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Can farmers and bats co-exist? Farmer attitudes, knowledge, and experiences with bats in Belize

Hannah G. Shapiro, University of Tennessee, 274 Ellington Plant Sciences, Knoxville, TN, USA *hshapiro@vols.utk.edu*

Adam S. Willcox, University of Tennessee, 105 McCord Hall, Knoxville, TN, USA

Mallory Tate, University of Tennessee, 274 Ellington Plant Sciences, Knoxville, TN, USA

Emma V. Willcox, University of Tennessee, 274 Ellington Plant Sciences, Knoxville, TN, USA

Abstract: Bats (Chiroptera) are often viewed negatively by the public. Negative public perceptions of bats may hinder efforts to conserve declining populations. In Belize, the presence of vampire bats (*Desmodus rotundus* and *Diphylla ecaudata*) exacerbates the potential for conflicts with humans because of the increased rabies transmission risks. To mitigate these risks, the Belize government provides farmers with assistance to trap and remove vampire bats. In June 2018, we surveyed farmers (n = 44) in and adjacent to the Vaca Forest Reserve in Belize to learn more about their attitudes, knowledge, and experiences with bats. This information may provide new insights and approaches to address farmers' concerns and enhance bat conservation efforts in Belize. Farmers held negative attitudes toward bats, exhibited low knowledge of their ecosystem services, and supported the trapping and use of toxicants to control bat populations to reduce the risk of rabies transmission between vampire bats and livestock. Farmers with livestock had more negative attitudes toward bats than farmers without livestock. Despite farmers reporting depredation incidences with fruit-eating and vampire bats, farmers expressed more negative attitudes toward vampire bats. We recommend that conservation education efforts target all stakeholders in the reserve to increase awareness about the importance of bats to ecosystems and highlight the dangers of indiscriminate trapping. Cumulatively, this may lead to positive attitude changes toward bats and their conservation.

Key words: Belize, common vampire bats, conservation, *Desmodus rotundus*, *Diphylla ecaudata*, hairy-legged vampire bats, human–wildlife conflict, neotropics, protected areas, rabies

Bat (Chiroptera) populations are declining worldwide because of habitat destruction (McCracken 2011), disease (Frick et al. 2010), bushmeat hunting (Mildenstein et al. 2016), and increased population control (Reid 2016, Frick et al. 2019). Bats are often considered keystone species, as they play an important role in dispersing seeds, pollinating plants, and suppressing populations of biting insects and agricultural pests (Boyles et al. 2011, Kunz et al. 2011, Ghanem and Voigt 2012, Wagner et al. 2014). However, despite their critical role in ecosystems and economies, bats have been historically disliked by people (Kahn et al. 2008, Prokop and Tunnicliffe 2008, Prokop et al. 2009).

The 2 most notable explanations for this negative attitude are the increased disease transmission risk associated with bats and a lack of understanding about the taxon (Prokop et al. 2009). Bats have been implicated as reservoirs for multiple diseases (e.g., rabies virus, Marburg virus, Nipah virus, coronavirus), making them an easy target for disease-related fears (Mickleburgh et al. 2002, Calisher et al. 2006, Wong et al. 2007, Schneider et al. 2009, Olival et al. 2017, López-Baucells et al. 2018, Centers for Disease Control and Prevention [CDC] 2020). Additionally, a lack of knowledge about bats has led to them being shrouded in myths (e.g., all bats are vampires, bats fly into people's hair), making them a potential target for persecution (Prokop and Tunnicliffe 2008, Prokop et al. 2009, Dickman and Hazzah 2016).

More than 70 different species of bats are found in Belize, 2 of which are the common vampire bat (*Desmodus rotundus*; Figure 1) and the hairy-legged vampire bat (*Diphylla ecaudata*; Reid 2009; Figure 2). The common vampire bat primarily feeds on mammalian blood (Lord 1993), and the hairy-legged vampire bat feeds on avian blood (Ito et al. 2016). Studies of bats in Belize have largely focused on species biology and ecology (Czaplewski et al. 2003, Miller 2003, Ter Hofstede and Fenton 2005); however, virtually no studies have looked at Belizeans' attitudes toward bats.

Bats in Belize are often the focus of human–wildlife conflict with farmers because of the

Figure 1. Common vampire bat (*Desmodus rotundus; photo courtesy of M. Tate*).

Figure 2. Hairy-legged vampire bat (*Diphylla ecaudata; photo courtesy of M. Tate*).

economic risk of losing their livestock to bat-transmitted diseases and fruit-crop depredation (Góngora 2003, Loan 2013). In response to rancher complaints of their livestock being harassed and bitten by vampire bats, the Belize Agricultural Health Authority (BAHA), the Ministry of Natural Resources and Agriculture, and Belize Livestock Producers Association provide services and resources to ranchers (Martinez 2012, Roberson 2014). These organizations have conducted multiple public awareness, educational, and vaccination campaigns to minimize the number of rabies incidences. Additionally, they recommend trapping and the use of toxicants to reduce vampire bat populations (Martinez 2012, Roberson 2014; M. Tate, University of Tennessee, personal communication).

It is essential to understand local stakeholders' perceptions of bats to create effective and sustainable conservation strategies. One theoretical framework that is commonly used to determine behavior toward wildlife is the cognitive hierarchy model (Vaske 2008). In this model, abstract values and value orientations are distinguished from more specific cognitions (i.e., attitudes and norms; Vaske and Donnelly 1999, Whittaker et al. 2006). This hierarchy goes from general to specific, and specific attitudinal or normative beliefs are more likely to predict behavior than general measures like values (Fishbein and Ajzen 1975, Vaske 2008). Attitudes toward wildlife have been a well-studied topic in the human dimensions of wildlife (Treves et al. 2006, Browne-Nuñez and Jonker 2008, Soulsbury and White 2016), as they are more flexible than values and are important predictors for behavioral intentions (Vaske 2008). Additionally, conservation efforts and outreach programs can be tailored to promote support for conservation actions if they incorporate stakeholder perceptions and attitudes toward wildlife (Fishbein and Azjen 2011).

Informed management decisions concerning bat population control versus bat conservation require an understanding of the biological and economic impact of bats on farming operations, but they also need to consider human perceptions of bats and bat management. To our knowledge, this study is the first to document farmer perceptions of bats in Belize. Our goal was to determine farmer attitudes, knowledge, and experiences with bats in the Vaca Forest Reserve (VFR), Belize. We chose the VFR because there are karst caves, both inside and outside the reserve, that provide suitable roosting sites for bats and because one of the primary anthropogenic activities within the reserve is livestock farming, making this a prime location for farmer–bat conflict (Meerman and Boomsma 2017). Discussions with local non-governmental organization (NGO) staff revealed that farmers with livestock in the VFR consistently deal with vampire bats and lose their animals to diseases or infections related to bat bites (R. Manzanero, Friends for Conservation and Development, personal communication).

Our first study objective was to survey farmers in the VFR to determine their (1) attitudes toward bats, (2) knowledge of bat ecology and ecosystem services, (3) experiences with bat depredation and bat-transmitted diseases, and

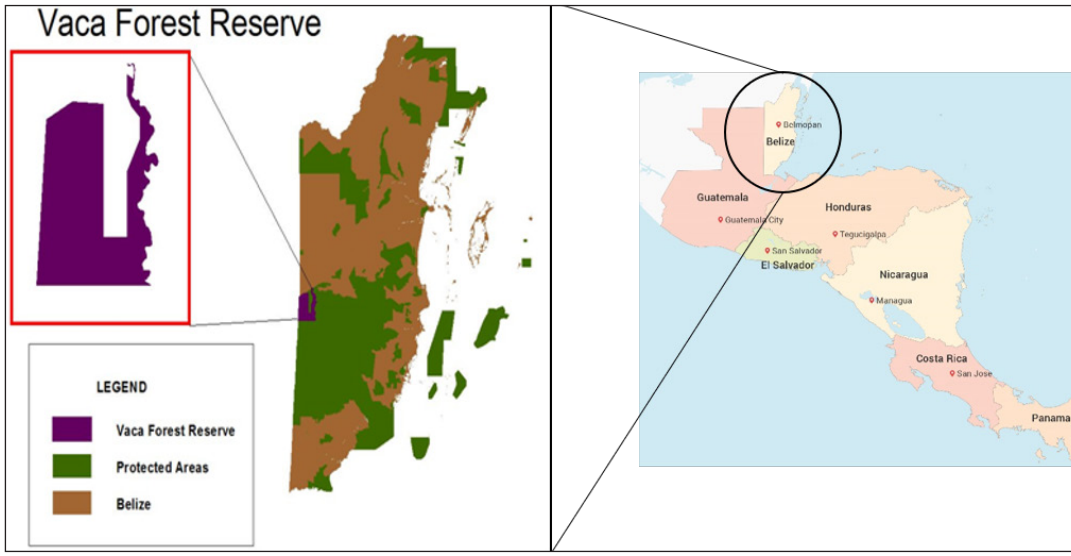

Figure 3. Location of the Vaca Forest Reserve in Belize. Map of Central America with countries – multicolor (from https://freevectormaps.com/world-maps/central-america/WRLD-CAM-PPT-02-0002?ref=atr).

(4) perceptions of bat management actions. Our second study objective was to determine what factors influenced farmer attitudes toward bats and bat management actions. The results of this study will be used to develop targeted education and extension materials that communicate the roles of bats in ecosystems and elucidate prevention measures for disease transmission.

Study area

The VFR is a 16,314-ha forest reserve located in the Cayo district of Belize (Figure 3). This reserve primarily consists of tropical evergreen seasonal broad-leaved lowland forest that has an average rainfall of <2,000 mm per year with a distinct dry season and an altitude ranging from 50–250 m above sea level (Meerman and Sabido 2001). The reserve was established in 1991, and amendments to its area were made in 2003 and 2010 to accommodate agriculture and hydropower projects. Under the Belizean Forests Act of 1927, the designation of forest reserve allows for the VFR to be managed for timber extraction and the conservation of soils, watersheds, and wildlife resources (Government of Belize 2000). This designation also allows for non-timber extraction, military exercises, ecotourism, research, and education. The VFR has become one of the most threatened areas in the Maya Mountain Massif because of agriculture expansion and intensification, the presence of a hydroelectric dam, and both legal and illegal logging practices (Manzanero and Melendez 2013). Approximately 63 farms were active in the reserve, according to a recent survey (Meerman and Boomsma 2017); however, that number has decreased to approximately 55 farms during survey implementation (R. Manzanero, Friends for Conservation and Development, personal communication).

There are 3 primary organizations in the VFR: the Belize Forest Department, Friends for Conservation and Development (FCD), and Friends of the Vaca Forest Reserve (FVFR). The Belize Forest Department is the official manager of the VFR. Their primary responsibility is to regulate timber activities; however, they do not have any employees in the reserve (Meerman and Boomsma 2017). Friends for Conservation and Development is a local NGO that has an interest in the VFR because of its importance and proximity to Chiquibul National Park, a park they co-manage with the Belize Forest Department. At the time of this study, they had 2 field assistants and an agroecology consultant that operated in the VFR to assess the status of the area and train farmers in sustainable farming techniques (Meerman and Boomsma 2017). The FVFR is a community-based organization of farmers who operate in the excised portion of the VFR. This group has expressed an interest in learning sustainable farming techniques to protect the VFR and its water sources (Meerman and Boomsma 2017).

Methods

Sampling

In June 2018, we surveyed farmers in the VFR and at their homes in the reserve's adjacent communities of San Ignacio, San Jose Succotz, and Benque Veijo del Carmen. We attempted to survey every farmer in and adjacent to the reserve. The questionnaire was written in both English and Spanish, as many farmers in the VFR are more proficient speaking in Spanish than in English. The Spanish survey was translated from the English survey by a Belizean, then back-translated to ensure consistency between the 2 questionnaires. The English and Spanish surveys were piloted with local community members and farmers to confirm that each question was applicable to farmers in the reserve and easy to understand. If a question contained language that was difficult to understand or conveyed a different meaning than intended, the question was rewritten and checked with members of our pilot group.

We collected response data using tablet computers through the program iSurvey (www.harvestyourdata.com). An FCD field technician introduced the researcher to the farmer, explained the purpose of the study, and asked for the farmer's permission to participate in the study. It took a maximum of 15 minutes to complete the survey. The researcher was fluent in both Spanish and English. Questions were read to the farmer by the researcher in English or Spanish, depending on the language the farmer preferred, and responses were entered into iSurvey. All research methods were reviewed and approved by the University of Tennessee's Institutional Review Board (UTK IRB-17-03669-XM) and a Belize Forest Department Scientific Collection/ Research Permit (Ref. No. WL/2/1/17[27]).

Survey design

Questions about farmer attitudes toward bats and knowledge of their ecosystem services were based on Fagan et al. (2018) and adapted to the VFR. Questions about bat diets, farmer experiences with bats, and farmer perceptions of future management actions were developed with the input of the FCD, ministry experts, and previous studies in the area (Shapiro and Willcox 2019). Farmer attitudes toward bats were measured using a variety of 5-point Likert style scale questions (ugly–pleasant, worthless–valuable, dangerous–harmless, very scary–very calming, very afraid–very fascinated, very unconcerned–very concerned, strongly dislike–strongly like). Farmer knowledge of bats was assessed using questions that focused on bat diets and common ecosystem services provided by bats in neotropical areas. Bat diet questions were measured using response choices of yes, no, or I don't know. Ecosystem service questions were evaluated using a 5-point Likert scale (very unimportant–very important). Farmer experiences with bats were determined using various yes/no questions, with topics ranging from bat sightings on their property to livestock–bat interactions. Lastly, farmer perceptions of future management actions were determined using a combination of yes/no and open-ended questions.

Statistical analyses

All statistical analyses were conducted in IBM SPSS Statistics 25. We used descriptive analyses to characterize farmer attitudes toward bats, knowledge of bat diets and ecosystem services, perceptions of risk, potential management actions, and group characteristics (age, farm worker vs. farm owner, gender, education level, and farm type). To determine if there were group differences in farmer attitudes and knowledge of bats, we used independent *t*-tests (when the independent variable had 2 subgroups) and 1-way between subjects ANOVAs (when the independent variable had >2 subgroups). We used factorial and multi-way ANOVAs to determine if there were interaction effects between predictor variables on attitudes toward bats. The independent and dependent variables for these analyses met normality assumptions (George and Mallery 2010).

Results

Farmer demographics

We surveyed 44 of the 55 farmers known to be located in and adjacent to the VFR. Our sample represents 80% of the target population. Most of the farmers were male (n = 39; 88.6%). Nearly half of the farmers reported that primary school was the highest level of education they attained (n = 23; 52.3%), followed by no formal education (n = 11; 25%), and completed high school (n = 4; 9%). The average age of our sample was 52 years old (SD = 15.9). The median farm size was 12 ha (min = 0.40 ha; max = 80.90 ha).

Table 1. Overall farmer attitudes toward bats (Chiroptera) and a comparison in farmer attitudes toward bats based on farm type between farmers that only grew crops (n = 23) and farmers that owned livestock (n = 21). Attitudes were measured on a Likert scale from 1 (negative attitude) to 5 (positive attitude), June 2018, Vaca Forest Reserve, Belize.

Attitude	Overall score (Mean ± SD)	Farm type (Mean ± SD)	
		Crops only	Has livestock
Ugly/Cute	2.24 ± 0.83	2.41 ± 0.80	2.05 ± 0.85
Worthless/Valuable	2.83 ± 1.06	3.00 ± 0.91	2.67 ± 1.19
Dangerous/Harmless	2.79 ± 0.88	2.90 ± 0.89	2.65 ± 0.86
Scary/Calming	3.00 ± 0.81	3.09 ± 0.85	2.90 ± 0.77
Afraid/Fascinated	2.89 ± 0.54	3.00 ± 0.43	2.76 ± 0.63
Strongly dislike/Strongly like*	2.79 ± 0.94	3.09 ± 0.92	2.48 ± 0.87
Very unconcerned/Very concerned*	2.70 ± 0.90	2.43 ± 0.84	3.00 ± 0.89

*P <0.05

The most common crops grown in the VFR were corn (*Zea mays*), beans (Fabaceae), citrus (Rutaceae), bananas (Musaceae), and plantains (*Musa paradisiaca*), and the most common animals raised were chickens (*Gallus gallus domesticus*). Farmers both sold their products at the market and used them for personal consumption. Many farmers utilized slash-and-burn agricultural methods and applied synthetic pesticides and herbicides to their land. Farm type was classified into 2 groups: crops only (n = 23; 52.3%) and currently owns livestock (n = 21; 47.7%).

Attitudes toward bats

Farmers percieved bats as being ugly, more worthless than useful, and more dangerous than harmless (Table 1). Farmers did not feel scared or calmed and were slightly unconcerned when they saw a bat (Table 1). Overall, farmers had slightly negative attitudes toward bats (Table 1). The only significant predictor variable for attitudes toward bats was farm type. There was a difference in overall attitude between farm types [$t(41) = 2.24$, $P = 0.03$; Cohen's $d = 0.68$]. Farmers who owned livestock had more negative attitudes toward bats than farmers who only grew crops (Table 1). There was also a difference in concern for seeing a bat on their farm between farm types [$t(42) = -2.16$, $P = 0.04$; Cohen's $d = 0.66$]. Farmers that only grew crops were less concerned if they saw a bat on their farm than farmers with livestock (Table 1).

Knowledge about bats

Farmers were somewhat knowledgeable about bat feeding habits. Fruit and livestock blood were identified as bat food by all farmers. Additionally, most farmers identified bird blood, wild mammal blood, and insects as bat food (Table 2). Human blood, leaves, and nectar were identified by the fewest farmers as bat food. Lastly, livestock flesh, which is not part of bats' diets in Belize, was identified as bat food items by a minority of farmers (Table 2).

Farmers were less knowledgeable of bat ecosystem services. Farmers thought bats were somewhat important for dispersing seeds ($\bar{x}$ = 3.62; SD = 1.12). Farmers thought bats were slightly more important than unimportant for controlling biting insects ($\bar{x}$ = 3.14; SD = 1.33) and neither unimportant nor important for controlling agricultural pests ($\bar{x}$ = 3.06; SD = 1.52). Farmers thought bats were not important for pollinating crops ($\bar{x}$ = 2.36; SD = 1.50). There was no significant relationship between knowledge of ecosystem services and attitudes toward bats. Furthermore, there were no group differences in farmer knowledge of ecosystem services.

Experiences

Farmers with livestock reported that it was very likely for their livestock to be bitten by a bat ($\bar{x}$ = 4.24; SD = 1.04). These perceptions were supported by the prevalence of self-reported bat bites to domesticated animals in the VFR, as most farmers have had animals bitten by bats (n = 33; 75%). The reason that the number of farmers with animals bitten by bats is greater than the number of farms that have animals and crops is because this question included all animals, including dogs (*Canis lupus familiaris*) and horses (*Equus caballus*),

Table 2. Responses (n = 44) of farmers in and adjacent to the Vaca Forest Reserve, Belize in June 2018 to the question "Do bats eat [insert food item]?" Farmers were given 3 answer choices: yes, no, and I don't know.

Food item	Yes	No	I don't know
Fruit	44 (100%)	0	0
Livestock blood	44 (100%)	0	0
Bird blood	43 (97.7%)	1 (2.3%)	0
Wild mammal blood	31 (70.5%)	2 (4.5%)	11 (25%)
Insects	30 (68.2%)	10 (22.7%)	4 (9.1%)
Human blood	22 (50.0%)	20 (45.5%)	2 (4.5%)
Leaves	18 (40.9%)	19 (43.2%)	7 (15.9%)
Nectar	17 (38.6%)	14 (31.8%)	13 (29.5%)
Meat/Flesh from livestock	13 (29.5%)	25 (56.8%)	6 (13.6%)
Meat/Flesh from wild animals	12 (27.3%)	25 (56.8%)	7 (15.9%)

Table 3. Self-reported incidences of vampire bat (*Desmodus rotundus*) depredation events of farmers (n = 44) in and adjacent to the Vaca Forest Reserve, Belize, June 2018. Farmers reported what animals were bitten and what happened to the animals after they were bitten.

Animal	Bite incidences	Animal condition after bite		
		Nothing happened	Got sick and survived	Died
Chicken (*Gallus gallus domesticus*)	24	4	2	18
Cow (*Bos taurus*)	19	10	2	7
Horse (*Equus caballus*)	9	5	1	3
Sheep/Lamb (*Ovis aries*)	5	1	1	3
Dog (*Canis lupus familiaris*)	2	0	2	0
Turkey (*Meleagris gallopavo*)	1	0	1	0

and was not restricted to a defined time period. Chickens were reported as the animal most commonly bitten by bats (n = 24; 73%) and the animal that died the most from being bitten (n = 20; 61%; Table 3).

We also asked farmers if bats should be managed in the reserve, and if so, what those management actions should be. We used the term "managed" so that farmers would not be biased in a positive or negative direction. The following open-ended question allowed for farmers to expand on what management actions they would support. Most farmers thought that bats need to be managed in the reserve (n = 32; 72.7%). Of these farmers, most of them wanted to trap, net, and/or poison bats (n = 23; 71.9%). A minority of farmers wanted to conserve bats (n = 2; 6.25%), were unsure of what to do (n = 6; 18.75%), or suggested vaccinating susceptible livestock (n = 1; 3.13%). More farmers that owned livestock wanted bats to be managed (n = 18; 85.7%) compared to farmers without livestock (n = 14; 59.1%); however, the result of the chi-square test showed this difference was not statistically significant (χ^2 = 3.41; P = 0.065; Φ = 0.28). Additionally, of the farmers that suggested trapping or poisoning bats as a management strategy, 69.5% owned livestock and 30.5% only grew crops.

We found there was a significant interaction between support for management of bats and farm type on farmer attitudes toward bats [$F(1, 39)$ = 5.75, P = 0.02, η^2 = 0.19, power = 0.65]. Regarding the significant interaction, simple effects analysis for farmers that only grew crops showed that attitudes did not differ for those that thought bats needed to be managed and those that did not. Additionally, simple effects analysis for farmers that owned livestock showed that farmers that

support the management of bats in the VFR ($\bar{x}$ = 2.28; SD = 0.75) had more negative attitudes than farmers who did not support management of bats in the VFR ($\bar{x}$ = 3.67; SD = 0.58). Qualitative analysis revealed that the farmers with livestock who did not support bat management actions either had no bat-related livestock deaths or had a cultural connection to bats through Mayan culture.

Discussion

Our study gauged small community attitudes toward bats with the goal of creating effective conservation messaging. Better information on farmers' attitudes, knowledge, and experiences with bats will be needed to create effective conservation education and extension materials. In addition to providing a description of farmer–bat conflicts, we found that farmers in the VFR held generally negative attitudes toward bats. Furthermore, we found that farm type was the only variable that influenced farmer attitudes toward bats. We also found that despite what our NGO partners communicated to us, farmers were able to differentiate between vampire bats and bats with other diets, as farmers were moderately knowledgeable of bat diets. However, farmers had little knowledge about the importance of bats to ecosystems. Lastly, we found that most farmers supported management of bat populations in the reserve, with most farmers suggesting trapping and the use of toxicants to control vampire bat populations.

The negative attitudes displayed toward bats and support for actively controlling bat populations are not unique to this area. Bats are viewed negatively in many areas of the world for multiple reasons, including myths (Prokop and Tunnicliffe 2008), people's lack of knowledge about them (Musila et al. 2018), and the lack of interaction people have with this nocturnal taxon (Kingston 2016). In our study, however, the dislike of bats in the VFR is primarily attributed to the fear of livestock losses from rabies. These fears are supported by recent studies that found the number of bat-related rabies cases affecting people and cattle in Latin America has increased (Lopez et al. 1992, Mayen 2003, Moran et al. 2015). Previous studies have found that people have negative attitudes toward animals that cause them financial loss. Frugivorous bats in Africa (Musila et al. 2018), the Middle East (Mahmood-ul-Hassan and Salim 2011), and southeast Asia (Aziz et al. 2017) are viewed negatively because of fruit-crop depredation. Interestingly, farmers in the VFR had more negative attitudes toward vampire bats than frugivores, despite farmers reporting fruit depredation incidences both on their farm and in their homes.

Farmers having an overall negative attitude toward bats, especially vampire bats, seems intuitive; however, previous research reveals that farmers in the area have a complex relationship with wildlife (Shapiro and Willcox 2019). A recent study conducted on farmer wildlife attitudes in the VFR revealed that farmers had an overwhelmingly positive attitude toward wildlife that are commonly involved in human–wildlife conflicts (i.e., jaguars [*Panthera onca*], pumas [*Puma concolor*]. This positive attitude toward big cats serves as a sharp contrast to the results found in this study. One possible reason for the discrepancy in attitudes may be the frequency at which human–wildlife conflicts occur. Farmers indicated that they commonly saw bats on their farm, whereas the previous study noted that farmers had few depredation incidences by big cats. Another probable explanation for the difference in farmer attitude toward bats and big cats is the transmission of disease. Even though big cats depredate livestock and pose a human safety risk, they are not commonly known to transmit disease to animals outside the feline family (Furtado and Filoni 2008). Bats, on the other hand, have been implicated as reservoirs for many diseases, including rabies, and more recently, COVID-19 (Calisher et al. 2006, Wong et al. 2007, Schneider et al. 2009, Olival et al. 2017, CDC 2020). Lastly, there is a large difference in the conservation context around these 2 groups of wildlife. In Belize, governmental agencies and NGOs are working to preserve big cat habitat and educate the public about their importance to ecosystems. Conversely, the government responds to bat–human conflict by trapping vampire bats and teaching farmers how to trap and poison bats (Martinez 2012; M. Tate, University of Tennessee, personal communication). Further research should integrate bats into human–wildlife conflict studies to determine how people's attitudes of bats compare to other controversial wildlife.

We found no relationships between knowledge, attitudes, and demographic variables. First, there was no relationship between in-

creased knowledge of bat ecosystem services and attitudes toward bats. Previous research has indicated that increased knowledge of bats can result in positive attitudes toward these animals (Prokop and Tunnicliffe 2008, Prokop et al. 2009). Conversely, other research suggested that there is no correlation between knowledge and attitudes of dangerous wildlife, or wildlife that poses a risk of physical attack or disease transmission (Özel et al. 2009). Farmers in our study did not reference any myths when describing their attitudes or experiences with bats, but they did emphasize the economic risks bats pose to their livelihood. Second, there was no relationship between education level and attitudes toward bats. This result contrasts with other studies that have documented that higher levels of education have a positive influence on attitudes toward wildlife (Røskaft et al. 2003, Musila et al. 2018).

Farmer support for trapping and the use of toxincants to control bats in the VFR highlights a common pattern of treating bats as agricultural pests and not as wildlife with value to biodiversity conservation and positive agricultural ecosystem services. In the VFR, BAHA staff conduct vampire bat trapping sessions, where they trap and deploy a toxicant on the backs of every individual captured, regardless of species (M. Tate, University of Tennessee, personal communication). This agency also trained farmers to trap bats; however, our research revealed that farmers lacked the knowledge to differentiate between vampire bats and other bat species (M. Tate, University of Tennessee, personal communication). Subsequently, the farmers trapped and deployed toxincants on any bat on their farm regardless of its diet and believed that the bats then carry the toxicant back to their roosts to spread to other bats within the colony (M. Tate, University of Tennessee, personal communication). The control of bat populations to reduce economic damages has been used in multiple locations in the world, including those that do not have vampire bats (Frick et al. 2019). Bats and their roosts have been targeted by individuals and government agencies for decades (Hadjisterkotis 2006). In some of these locations, attitudes toward bats or knowledge of their ecosystem services plays little to no role in people's behaviors (Musila et al. 2018). Future research should investigate how farmer perceptions of damages caused by bats compare with real damages.

With farmers expressing negative attitudes toward bats, having a low-to-moderate knowledge of bats, and supporting the trapping and poisoning of vampire bats, it is crucial that conservation efforts focus on changing farmer attitudes and behavior. Research has shown that simply increasing a person's knowledge is not an effective way to change their attitudes or behavior (St. John et al. 2010, Teel et al. 2015). Rather, we suggest the combination of technical solutions, like accessible vaccination programs, and the development of an educational program that focuses on increasing the number of positive experiential learning opportunities with bats to target the affective component of attitudes (Kingston 2016). Additionally, current approaches to bat management by governmental agencies and NGOs need to be evaluated. The risks that vampire bats pose to farmers' livelihoods should not be ignored, but bat trapping programs need to be evaluated to determine if they lower the risk of disease transmission to livestock, how nontarget species are affected, and how bat population declines would impact ecosystems.

There are 2 primary limitations of this study. First, while this study surveyed 80% of the farmers in the reserve, our sample size only consisted of 44 farmers. Thus, these results are only applicable to the VFR and cannot be used to generalize farmer attitudes toward bats across Belize. Second, there is a possibility that some of the positive attitudes we saw toward bats were partially due to acquiescence bias or social desirability bias. Even though attitudes toward bats were normally distributed, farmers may have been swayed to denote more positive attitudes because of our connections with the local conservation organization.

Management implications

We provide the first description of farmer's attitudes toward, knowledge of, and experiences with bats in Belize. While this paper represents an important case study on farmer relationships with bats, it also reveals the importance of understanding the context of bats in local communities. Many studies reveal that people's attitudes and experiences with bats are negative; however, recent studies have shown that this negative attitude cannot be generalized. Studies in other counties have revealed that people's attitudes toward bats have become more

positive (Fagan et al. 2018, Musila et al. 2018; D. Ader, University of Tennessee, unpublished data). However, even with some communities expressing positive attitudes toward bats, bat control efforts and roost destruction are significant threats to the taxon. It is essential to document people's relationship with bats and incorporate these perceptions into educational efforts and management decisions, thus increasing the potential for successful conservation efforts.

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Associate Editor: John Tomeček

Hannah G. Shapiro is a master's candidate in the wildlife and fisheries science program at the University of Tennessee. Her master's thesis focuses on visitor perceptions of bats and cave management actions in U.S. national parks, with the goal of improving conservation and recreation in U.S. national parks.

Adam S. Willcox is a research assistant professor in the Department of Forestry, Wildlife and Fisheries and the Smith Center for International Sustainable Agriculture at the University of Tennessee. Recent research projects have included endangered species management, hunting, zoonotic disease risk, integrating agriculture with wildlife conservation, and community-based conservation, among others. He is a returned U.S. Peace Corps volunteer and has spent much of his career working with communities in sub-Saharan Africa, Central America, and the United States.

Mallory Tate is a master's student at the University of Tennessee studying wildlife and fisheries science. Her research interests include bat ecology and behavior as well as the dynamics between humans and wildlife.

Emma V. Willcox is an associate professor of wildlife science at the University of Tennessee. She has a B.S. degree in zoology, M.S. degree in conservation biology, and Ph.D. degree in wildlife ecology and conservation. Research in her lab is focused on examining how mammals respond to anthropogenic stressors and the threats emerging infectious diseases pose to mammal populations, with a focus on rare and imperiled species.