differences in bat captures considering three response groups: all bats, only echolocating bats, and only nonecholocating bats. We fitted all models using the glmer function in the "lme4" package (Bates 2010), with the number of bats captured for each group in each mist-net type as dependent variable and mist-net type as a predictor with three categories (Bird mist net, Regular bat mist net, and Ultrathin bat mist net). In other words, the total number of bats caught each night was partitioned into the different mist-net types and then used as dependent variable in this model. Models incorporated a random term accounting for field season variability and site heterogeneity (1|field season/site) and an offset for total capture effort at each site and per mist-net type (calculated as log number of mist net hours; 1 mist net hour [mnh] equals one a 12-m net open for 1 h). We assessed the significance of the predictors with a likelihood ratio test, where we compared our model to the null model. Significant results were analyzed further via multiple comparison tests with Tukey's contrasts (adjusted *P* values reported) using the R package "multcomp" (Hothorn et al. 2008).

To investigate if body size and mass of captured bats changed between the different mist-net types (*objective 2*), we used a linear mixed effect model with forearm (FA) length (mm) and body mass (g) of each captured bat as response variables and mist-net type as categorical predictor. Models contained one random term accounting for field season and site (1|field season/site). We log transformed both response variables to conform to the assumption of a normal distribution. We assessed the significance of the predictors with a likelihood ratio test as above. Five nights were considered outliers and removed from all previous analyses due to the presence of large roosts within three farms. Large roosts can create areas with higher bat densities and affect habitat homogeneity within the farms. See Supplementary Data SD1 for more details on the structure of the models.

To address our third and final objective, we used individual-based rarefaction and extrapolation curves in iNEXT package (Hsieh et al. 2016) to assess differences in bat species diversity between mist-net types. We estimated the expected number of species caught after extrapolating individuals to 1,000 individuals for echolocating bats and 500 for nonecholocating bats, and estimated the 95% confidence intervals by a bootstrap method based on 500 replications, where nonoverlapping confidence intervals indicate definite significant differences at a level < 5% (Chao et al. 2014). Finally, we characterized differences in assemblage composition by means of a nonmetric multidimensional scaling (NMDS) ordination based on a Bray–Curtis dissimilarity matrix, using the number of captures per field season and landscape standardized by effort (for each mist-net type) and square root transformed to reduce the influence of extreme values. We tested for compositional differences between mist-net types using a permutational multivariate analysis of variance (PERMANOVA) with the number of captures per field season also standardized and square root transformed. We carried out both analyses using the "vegan" package (Oksanen et al. 2013).

Results

During the period of the study (9005.2 mnh), we captured 1,099 bats belonging to 31 species in 38 cacao farms. Bird mist nets captured 289 bats of 24 species (2327.7 mnh), Regular bat mist nets captured 481 bats of 26 species (3333.6 mnh), and Ultrathin bat mist nets captured 329 bats of 26 species (3,344 mnh; see Table 1 and Supplementary Data SD2 for a list of all captured species). Echolocating bats represented 66.42% of all captures, with values ranging from 62.63% for Bird mist nets, to 67.15% for Regular bat mist nets, and 68.69% for Ultrathin bat mist nets.

Regular bat mist nets showed overall higher capture rates, while Ultrathin mist nets showed the smallest. A likelihood ratio test showed that the mist-net type used for sampling affected capture rates for echolocating bats but not for nonecholocating bats (Fig. 2 and Table 1; Supplementary Data SD1). However, only Ultrathin bat mist nets showed significant differences from the other two types of mist nets. Given that echolocating bats represent ca. 65% of all captured bats (see Table 1), observed patterns for all and echolocation bats were similar. Nevertheless, some differences still are evident due to marginally higher capture rates for frugivorous bats in the Regular bat mist net.

Finally, FA and body mass did not differ significantly among mist-net types (Fig. 3; see Table 1 for more detail on FA and body mass of each species). However, mist nets with larger meshes (Bird and Ultrathin bat mist nets) seemed to capture marginally heavier and bigger nonecholocating bats.

Individual-based rarefaction and extrapolation curves showed a higher number of species of echolocating bats for Regular bat mist nets than for the other two mist-net types;

Table 1.—Number of captures, forearm size (FA), and body mass (weight) for each bat species captured in 38 cacao plantations between January 2018 and February 2020

Taxon	FA (mm)	Weight (g)	Bird mist net (2327.7 mnh)		Regular bat mist net (3333.516 mnh)		Ultrathin bat mist net (3,344 mnh)	
			Captures	Capture rate	Captures	Capture rate	Captures	Capture rate
Nonecholocating bats			108	0.046	158	0.047	103	0.031
Casinycteris argynnis	56.1	28.1	42	0.018	16	0.005	2	0.001
Epomops franqueti	91.7	114.6	33	0.014	51	0.015	47	0.014
Hypsignathus monstrosus	137.3	Not Available	0	0.000	1	0.000	0	0.000
Megaloglossus woermanni	42.2	16	15	0.006	37	0.011	14	0.004
Micropteropus pusillus	51.1	27	4	0.002	21	0.006	20	0.006
Myonycteris angolensis	76.6	75	1	0.000	2	0.001	4	0.001
Myonycteris torquata	58.3	34.1	4	0.002	22	0.007	1	0.000
Nanonycteris veldkampii	49.5	23.9	0	0.000	0	0.000	4	0.001
Rousettus aegyptiacus	94.6	129.6	6	0.003	6	0.002	6	0.002
Scotonycteris zenkeri	48.6	17.9	3	0.001	2	0.001	5	0.001
Echolocating bats			181	0.078	323	0.097	226	0.068
Doryrhina cyclops	66.6	32	18	0.008	18	0.005	11	0.003
Glauconycteris argentata	40.2	7.5	1	0.000	0	0.000	0	0.000
Glauconycteris beatrix	35.6	4.2	0	0.000	0	0.000	3	0.001
Glauconycteris poensis	37.3	7.4	0	0.000	1	0.000	3	0.001
Hipposideros beatus	44.2	7.6	2	0.001	5	0.001	4	0.001
Hipposideros caffer	47	9.6	3	0.001	3	0.001	2	0.001
Hipposideros curtus	44	7.1	4	0.002	3	0.001	0	0.000
Hipposideros fuliginosus	57	14.6	32	0.014	75	0.022	64	0.019
Hipposideros ruber	51.3	10.3	47	0.020	108	0.032	42	0.013
Hipposideros sp.	48.1	9.3	16	0.007	11	0.003	14	0.004
Macronycteris gigas	103.4	93.1	1	0.000	4	0.001	1	0.000
Miniopterus inflatus	48.2	11	0	0.000	1	0.000	0	0.000
Myotis bocageii	38	5.8	0	0.000	1	0.000	2	0.001
Neoromicia sp.	29.9	5.5	2	0.001	9	0.003	2	0.001
Nycteris grandis	58.8	26.8	4	0.002	2	0.001	3	0.001
Nycteris sp.	40.6	9.4	9	0.004	26	0.008	22	0.007
Nycticeinops schlieffeni	34.9	6	0	0.000	0	0.000	1	0.000
Pipistrellus sp.	28.2	3.5	1	0.000	1	0.000	1	0.000
Rhinolophus alcyone	51.8	15.6	32	0.014	44	0.013	49	0.015
Rhinolophus landeri	44.1	8.7	8	0.003	11	0.003	2	0.001
Scotophilus nux	57.1	27	1	0.000	0	0.000	0	0.000
Total captures			289	0.124	481	0.144	329	0.098

Capture rates are shown as the total bat captures per mist-net type divided by mist-net hours (mnh), where 1 mnh equals one 12-m mist net open for 1 h. FA and weight are shown as mean values in millimeters and grams, respectively. See Supplementary Data SD2 for more details regarding the number of captures per field campaign/season.

however, because the 95% confidence intervals overlapped, the results were not significant (Fig. 4A). Nevertheless, we estimated the number of species for echolocating bats to be 18.64 (*SE* ± 3.46), 26.92 (*SE* ± 10.19), and 18.32 (*SE* ± 1.83) in Bird, Regular bat, and Ultrathin bat mist nets, respectively, while for frugivorous bats, it was 8.49 (*SE* ± 1.3), 9.25 (*SE* ± 0.72), and 9.12 (*SE* ± 0.43). The NMDS ordination showed no clustering of differences among assemblages captured with the three mist-net types and had a stress value of 0.174, conveying a good representation of the data along two dimensions. Bat assemblage composition did not differ significantly across mist-net types (Fig. 4B; F_{11} = 1.0642, R^2 = 0.0684, P = 0.414).

Fig. 2.—Comparison of mean (±95% confidence interval) capture rate (bats/mnh) for all, echolocating, and nonecholocating bats between three mist-net types. Plot based on generalized linear mixed model (GLMM) model. Significant differences in capture rates based on likelihood ratio tests are indicated as **P <0.01. Five nights were considered outliers due to the presence of large roosts within three farms and removed from the analysis.

Discussion

Bat captures varied with the different mist-net types but only for echolocating bats, with capture rates being higher for Regular bat and Bird mist nets, with significant differences only when comparing them with Ultrathin mist nets. Our hypothesis that mist nets with larger mesh size would capture larger bats was not supported by our data, because body mass and FA size of captured bats did not change significantly among mist-net types. However, our results indicated a tendency that smaller meshes were better for capturing bats in our study area. We also did not find significant patterns for species diversity and composition.

Regular bat mist nets had the highest capture rates for echolocating bat abundances, with marginal differences compared to Bird mist nets. Although these mist nets had the same size of denier/ply, Regular bat mist nets had the smallest size of mesh and so could indicate that smaller meshes are better to capture bats in our study area. Akinpelu (2013) showed that a mesh of 36 mm could improve the capture rate of small bird species with 200 mm body length, whereas larger mesh sizes could improve the capture rate of larger and heavier bird species. Contrary to their findings, the mist-net type that we used did not appear to affect the sizes of the bats we captured (i.e., FA and body mass). Only three large echolocating bats species were captured during our sampling, *Nycteris grandis*, *Doryrhina*

Fig. 3.—Violin plot showing the distribution of forearm (FA) and weight of echolocating and nonecholocating bats for each of three mist-net types. Red dot represents the respective mean values.

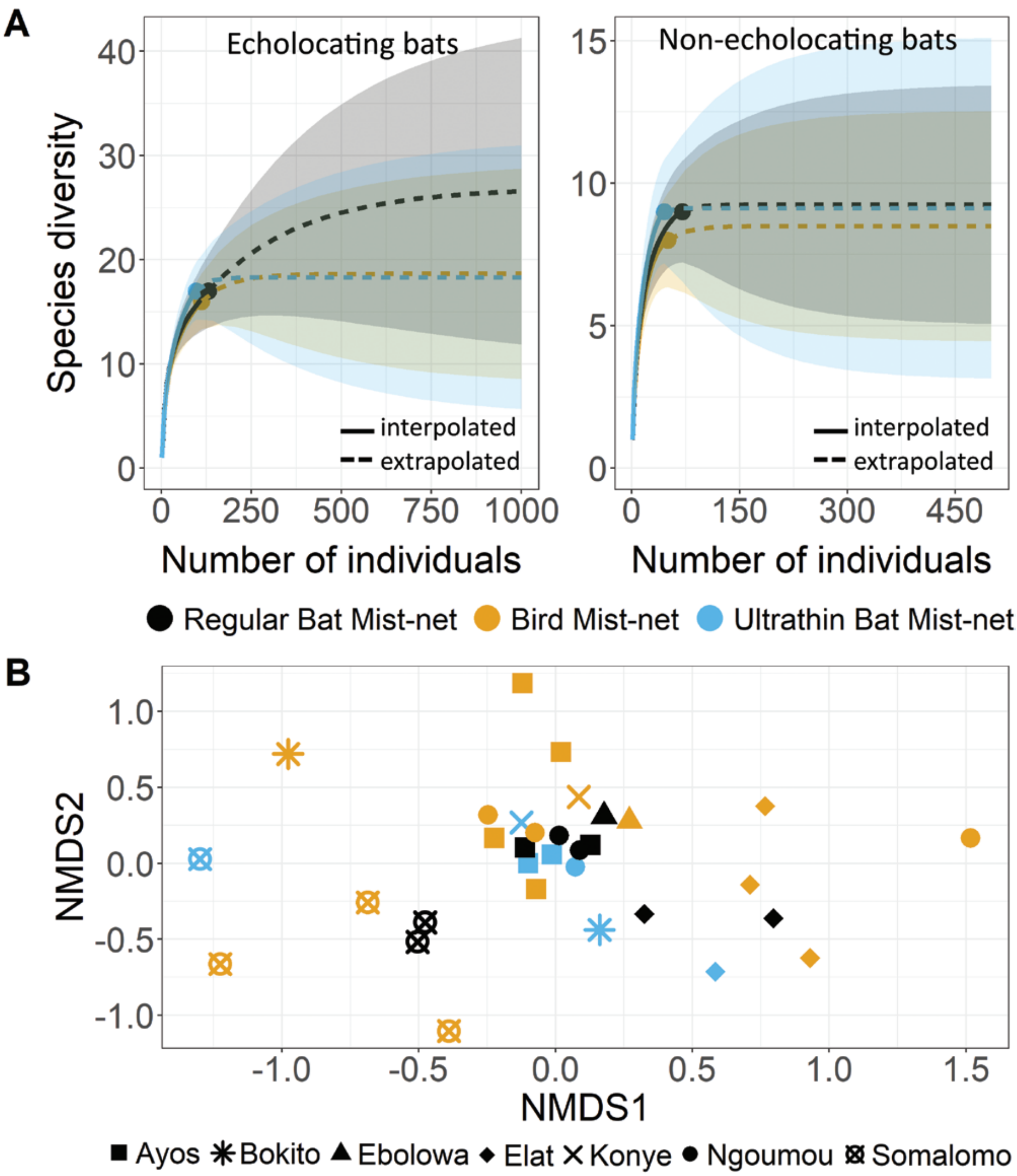

Fig. 4.—Plots showing an A) individual-based rarefaction and extrapolation curve for the number of bat species caught for the three mist-net types. We obtained the 95% confidence intervals by a bootstrap method based on 500 replications; and B) arrangement of the eight sampled landscapes based on three different types of mist nets and four field seasons along the axes of a nonmetric multidimensional scaling (NMDS) ordination based on Bray–Curtis dissimilarity.

cyclops, and *Macronycteris gigas* (see Table 1; ACR 2019). The fact that our echolocating bat community lacks large common species that can be common in other African bat communities may explain why only captures were affected by mist-net type while bat size parameters did not differ. Hence, studies conducted in areas where echolocating bat communities are composed by more large species are needed to know if this is a real pattern or an artifact caused by the small FA range in our bat community (~80% of bats between 40 and 60 mm of FA).

Ultrathin bat mist nets are assumed to be more efficient at capturing echolocating bats that emit at higher frequencies. For example, our most frequently captured species, *Hipposideros ruber*, emits ca. 135 kHz (see Table 1; ACR 2019) which allows them to detect smaller objects (Schnitzler and Kalko 2001). However, our results showed not only that species diversity and composition did not change significantly among mist-nets type but also that the small denier/ply and the large mesh size of these mist nets offered the worst combination of characteristics to maximize captures for echolocating bats. Denier/ply is a characteristic associated with the thickness and number of threads of a net, meaning that nets with higher denier/ply are heavier and so offer more resistance to bats when captured. One possible explanation for these results is that the very small denier/ply makes these nets very fragile and light, allowing bats to bite themselves out quickly from the mist net and escape, lowering capture rates; however, this hypothesis remains untested. Hence, studies controlling more strictly the time that mist net are checked (e.g., intervals of less than 5 min; MacCarthy et al. 2006) and using different combinations of mesh size should be undertaken to assess whether these mist nets really have lower capture rates or if they are not appropriate for this kind of survey due to bats escaping more easily.

Our results highlight the importance of considering local bat communities when choosing the ideal mist-net type for bat surveys. Using the right type of mist nets that improve the sampling of bat communities will help to further our knowledge of tropical bat assemblages and consequently create more adequate conservation recommendations, avoiding potential biases that may be related to comparisons among studies/sites/habitats that used different mist nets. Finally, with this study, we showed that thinner mist nets may not be always the better option to capture bats that echolocate at high frequencies and that bird mist nets can sample echolocating bats almost as well as bat mist nets, at least in Central Africa. Also, because ultrathin mist nets are made of a very fragile thread and cannot be repaired, they lasted only 50% as long as bird mist nets in our study. We therefore recommend researchers, when carrying out full- or half-night surveys, to use mist-net types similar to our Regular bat type as first option, and Bird mist nets as a second option, due to their efficiency, durability, and longevity. These types of mist nets can be used during more field seasons without jeopardizing the sampling, an important factor to consider in regions or projects where funding is scarce.

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Conflict of interest

The authors declare that they have no conflict of interest.

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Supplementary Data

Supplementary data are available at *Journal of Mammalogy* online.

Supplementary Data SD1.—A) Structure and detailed information for each model run for objective 1 and 2. B) Results of likelihood ratio tests and multiple pairwise comparisons comparing abundance, forearm size, and body mass between the three mist-net types.

Supplementary Data SD2.—Table containing the number of captures for each bat species.

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