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ANIMAL SCIENCE

ID please: Evaluating the utility of Facebook as a source of data for snake research and conservation

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Abstract: Social media has the potential to provide large amounts of biological data, especially for notoriously difficult groups of organisms to study in nature such as snakes. Here, we explored the utility of various Facebook communities to provide data for research on Colombian snakes. Specifically, we determined the richness, distribution, rarity, and popularity of snake species and compiled information on natural history observations and human–snake interactions. We also explored the spatial structure of posts using a geographically weighted regression model. Queries relating to species identifications made up 86.1% of Facebook posts. The portion of the snake community "sampled" by snake-related Facebook posts was not representative of the total richness of snake species in Colombia; however, these posts permitted a greater proportion of snake species to be sampled more rapidly compared with traditional snake sampling approaches. Facebook posts provided new distributional records for 9–21% of Colombian snake species. Rainfall, rural population, and internet availability were the strongest predictors of snake-related Facebook posts. Although the use of Facebook for compiling information on snakes is not free of bias, our findings demonstrate that Facebook communities provide a potentially powerful source of data that could aid studies of snake biology.

Key words: Colombian snakes, internet ecology, snakebite, snake–human conflict, social media, wildlife.

INTRODUCTION

Strengthening public awareness of wildlife can have a substantial impact on the success of wildlife conservation and management strategies. The establishment of widely accessible and user-friendly platforms that allow members of the lay public to engage in wildlife-related conversations has become a major target of conservation efforts to address the challenges associated with ongoing global biodiversity loss (Maxwell et al. 2016, Wu et al. 2018).

The social media revolution has enhanced public awareness of wildlife and the need for increased conservation efforts through online platforms such as Facebook, YouTube, Twitter, iNaturalist, blogs, and wikis (Toivonen et al. 2019, Jarić et al. 2020, Maritz & Maritz 2020). The effectiveness of these online social media platforms to contribute to conservation efforts lies in their widespread influence, especially their ability to be used in multiple languages, the rapidity with which information can be exchanged, their wide accessibility, and their ability to connect inhabitants of rural areas, who are more likely to interact frequently with imperiled species, with conservation scientists (Dubose 2011, Jarić et al. 2020). For example, Facebook, which is by far the most popular social networking site worldwide in terms of the number of monthly active users (Toivonen et al. 2019), features various wildlife-related communities; the rapid growth of such groups has permitted the creation of large networks that permit information on wildlife to be exchanged rapidly on a global scale (Nouh & Nurse 2016, Jarić et al. 2020).

Vertebrates, especially charismatic species such as birds and large mammals, have garnered the most public support and engagement (Castillo-Huitrón et al. 2020, Roque De Pinho et al. 2014, Vincenot et al. 2015). Less popular species that do not easily engender empathy nor are widely considered charismatic face particularly difficult conservation challenges. Snakes are among the most maligned vertebrates and tend to promote anger, fear, and disgust among the general public (Lynch et al. 2014, Castillo-Huitrón et al. 2020). Indeed, some countries have supported bounty systems that promote the harvesting of snakes, the organization of systematic hunting activities (e.g., rattlesnake roundups), and the deliberate killing of snakes because they are considered dangerous or life-threatening (Doods 1987, Lynch et al. 2014). Consequently, financial support for snake conservation initiatives is limited because of a lack of public support and participation (Burghardt et al. 2009). This, coupled with the cryptic behavior and low encounter rates of snakes (Dorcas & Wilson 2009, Angarita-Sierra & López-Hurtado 2020), makes gathering the information needed to advance snake conservation efforts particularly challenging.

Internet Ecology (iEcology; Jarić et al. 2020) is an emerging and cost-effective research approach that uses diverse online data sources and methods to generate insights on species distribution, ecological interactions, and anthropogenic impacts. Social media is a major source of ecological data for iEcology. Recent research has demonstrated the utility of social media, namely Facebook groups, for compiling images and videos that can be used to extract ecological data on elusive organisms such as snakes (Maritz & Maritz 2020). Facebook has also permitted the creation of communities that foster constructive emotions and positive beliefs about snakes. The ability of such platforms to provide valuable biological data and influence social perceptions of snakes could greatly promote increased understanding of snakes and garner support for snake conservation efforts (Nouh & Nurse 2016).

In this study, we tested the hypotheses that Facebook users are a robust source of scientific data on snake biology and snake–human interactions and that Facebook posts have a spatial structure related to social and climatic variables. We addressed these hypotheses using various Colombian Facebook groups that engage in advocacy for snake research and conservation. Although Colombia lacks an active herpetocultural community (unlike Germany, Japan, China, Canada, or the USA; Heichler & Murphy 2004, Jassen 2018, Loughman 2020, Rossi & Rossi 2000), and most Colombians champion spurious adages such as “the only good snake is a dead snake” (Lynch et al. 2014, Cañas-Dávila et al. 2016), an increasing number of groups of academics, researchers, zookeepers, policymakers, and members of the lay public engaged in snake research and conservation efforts have developed robust initiatives aimed at altering the negative perceptions of Colombians towards snakes (Lynch et al. 2014). This has resulted in the creation of a large, robust, and growing Facebook community focused on snake research and conservation advocacy.

The aim of this study was to explore the utility of the Facebook social network as a source of scientific data for snake research, as well as to provide insight into how online communities could be used to study unpopular and unappealing species. Specifically, our objectives were to (1) characterize the types of information that can be derived from Facebook groups through manual searches; (2) explore the ability of Facebook group administrators to assign taxonomic identification to the species posted; (3) evaluate the features of the users making posts of snake sightings; (4) assess the relative importance of climatic and social variables in explaining the spatial structure of the Facebook posts; and (5) estimate the relative contributions of Facebook posts to providing new information on snake species distributions, natural history data, and ecological interactions.

MATERIALS AND METHODS

Sampling and data acquisition

Social media data were collected by manual searches from 03 June to 30 September of 2020. We performed daily searches on the Facebook social network from 20:00 to 00:00 h (Colombian standard time zone GTC-5) for a total of 488 h of sampling effort. During this sampling window, we recorded all the posts published in each Facebook group from 0:00 to 20:00 h of each sampling day. Posts published from 20:00 to 00:00 h were included in the samples of the following day. Thus, all posts retrieved were available to accumulate likes, shares, and comments from Facebook users between 20 and 24 hours. The target Facebook community was composed of Colombian groups related to snakes, herpetofauna, biodiversity conservation, and Colombian wildlife. Facebook pages of journals or newspapers that reported environmental notes, environmental governmental agencies, and non-governmental agencies that advocate for Colombian wildlife were also sampled.

Searches of Facebook groups were conducted daily from the first to the last day of sampling using two approaches: (1) querying Facebook's browser with the following Spanish key words: Topic =(serpientes* OR ofidios* OR culebras* OR víboras* OR anfibios* OR reptiles* OR herpetología* OR herpetólogos* OR biodiversidad* OR ecología* OR conservación* OR flora* OR fauna* OR silvestre* OR conservación* OR) AND Colombia; and (2) Given that members of several Facebook groups can repost the sightings of posts originally published in other groups, we considered sightings from new Facebook groups that were not previously detected by the above algorithm. All new Facebook groups detected were added to our cumulative list of groups, as well as subsequent manual searches.

We recorded a total of 36 variables from social media posts that were clustered into the following categories: name of the Facebook group, date, sex of the user that posted the content, taxonomic name, common name reported, geolocation, post feedback, post type, media type, media quality (High = when the snake can be clearly observed and identified from the picture/video; Medium = when the picture/video allows the snake to be observed, but the snake cannot be clearly identified; and Low = when the snake cannot be easily observed nor identified), and remarks (Table I).

We determined the gender and biology background of users based on their Facebook profiles. We considered users with a background in biology to be those that reported having studied biology, health sciences, environmental sciences, or related fields within the natural sciences. Taxonomic names and identifications followed the updated version of the Reptile Database (Uetz et al. 2020), as well as Campbell & Lamar (2004) and Valencia et al. (2016) for elapids and vipers (Elapidae and Viperidae).

Table I. Elements of social media data retrieved through the manual searches in Facebook.

Facebook group information	User information	Taxonomic information	Snake report information	Geolocation	Media type	Post feedback	Post type	Remarks
Name of the group	Gender: Male/Female Institution	Family	Venomous: Yes/ No	Department, municipality, locality	Picture	Number of Comments	Asking for taxonomic identification	Snakebite accident. Feeding. Preyed-upon Deliberate killed by human. Road killed. Antipredator display. Found dead. Thanatosis Albinism. Melanism. Relocated.
		Genus	False venomous: Yes/No	Elevation	Video	Number of shares	Showing	
		Species, vernacular name	State: Alive/ Dead, Unknown	Geographic coordinates	Quality: Good/ Middling/ Bad	Number of likes		
Number of followers when the searchers ended	Kind of reporter: With a background in biology / Without a background in biology	Non-snake	Timestamp: time when content was shared					
		Fake						
		Taxonomic identification: Correct, partial, incorrect						

For blind snakes (Scolecophidia), we followed the taxonomy of Peters and Orejas-Miranda (1970), Pinto et al. (2010), Caicedo-Portilla (2011), and Hedges et al. (2014). For boids (Boidae), we followed the taxonomy of Köhler (2003), Passos & Fernandes (2008), and Henderson et al. (2009); for pipe snakes, dwarf boas (Tropidophiidae), and colubrids (Colubridae), we followed the taxonomy of Peters & Orejas-Miranda (1970), Williams (1970), Köhler (2003), Passos et al. (2009), Passos & Arredondo (2009), Passos & Lynch (2010), Angarita–Sierra et al. (2013), Vázques-Restrepo et al. (2018), and Carvajal-Cogollo (2019). We classified the snakes posted as venomous, non-venomous, and false venomous following Campbell & Lamar (2004). We also recorded whether the snake was dead or alive.

We also made comparisons of snake color patterns in the pictures and videos posted by Facebook users with the pictures embedded in the references described above, as well as those housed in the reptile database (Uetz et al. 2020), Bioweb (Torres-Carvajal et al. 2020), and SantanderHerps (Meneses-Pelayo et al. 2016) for taxonomic identification. We evaluated the accuracy of the taxonomic identification assigned by the Facebook group administrators as good when the identification to species was accurate; partial when the identification to species was inaccurate but the identification to the genus and family was accurate; and bad when the identification to the family level was inaccurate. Taxonomic identifications provided by other users were not considered.

Given the high diversity of snakes in Colombia (~324) and the lack of information on many species (Cadle 1992, Lynch et al. 2014, Uetz et al. 2020), the taxonomy of several snake species has yet to be resolved . In addition, several wide-ranging taxa are thought to represent species complexes. The Supplementary Material - Table SI summarizes the criteria that were used to assign identifications to snake species with lingering challenges.

To avoid sampling duplicate posts among Facebook groups, we identified the original reporter of each post, as well as the Facebook group in which it was posted and shared for the first time. Posts outside of the sampling period were discarded, as well as posts with their content nested in previous posts.

We determined the geographic location of the sighting in each post using one of four approaches. We used geographic coordinates provided by the users in their posts if provided. If coordinates were not provided by users, we obtained geographic coordinates according to locality names, municipality, and department names provided in the post by the user using Google Earth® and geographical gazetteer GeoNames (GeoNames 2020). When posts lacked a locality name, we directly queried Facebook users about the locality and then obtained the geographic coordinates using Google Earth® and geographical gazetteer GeoNames as described above. In cases in which the detailed locality or geographic coordinates were impossible to obtain, we obtained geographic coordinates based on the centroid of the nearest municipality. Posts without geographic coordinates were not used in spatial analyses.

To identify the Facebook posts that contribute novel information to the known current distributions of species, we gathered georeferenced data for all snake species in Colombia present in the Facebook database from the Global Biodiversity Information Facility (GBIF) using the R package rgbif (Chamberlain et al. 2021). We then placed all Facebook records for each species into two buffers (50 and 100 km) surrounding available records from the GBIF. We used these buffers because most distribution extensions are determined based on the Euclidean distance from the nearest record; thus, records from areas falling outside the buffers are records that represent range extensions. The records that fall within these buffers were retrieved from Facebook database to identify records that significantly add new distributional information.

Statistical analysis

Based on the dispersion and relative abundance of the posts, we built an ordinal hierarchy to classify the snake observations by Facebook users, ranging from extremely rare to extremely common species (Table II). We employed one-way analysis of variance (ANOVA) to compare the number of posts between days, weeks, and months. Before carrying out ANOVAs the number of posts were square root transformed using the Tukey´s staircase transformation method (Erickson & Nosanchuk 1992).

We assessed the completeness of our exploration of the Facebook community using the clench parametric model. This model assumes that the probability of adding a Facebook group to the list decreases with the number of Facebook groups already recorded, but that it increases over time (Colwell & Coddington 1994, Gómez-Anaya et al. 2014). For both ANOVA and the completeness model, assumptions of normality and homogeneity of variances were tested using a Kolmogorov-Smirnov test and Brown-Forsythe Leven-type test. We assessed the completeness of species richness by estimating the theoretical richness through the non-parametric first and second-order Chao estimators with the software EstimateS version 9.1.0 (Colwell 2013).

We assessed differences between the number of dead and live non-venomous, venomous, and false venomous snakes performing a G-test and Chi-square (χ^2) test. False venomous snakes were defined as harmless or mildly venomous snakes that mimic the bright coloration of highly venomous coral snakes (e.g., *Erythrolamprus bizona*), or the head shape, dorsal color pattern, and behavior of pit vipers (e.g., *Leptodeira annulata*, *Xenodon angustirostris*).

Index of snake popularity

Based on the number of “likes” received by each post, we built a popularity index based on the index *h* proposed by Hirsch (2005). In our index, the number of posts for a species by day corresponds to the number of articles published over *n* years by an author in the original *h* index, and the likes received by each species corresponds to the number of citations for each paper. Prior to calculating the popularity index, we assessed whether Facebook group size and the state of the snake (dead or alive) are sources of bias. We hypothesized that the number of likes received would increase with Facebook group size. To test this hypothesis, we performed a linear regression between the number of followers per Facebook group, the total number of likes received, and the number of snake posts published. All variables were log-transformed prior to performing the statistical analysis; assumptions of normality, autocorrelation, and homoscedasticity were evaluated using the Kolmogorov–Smirnov test, Durbin–Watson test, and Breusch–Pagan test, respectively. There was no correlation between the number of followers per Facebook group and the total number of likes received (F =: 3.73, df = 1-24, P = 0.065; r^2 = 0.09) nor between the number of followers per Facebook group and the number of snake posts published (F =1.17, df = 1-24, P = 0.29; r^2 = 0.006). Therefore, Facebook group size was not a source of bias.

Second, we hypothesized that posts of dead snakes would receive fewer likes than posts of live snakes. To test this hypothesis, we performed a Wilcoxon rank-sum test with

Table II. Ordinal categories according with the frequency of posts retrieved from Facebook groups. Post range: posts interval in which a snake species is allocated. Posts mean: average of posts of the snake species is allocated per posts interval.

Category	Posts range	Species	Posts mean
Extremely common	>84	2	94.5
Common	67-83	1	72
Frequent	50-66	1	62
Uncommon	34-99	8	40.3
Rare	17-33	15	23.3
Extremely rare	<16	97	3.5

continuity correction. All variables were log-transformed prior statistical analysis. There were significant differences in the number of likes received between posts of dead and live snakes (W = 239496, P = <0.0001); therefore, the dead or live status of snakes is a significant source of bias.

In light of the above tests and based on the *h* index, we defined a species with an index of popularity (P) if its posts have at least P likes for each one and the other posts (N total posts - P) have ≤ P likes each. Only likes earned from posts of live snakes were included. In addition, we considered a snake species as popular when the index of popularity P > 10.

Finally, we assessed the differences in the frequency at which posts were shared and comments were left by users between popular and unpopular snakes by conducting Wilcoxon rank-sum tests with continuity correction. All statistical analyses were conducted using the software Rwizard 4.3 (Guisande-Gonzáles et al. 2014) and the R packages lmtest (Hothron et al. 2021) and stats (R Core Team 2013)

Spatial analysis

To evaluate the spatial patterns of the posts, we examined the relative contributions of various climate variables, such as the average yearly precipitation and average yearly temperature, to explaining patterns in snake occurrence (Fick & Hijmans 2017, Angarita-Sierra & Lozano-Daza 2019). We also determined the effect of the total human population according to the 2018 census by the National Administrative Department of Statistics (DANE 2018) and an index of internet penetration in 2017 obtained from the National Ministry of Information and Communication Technologies. We obtained climatic variables based on the actual conditions from the BIOCLIM server (Charlton et al. 2002). The total human population and index of internet penetration were obtained from the data base of National Technology and Communication Colombian Ministry for the year 2017 (latest year available see: https://colombiatic.mintic.gov.co). All variables were obtained at the municipality level, which is the smallest political division of Colombia.

We assessed the effects of each explanatory variable for each post as response variables using a geographical weighted regression model (GWR) to minimize spatial-correlation bias. First, we defined the bandwidth employing the adaptive approach, in which the corrected AIC (AICc; Akaike 1973) was minimized using a Gaussian kernel, resulting in 20. Second, we performed model selection between all possible lineal combinations of the explanatory variables. Third, we selected the “best” regression model using the AICc, and we considered models with a difference between AICc values of less than two to be equally plausible (White & Burnham 1999). We employed the same approach to select the explanatory variables and found that population, rural population, and precipitation were the “best” explanatory variables. Fourth, this model (equation 1) was run, and the local p-values were corrected using the Fotheringham-Bryne approach because of its design for GWR models (McCain 2010). All statistical analyses were performed using the R environment and the GWmodel package (Lu et al. 2014). Finally, we produced maps of the estimated slopes of the model in QGIS version 3.4.1, and the slopes for municipalities showing a non-significant relationship at a confidence level of 0.05 were set to 0.

$$y_i = \beta_{0i} + \beta_{1i}x_{1i} + \beta_{2i}x_{2i} + \beta \qquad (1)$$

In this model, subindex denotes the geographic area defined by the selected bandwidth; is the absolute number of posts per each municipality; is the intercept of the model; , and are the slopes for each explanatory variable (Internet penetration, Rural population, and rainfall, respectively); and indicates the standard error of the regression.

RESULTS

Post account

A total of 1,543 post were retrieved from 26 Facebook groups, of which 81%, 16%, and 3% were posted by males, females, and institutions, respectively. Most posts were published by those without an education in biology (89.2%). The remaining 10.8% of the post were users with a background in biology (8.6%), institutions that advocate for wildlife conservation (1.9%), or users with an unknown educational background (0.3%). A total of 86.1% of the post were queries regarding snake identification, and the remaining 13.9% of posts were posts of pictures or videos snakes without any caption. The most frequent media types employed by users were pictures (83.3%) and videos (11.7%), and the frequency of good quality pictures/videos was significantly higher compared with pictures and videos with mediocre or bad quality (χ^2= 2064.3, df= 2, *P*<0.001).

The number of daily and weekly posts was similar with an average of 13.64±6.81 and 13.66±7.07 posts, respectively. During the study period, there were six days without posts. Wednesday and Sunday were the days with the highest number of posts, and most posts were concentrated in the second half of the month (Figure 1, Table III). There were no significant differences in the number of daily or weekly posts ($\text{ANOVA}_{\text{days}}$ *F*= 0.40, *P*= 0.87; $\text{ANOVA}_{\text{weeks}}$ *F*= 0.16, *P*= 0.92). However, there were significant differences in the number of monthly posts, and September was the month with the highest average number of posts ($\text{ANOVA}_{\text{months}}$ *F*= 4.67, *P*= 0.004). According to the accumulative curve (Figure 2a), sampling completeness reached 95.6%, indicating that the Facebook groups retrieved provided a robust representation of the target Facebook community.

Taxonomic account

A total of 124 species were observed from 1,333 posts (86.4% of the total posts), representing nine families and 50 genera. We were able to classify 100% of the snakes posted to a family, 98% to genus, and 87% to species. The remaining 13.6% of the posts that could not be allocated to species were either fake posts and posts with low quality photos or videos that did not allow taxonomic identification. Most species were clustered into four families (Colubridae= 69.9%;

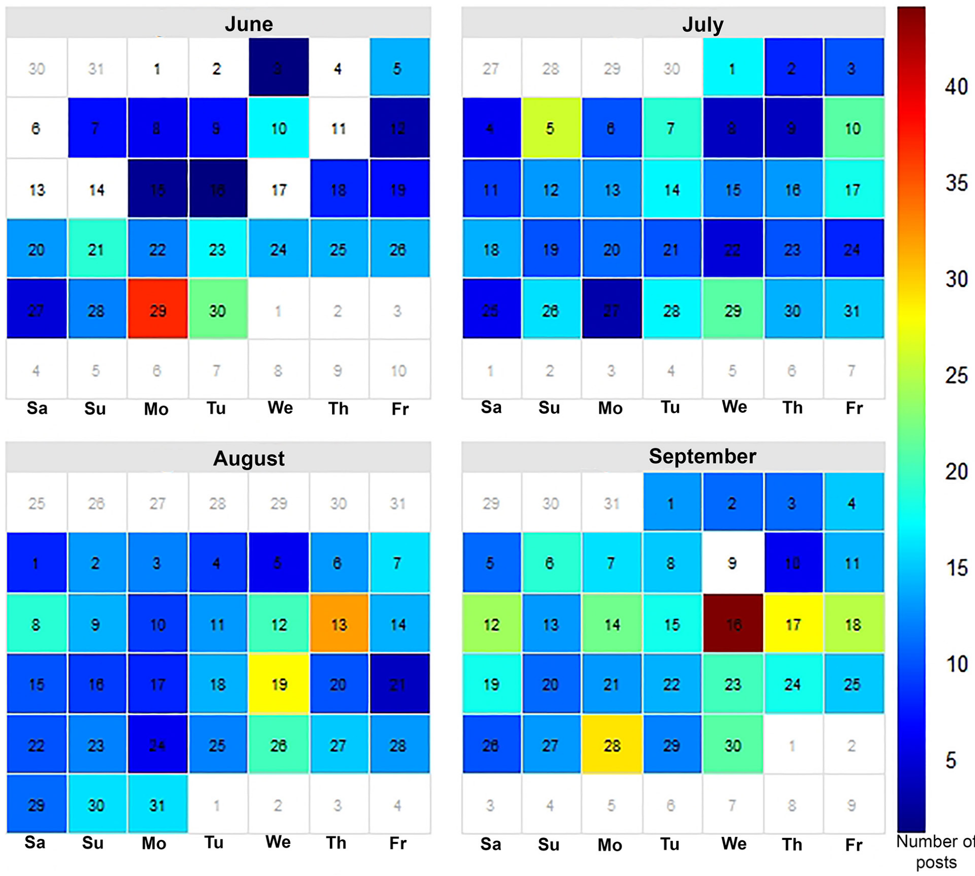

Figure 1. Daily, weekly, and monthly posts gathered from our survey of the Colombian Facebook community. Calendar plot depicting the number of posts by day during the study period. Sa= Saturday, Su= Sunday, Mo= Monday, Tu=Tuesday, We= Wednesday, Th=Thursday, Fr=Friday.

Viperidae= 13.2%; Boideae= 8.5%, and Elapidae= 6.0%, Figure 3). The remaining five snake families comprised 1.10% of all species, and 1.4% were posts with pictures or videos that capture snake-like organisms ("Worm lizards" Amphisbaenidae= 9; "blind snakes" Caecelidae= 5; "earthworms" Glossoscolecidae= 1, Lumbricidae= 1; "spectacled lizards" Gymnophthalmidae= 3). Among the ten snake species of conservation concern in Colombia, only two species (*Micrurus medemi, M. sangilensis*) were detected from Facebook posts and were rare according to the low frequency at which posts of the species were published (Table II).

We detected two fake posts (plastic snakes), one snake species that was reported outside of its historical distributional range (*Zamenis scalaris*, a picture retrieved from iNaturalist and posted as an observational record), and one species present in Colombia (*Porthidium nasutum*) but whose picture was downloaded from a reptile database (https://reptile-database.reptarium.cz) and posted as an observational record. These posts were excluded from analyses. The completeness assessment of species richness showed that the theorical number of expected species ranged from 171 to 176, corresponding to 70.5% and 72.5% of the sampling completeness according to the second and first-order Chao estimator, respectively (Figure 2b). These results indicated that the species richness observed from the Facebook community did not accurately represent the total species richness of Colombia.

Among the fifteen snake genera with the highest number of posts, *Micrurus* (Coral snakes), *Atractus* (Ground snakes), *Erythrolamprus* (False coral snake or Ground snake). *Chironius* (Sipo or hunter snake), and *Dipsas* (Snail-eater

Table III. Descriptive statistics of the social media data retrieved monthly, weekly, and daily through the manual searches in Facebook.

Time	*n*	Total posts	Posts mean	Minimum	Maximum	Standard deviation
Month						
June	22	252	11.45	1	37	5.95
July	31	380	12.26	3	26	8.26
August	31	412	13.29	4	32	5.52
September	29	499	17.21	6	44	7.55
Weeks						
First	25	337	13.48	1	32	6.39
Second	28	406	14.50	4	44	8.56
Third	30	411	13.70	1	37	6.60
Fourth	30	389	12.97	3	29	6.22
Days						
Monday	17	225	13.24	2	37	9.03
Tuesday	17	230	13.53	1	22	4.99
Wednesday	16	261	16.31	1	44	10.52
Thursday	15	204	13.60	4	32	7.62
Friday	17	226	13.29	3	25	5.63
Saturday	15	174	11.60	5	24	5.29
Sunday	16	223	13.94	7	26	4.57

snake) were the taxa with the highest species richness. The five species with the highest number of posts were *Leptodeira annulata* (*n*= 96), *Boa constrictor* (*n*= 93), *Bothrops asper* (*n*= 72), *Erythrolamprus epinephalus* (*n*= 62), and *Lampropeltis micropholis* (*n*= 47) (Figure 3). Most of the species recorded (97 species) had less than 16 posts (average of 3.5 posts per species). By contrast, *Leptodeira annulata* (False fer-de-lance or banded cat-eyed snake), *Boa constrictor* (boa), *Bothrops asper* (fer-de-lance or mapaná), and *Erythrolamprus epinephalus* (false water cobra) were commonly posted species (Table II).

Species identifications by Facebook group administrators were highly accurate. Species identifications were accurate to the species level 77.9% of the time and to the genus and family level 14.7% of the time; 7.4% of the identifications were inaccurate. Misidentifications were associated with three main factors: first, taxonomically puzzling species (Table SII); second, unknown taxa of uncommonly encountered families of snakes (e.g., Aniliidae, Anomalepididae Leptotyphlopidae, Tropidiphiidae, Tropidiphiidae, and Typhlopidae); and third, Facebook group administrators assigning specific epithets when information needed to make such identifications was lacking.

Most of the snakes posted were non-venomous snakes. However, the frequency of posts of dead venomous snakes was significantly higher than that of non-venomous snakes (χ^2= 18.2, df= 1, P<0.001). The frequency of posts of live false-venomous snakes was significantly

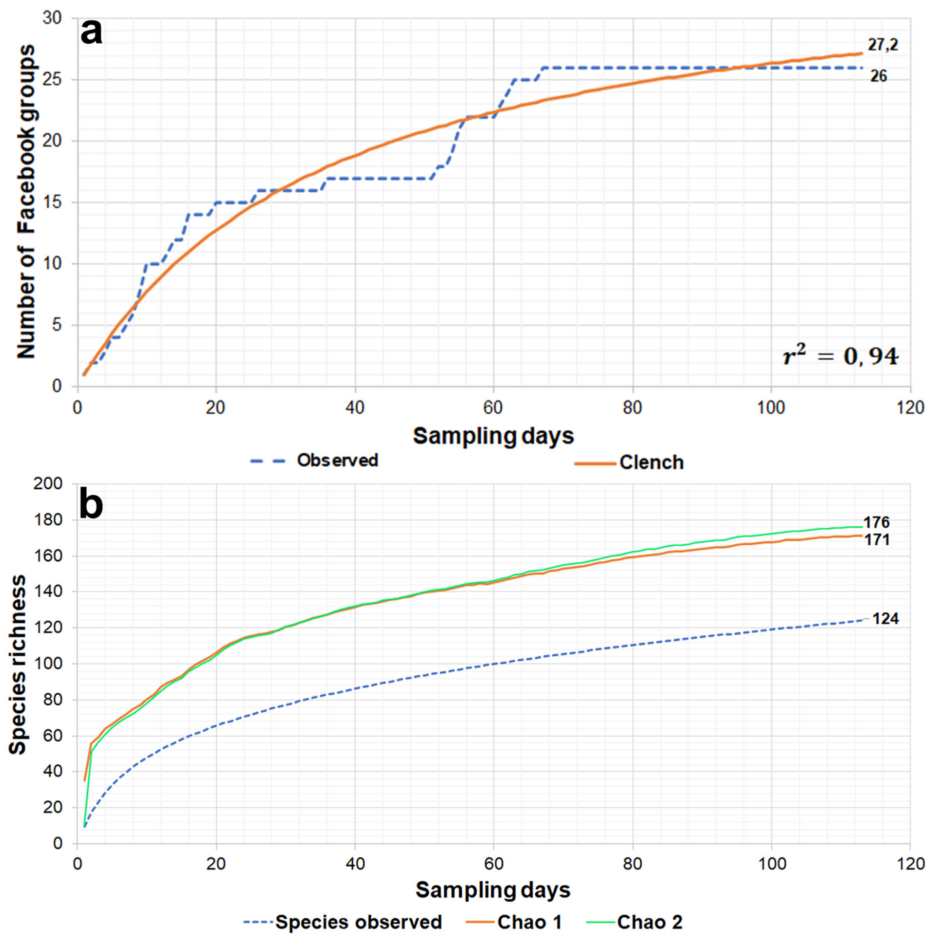

Figure 2. Sample completeness curves. (a): Accumulation curve of Facebook groups observed as a function of the sampled days. The Clench function was used to compare the percentages of the observed number of Facebook groups against predicted values. (b) Accumulation curve of snake species posted as a function of the sampled days. Chao estimator of the first and second grade were used to compare the percentages of the observed number of species against predicted values.

higher than that of venomous snakes (χ^2= 5.95, df= 1, *P*<0.01).

Snake species distributions

Facebook posts contributed important information to the known distributions of snake species from GBIF (Figure 4). Georreferenced information for two snake species were completely lacking in GBIF: the viper *Bothrops ayerbeii* and the snail-eating snake *Sibon argus*. For *Bothrops ayerbeii*, we obtained information on its distribution from the original description of this species (Folleco-Fernández 2010); however, no presence data for *Sibon argus* could be obtained. Thus, the first record of *Sibon argus* for Colombia was contributed by one of the Facebook posts sampled in our study. This new record of *Sibon argus* was posted by Carlos Mario Bran on 16 June 2020 and was retrieved from the Facebook group UrabaNature. This snake was observed at night in a well-conserved secondary rainforest [canopy approximately 30 m, and forest structure dominated by *Phytelephas seemannii* (Tagua palm)], at Finca La Boga, vereda Bedó, municipality of Mutatá, Antioquia Department (07° 44´19,39" N; 76° 41´50,57" W; 600 asl; Figure 5).

Based on the distribution buffers for each species, Facebook posts added distribution extensions for 29 and 67 species that were at least 100 km and 50 km away from available distribution data recorded in GBIF. These distribution extensions represent 23.4% to 54% of the species detected in Facebook posts

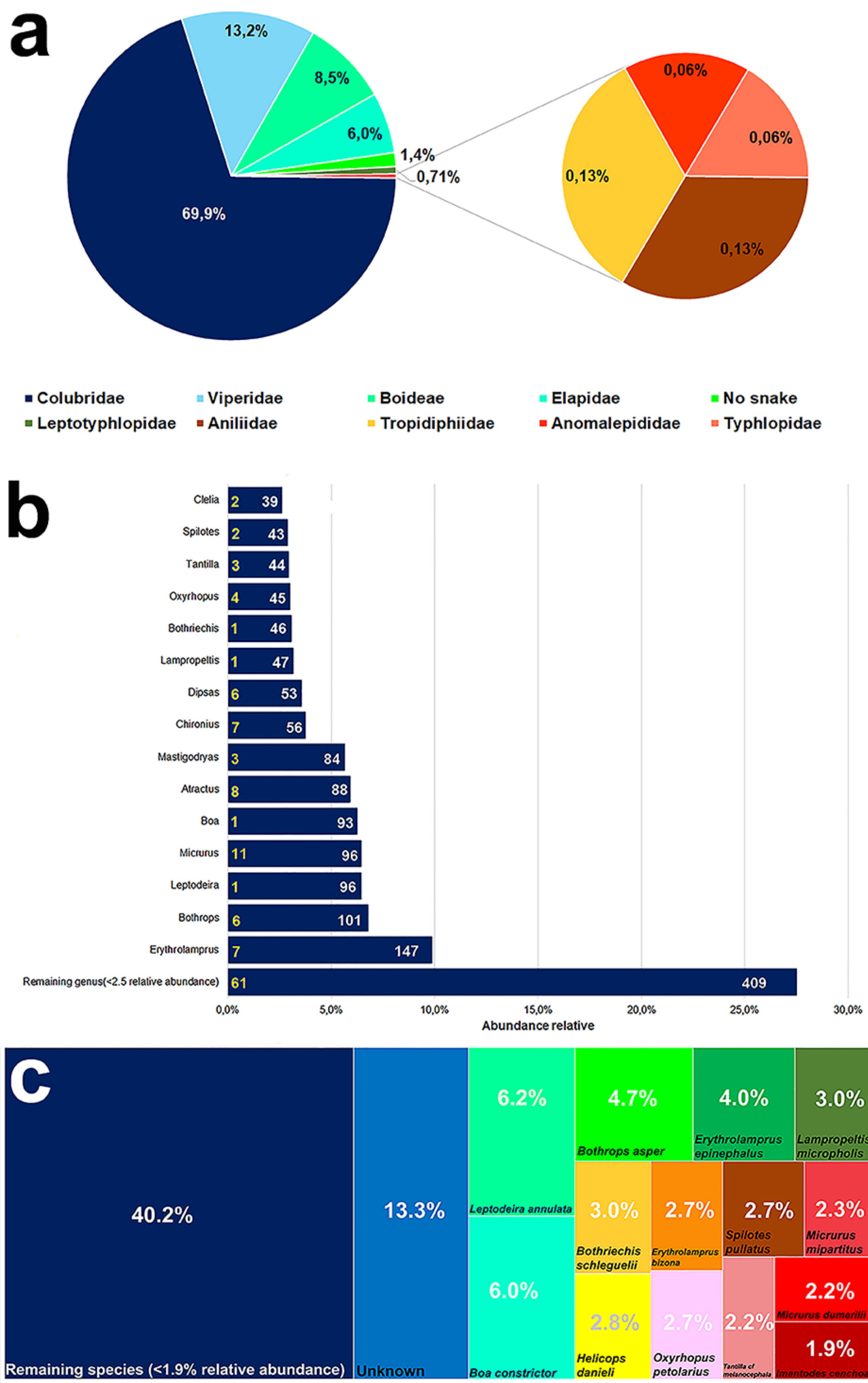

Figure 3. Snake diversity estimated from Facebook posts. (a) Relative abundance of posts clustered by snake families. (b) Relative abundance of posts by genera. Numbers in yellow depict species richness. Numbers in white depict the absolute abundance of posts. (c): Relative abundance of posts by snake species.

(Figure 4). Most of the new records were from the trans-Andean region of Colombia, especially in the Department of Antioquia, but there were also important records from the cis-Andean region of Colombia (Table SV-VI).

Index of snake popularity

The index of snake popularity showed that Colombian Facebook group users had a tendency to post 30 snake species, which represents 24% of the species richness observed. Species such as *Boa constrictor*, *Bothrops asper*, *Bothriechis schlegelii*, *Micrurus mipartitus*, and *Spilotes pullatus* were the top five most popular snake species (Figure 6). However, *Eunectes murinus* (*n*= 36963 likes), *Boa constrictor* (*n*= 7473 likes), *Bothrops asper* (*n*= 6623 likes), *Bothriechis schlegelii* (*n*= 5426 likes), and *Erythrolamprus bizona* (*n*= 4200 likes) were the five snake species that received the highest number of likes. Significant differences in the number of “shares” and “comments” were observed between popular and unpopular snakes (W= 47, P< 0.001). The number of shared posts and comments were higher for popular snakes than for unpopular snakes.

Spatial analysis

After calibrating the GWR, the model had a total adjusted R-squared of 0.58, which indicated that the predictor variables and the geographic distribution explained geographic patterns in the number of posts. There were also few municipalities with more than 24 posts, and most of the municipalities had less than 8 posts (Figure 7a). In addition, the local R-squared was greater in the inter-Andean valleys than in the Orinoco and Amazonian ecoregions, which is consistent with the density of posts from these Andean municipalities (Figure 7b). The values for the estimated intercept of our model that represented the number of expected reports when all explanatory variables were equal to zero was negative (median = -3.63e-1; its spatial distribution is shown in Figure S1).

We also found that the estimated slope was positive and significant in most of the municipalities for the three explanatory variables, meaning that posts of snake encounters were higher for areas with greater internet penetration, denser populations, and rainfall. The median of the estimated values for these three variables was 9.14, 4.76×10^{-6}, and 3.23×10^{-4} (Figure 7c-e). Finally, the slopes of internet penetration and population were greater for most of the municipalities of the Department of Antioquia than in other municipalities. The slope for precipitation was highest for a part of Antioquia located on the eastern face of the Andean Central Cordillera (Figure 7e).

Natural history remarks

We obtained valuable natural history observations for several snake species, including observations relating to ecological interactions, snake–human conflict, and public health (Figure S2). For example, chromatic abnormalities from hypopigmentation to hyperpigmentation were detected for the first time in *Atractus crassicaudatus* and *Dipsas sanctijoannis* (albinism), as well as in *Bothriechis schlegelii* and *Mastigodryas boddaerti* (melanism). Conspicuous deviations from the typical color pattern (but previously reported) were observed in *Bothriechis schlegelii* (homogeneously golden-brown or candy apple red), *Leptodeira annulata* (white nuchal collar), *Tantilla semicincta* (striped pattern), and *Pliocercus euryzona* (yellow rings).

Facebook users reported observations of antipredator displays in *Dipsas sanctijoannis, Erythrolamprus bizona, Erythrolamprus epinephalus, Erythrolamprus pseudocorallus, Sibon nebulatus,* and *Spilotes sulphureus,* and

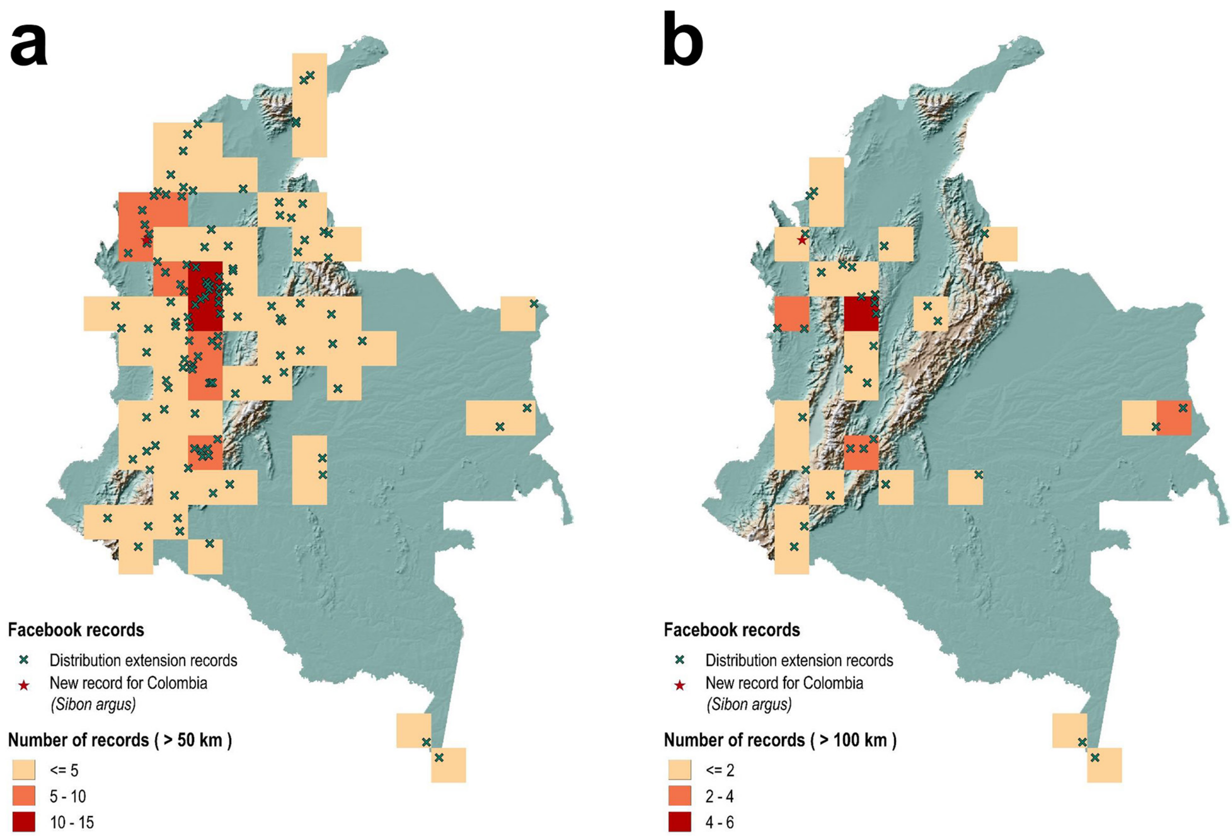

Figure 4. Distribution extensions derived from Facebook posts of Colombian snake species reported in the Global Biodiversity Information Facility (GBIF). (a) Records that fall outside the 50-km buffer around available GBIF records. Distribution extensions were documented for 176 species, and most Facebook-based distribution extensions were in the trans-Andean region of Colombia, but the most conspicuous extensions to the distributions of species were in the cis-Andean region. (b) Records that fall outside the 100-km buffer around available GBIF records. Distribution extensions were documented for 40 species, and most Facebook-based distribution extensions were in the trans-Andean region, but the most conspicuous extensions to the distributions of species were in the cis-Andean region.

the most frequently reported displays included dorsoventral neck compression, body elevation, tail coiling, and crouching. Two posts documented thanatosis in two unrelated species *Chironius monticola* and *Stenorrhina* cf. *degenhardtii*. Videos of both events revealed the distinctive characteristics of thanatosis, including immobility with a stiff posture maintained by pronounced tonic muscular activity, supination of the head and body, unresponsiveness to physical stimulation, and mouth gaping. These displays were maintained for both species for a few minutes. However, when the snakes were left unmolested, both snakes began to move again, which surprised those filming the snakes.

Three reproductive events were recorded. First, a group at four *Eunectes murinus* (anaconda), one female and three males were filmed in a mating ball in the flooded savannas of the municipality of Trinidad (Casanare Department) at the end of the rainy season (September). Second, a *Mastigodryas pleii* couple was filmed mating in the backyard of a rural house in the municipality of Anza (Antioquia Department) during the low dry season (August). Facebook users recorded a hatching of five eggs

Figure 5. New country record of *Sibon argus*. Finca La Boga, vereda Bedó, municipality of Mutatá, Antioquia Department. Picture by Carlos Mario Bran.

of *Erythrolamprus bizona* in the municipality of Gachalá (Cundinamarca Department) during low dry season (August).

Posts on two types of ecological interactions, feeding and predation, were recovered. Feeding events were obtained from a total of 24 posts of 15 snake species. Most of the prey records were consistent with the known dietary breadth of each snake species (Table SIII). However, in the municipality of Betania (Antioquia Department) a specimen of *Pliocercus euryzonus* was observed feeding on a fish at the edge of a creek in the Farallones de Citará Natural Reserve, which represents a new food record for this species. Predation events were recorded for a total of 16 posts representing nine snake species. Ophiophagy by snakes represented 56% of the posts, followed by birds (25%) and mammals (19%). One avian predation event by chickens was reported, and two of the three mammalians predation events were caused by cats and dogs.

Snake–human encounters mainly occurred in rural and peri-urban areas (71%) rather than urban settlements (29%), and both negative and positive interactions were observed. Most of the dead snakes reported were deliberately killed by humans (75%), road-killed (16%), or found dead in their natural habitat (9%); a significantly high number of snakes were deliberately killed by humans (χ^2= 224.98, *df*= 2, *P*<0.001). A total of 13 snake bite accidents (in all cases snakes were killed by humans) were reported in rural areas. These included front-fanged venomous snakes (8 posts, 5 species), opisthoglyphous snakes (2 posts, 2 species), two aglyphous snakes (2 posts, 2 species), and one unknown taxon (Table SIV). Most snake bite accidents reported were caused by pit vipers and coral snakes (69%). *Bothrops asper* was the cause of most bites. A total 99 (6%) posts reported positive interactions in which users relocated the snakes to available near natural habitat rather than kill it. Nevertheless, the behavior of users towards snakes in most of the posts (74%) was neutral (no attempt was made by users to kill or relocate snakes).

DISCUSSION

The posts sampled in our survey of the Colombian Facebook community revealed that these groups can contribute to our knowledge of snakes and their conservation. Most members of this community are males lacking a background in biology that seek identifications of the snakes in their photographs or videos. In general, the quality of the media uploaded was good, and the geographic information associated with the posts was often complete enough for the geographic location of the sighting to be determined.

Species identifications by Facebook group administrators were usually correct, indicating that the group administrators could contribute to enhancing the knowledge of users of snakes and alter social attitudes towards snakes. However, we strongly recommend that the Facebook group administrators be conservative when providing snake identifications in light of the remaining

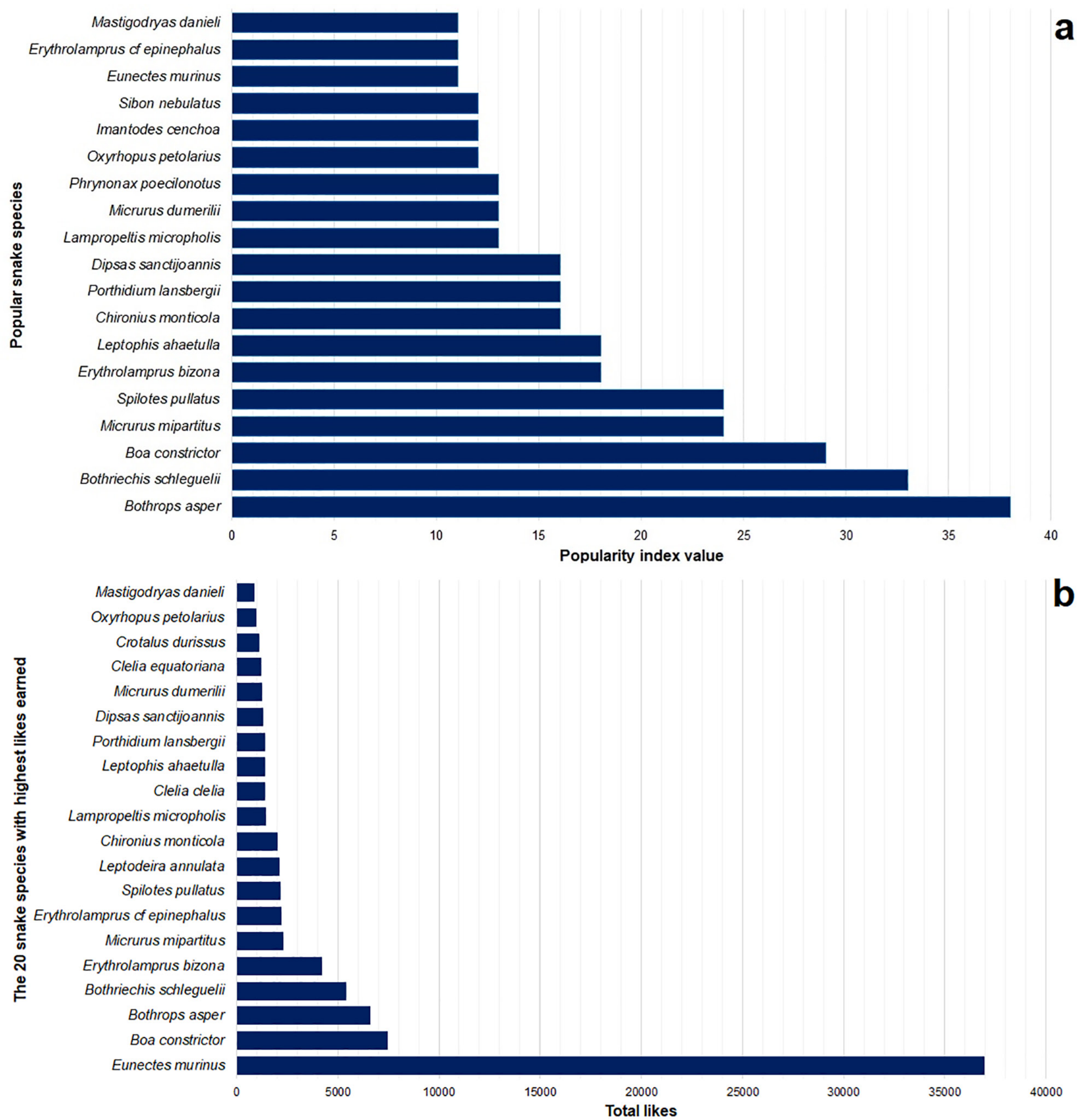

Figure 6. The most popular snake species according to the Colombian Facebook community engaged in snake advocacy. (a) Bar plot showing snake species with an index of popularity >10. (b) Bar plot showing the 20 snake species that received the greatest number of likes.

taxonomic uncertainties of several common snake species in Colombia. Even for taxa without taxonomic uncertainties with good quality pictures and videos, taxonomic identifications can still be difficult to assign when key characters are not visible (e.g., the posts only allowed the review of conspicuous external characters rather than detailed or internal diagnostic characters such as scutellation or hemipenial morphology). Therefore, we recommended that in cases when suitable information for species identifications are lacking that identifications

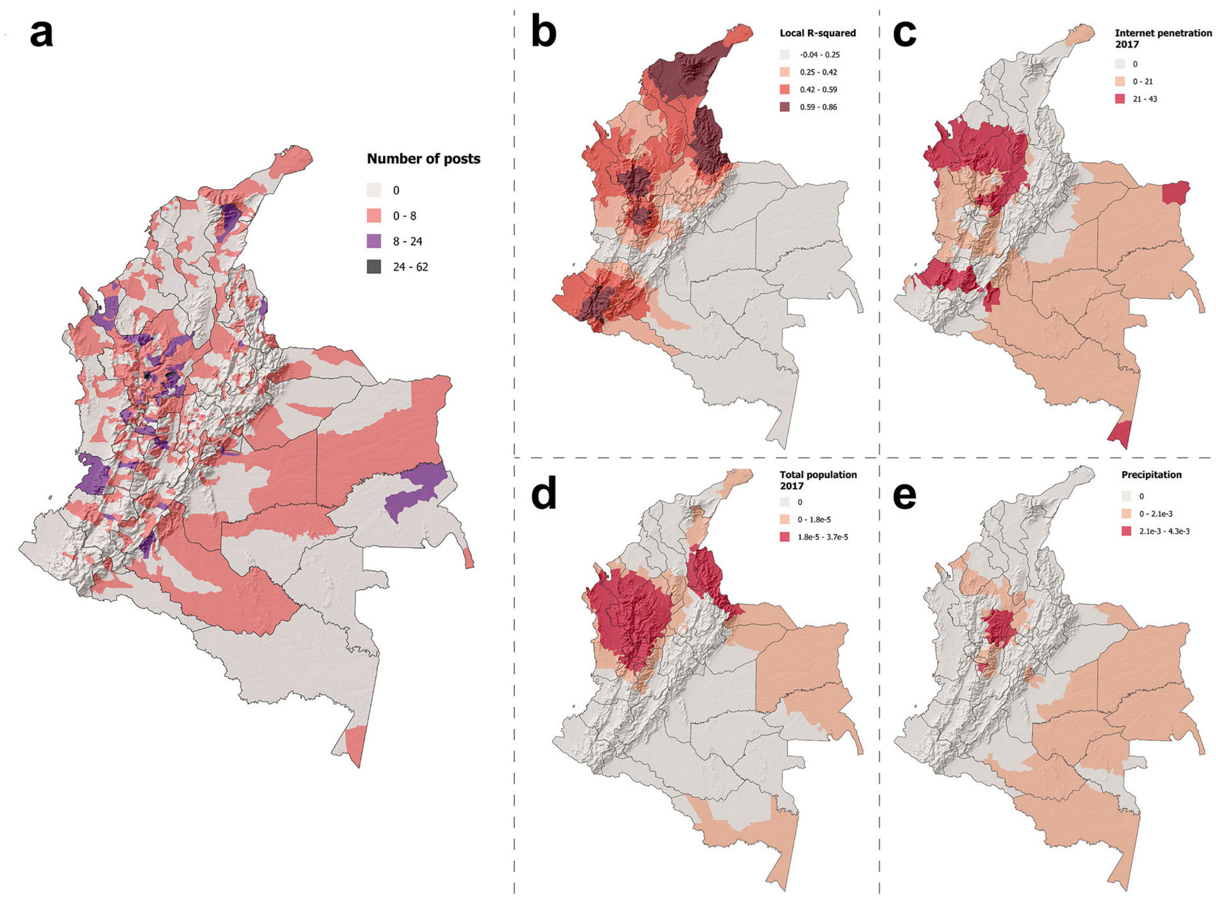

Figure 7. Data and estimates used in the GWR model. (a) Geographic distribution of posts. (b) Local R-squared for all municipalities. (c) Estimated slope for internet penetration. (d) Estimated slope for total population. I Estimates slope for precipitation.

be made to the genus or family level. Remaining conservative in identifications would help reduce misconceptions and enhance properly circulating specialized knowledge.

No temporal pattern was associated with the number of posts posted daily, weekly, or monthly across the sampling period. Significant differences observed in the number of monthly posts were an artefact stemming from the number of Facebook groups accumulated over time. Despite the relatively short sampling period of our study (4 months), we were able to sample a high percentage of the target Facebook community. However, this sampling period might not be sufficiently long to permit general conclusions relating to the pattern of posts over time. As our social media data were collected during the COVID-19 lockdown, these unusual circumstances might have affected the patterns of social media posts, including their frequency. Further studies are needed to elucidate whether there is a temporal pattern associated with the number of posts (La Sorte & Somveille 2020). Such studies could aid the development of conservation strategies for Colombian snakes, as information on the temporal pattern of snake sightings could help stakeholders and conservation practitioners to optimize the timing of conservation campaigns, surveys, and webinars in the Facebook community (Wu et al.

2018). In addition, temporal patterns associated with the number of posts could improve our understanding of human–snake interactions, as well as social attitudes during encounters with snakes.

High snake species diversity in Colombia stems from the complex geography and topography of the country and the convergence of diverse terrestrial ecoregions, such as the Andes, Chocó, and Amazon (Cadle 1992, Cadle & Greene 1993, Rangel-Ch 1995). A total of 41.3% of the snake species documented in the country were recorded by the Colombian Facebook community (~324 species; Uetz et al. 2020). Although our sampling of Facebook posts only represents a small subset of the total number of snake species in Colombia, the number of snake species recorded by Facebook users exceeds the number of species detected in most comprehensive snake studies conducted in Colombia, as well as the number of localities and municipalities (Lynch 2015).

Achieving high sampling completeness of tropical snake assemblages is always a major challenge for both iEcology or traditional sampling approaches (Maritz & Maritz 2020). Duellman (2005) employed a standardized and intensive survey design in a fixed area of the Cuzco Amazonian rainforest and invested 992 person/days of field work. His results showed that the rate of discovery of snakes is much lower and more gradual than rates for anurans and lizards over the same sampling period. Indeed, the rate of discovery of snake species was still increasing near the end of his study. This study revealed the tremendous amount of effort that is required to thoroughly sample a snake community in a single locality of tropical rainforest.

Duellman (2005) and Lynch (2015) implemented sampling approaches that were focused on maximizing the detection of snakes; however, neither study managed to obtain a completely representative sample of the local fauna. Although our sampling of occasional encounters with snakes from Facebook posts was far from representative of the total diversity of snakes in Colombia, the richness and geographic breadth of the species detected were high over the relatively short time frame of the study compared with traditional snake sampling.

Despite the biases associated with estimating snake distributions based on GBIF data alone compared with all sources of snake records in Colombia (Vásquez-Restrepo 2021), Facebook posts enhanced our knowledge of the distribution of 9–21% of Colombian snake species. Although our approach is based on the classic distribution extension methods that use Euclidean distance thresholds to define range extensions, open-source datasets of diversity and climate permit the development of more refined models, such as niche modelling or geometric models, that can be used to estimate the current distributions of species, and new information can be obtained from Facebook records. Moreover, Facebook posts confirmed the presence of *Sibon argus* in Colombia. Therefore, stakeholders, ecologists, and conservation practitioners could use this approach to design citizen-science initiatives to enhance the completeness of snake inventories, implement surveys that improve our understanding of snake–human conflicts, and delimit the local threats for snake conservation.

Networks of human observers have been shown to make valuable contributions to the collection of scientific data in diverse fields, such as astronomy, meteorology, and biology (Sullivan et al. 2009, Tiago et al. 2017, Luo et al. 2021). Over the last decade, several international and national initiatives (e.g., Global big day, Ebird: https://ebird.org/globalbigday;

BirdTrack: https://www.bto.org/our-science/projects/birdtrack; RECOSFA: http://www.recosfa.com) have demonstrated that citizen-science initiatives can significantly contribute to predictions of species distributions and reduce the financial and temporal expenditures associated with monitoring programs and research (Tiago et al. 2017, Robinson et al. 2020). In addition, occasional records of encounters gathered from Facebook users can be used as indicators of the reliability and completeness of snake distribution data to improve the efficiency with which biological surveys are designed, as well as enhance our knowledge of snake species distributions, habitat associations, and threats (Robinson et al. 2020).

Several biases associated with snake inventories and ecological data that require consideration by stakeholders, ecologists, and conservation practitioners. First, local overrepresentation of species or ecological interactions stemming from variation in internet penetration, human population density (=high number of observers), snake popularity, or events that happen frequently near humans in peri-urban areas, crops, road edges, or frequently visited nature reserves (Sánchez-Paniagua et al. 2017, Maritz & Maritz 2020). Second, the lack of stability of posts over long periods impedes the consistency of research because the permanence of posts and their associated media are not guaranteed (Maritz & Maritz 2020). Three, the spatial and temporal structure of snake records and ecological data. We demonstrated that snake Facebook posts were driven by rainfall, population, and internet penetration, which are climatic and social variables with a clear spatial structure (see below). Although we did not detect a temporal pattern associated with snake posts, previous studies have found temporal patterns associated with the number of posts posted (Maritz & Maritz 2020). Specifically, distinguishing between true and false absences of snake records requires repeated posts to the same sites over long time scales, as well as the detection of seasonal snake occurrence patterns (O'Donnell & Durso 2014).

We found that the spatial distribution of Facebook posts was driven by rainfall, population, and internet availability. Interestingly, temperature did not play a significant role after model selection, which appears to be inconsistent with the higher diversity of snakes in warm tropical areas (McCain 2010). This can be explained by the lack of homogeneity in the reporting of these groups for Colombia; that is, areas with more posts were not necessarily in regions with higher snake diversity or abundances. We also found that internet penetration could significantly increase the number of posts, but only in northern Antioquia and Cauca departments, as well as in various municipalities where this variable is strongly correlated with the number of posts. Thus, internet availability is an important barrier that needs to be improved to enhance the efficacy of citizen science-based studies of snake biology.

The effect of human population size on the numbers of posts is strong in the Andean coffee region (Antioquia, Risaralda, Quindío, and Caldas) and in the lowlands in northwestern Colombia (Chocó and northern Antioquia). In areas where awareness among the public is high and there is interest in sharing snake encounters on social media, Facebook can be used to identify key users or groups (activists or researchers) that seek to strengthen conservation and research initiatives (Nouh & Nurse 2016). Citizen science and conservation-based studies should be conducted in these regions because people would be more likely to collaborate and ensure the success of these approaches (Alves et al. 2014, Pinheiro et al. 2016).

The citizen science data recovered in this study make a valuable contribution not only to our knowledge of the occurrence of snakes but also to our knowledge of the natural history of Colombian snakes. Collection of these data represents the first step of the scientific method, and provide the information needed to assess evolutionary hypotheses and develop conservation strategies (Vitt 2013). Although ostensibly disinterested yet curious, Facebook users posted various new distribution records, such as the first record of *Sibon argus* for Colombia, which was previously predicted based on the distribution of this species in Panamá (Köhler 2003, Vera-Pérez 2019), as well as previously unreported natural history observations of Colombian snakes.

For example, albinism and melanism are widespread in the animal kingdom but are infrequently observed in snake populations. Characterizing phenotypic variation and reconstruction of the evolutionary history of snakes are important for linking mutations to ecologically significant traits (Bourgeois et al. 2017). Pigmentation is a promising axis of phenotypic variation for exploring the connections between the genotype and phenotype of ecologically important traits (Hoekstra 2006). Thus, although Facebook users posted atypic snake morphs as anecdotical observations, they were contributing to the documentation of events that are difficult to track, such as local adaptations, ecologically mediated divergence, or speciation in natural populations of snakes.

Facebook users also made important contributions to the reproductive biology and behavior of several Colombian snake species. The reproductive biology of Neotropical snakes has been widely studied. However, information on the natural history of the snakes of Colombia is lacking compared with the snake fauna of other countries. Currently, reproductive studies have only been conducted on two of ~324 Colombian snake species, and reproductive data on other species are scarce (Gualdrón-Durán et al. 2019, Angarita-Sierra & López-Hurtado 2020). A lack of basic biological information deeply constrains the formulation of snake conservation initiatives and strategies (Lynch 2012, Lynch et al. 2014). Thus, reproductive information retrieved from the Facebook community can minimize the gaps in our knowledge over time, as well as help us increase our understanding of the general reproductive patterns of snakes in the tropical Andes.

Animal behavior is perhaps one of the most important axes of trait variation for fostering the appreciation of species and promoting positive attitudes that can support conservation efforts (Drouilly et al. 2021). Thus, a broad knowledge of snake behaviors during snake–human encounters is key for the development of robust conservation strategies, as well as for understanding human attitudes towards snakes. Snake behaviors that are perceived as unpleasant, aggressive, or threatening can provoke negative (defensive) attitudes, whereas pleasant, harmless, or friendly behaviors can induce positive attitudes during snake encounters (Pinheiro et al. 2016).

The Facebook community plays three main roles in the implementation of conservation strategies. First, observations of snake behavior records address gaps in our knowledge of the natural history of snakes (e.g., thanatosis: ‘death’ displays that serve as an unusual form of camouflage). Second, research findings on snake behaviors can be used for public education to promote understanding. Third, data from the Facebook community can be used to understand snakebite patterns. Despite the low number of snakebite accidents reported by Facebook users, these patterns are consistent with the general pattern of snakebite accidents in Colombia in which clinically important cases of envenomation are most often caused by viperid and elapid species. Snakebite accidents occur in rural areas; the fatality rate from snake bites is low, the rate at which victims of snake bites seek medical assistance is moderate, and the morbidity rate among neglected tropical diseases is high (Chippaux 2017, Otero-Patiño 2018, Nuñez León et al. 2020). Snake bites caused by opisthoglyphous and aglyphous snakes have been reported, indicating that the clinical relevance of boid and colubrid species requires re-evaluation (Angarita-Sierra et al. 2020). An unusual snakebite accident caused by *Ninia atrata* was reported by one Facebook user; bites of this species are not known to generate symptoms of envenomation. This species is a small (113–400 mm body size), semifossorial, and non-venomous snake that is considered harmless and passive, but might bite when threatened, a behavior that was previously unreported for this species (Angarita-Sierra 2015).

Finally, our results showed that the Colombian Facebook community engaged in snake advocacy can provide a valuable source of scientific data for snake biology research, conservation, and snake–human interactions. Facebook could thus be used as a tool to implement snake research and conservation strategies and alter negative attitudes and behaviors towards snakes. Furthermore, the Colombian Facebook community can be used to spread knowledge about snakes and dispel myths and misconceptions. This community could also make valuable contributions to Colombian herpetoculture by providing new scientific insights and fostering positive feelings towards snakes and other reptiles.

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SUPPLEMENTARY MATERIAL

Table SI. Taxonomic treatment and criteria used to allocate the puzzling snake species posted by Facebook users.
Table SII. Species list summarizing the posts-feedback.
Table SIII. Alimentary items recorded in the Facebook posts.
Table SIV. Snakebite accident reported by Facebook users.
Table SV. Distribution extensions derived from Facebook posts of Colombian snake species reported in the Global Biodiversity Information Facility (GBIF). Records that fall outside the 50-km buffer around available GBIF records.
Table SVI. Distribution extensions derived from Facebook posts of Colombian snake species reported in the Global Biodiversity Information Facility (GBIF). Records that fall outside the 100-km buffer around available GBIF records.
Figure S1. Estimated intercept for the GWR model.
Figure S2. Notable natural history observations. (a) Albinism in Atractus crassicaudatus. (b) Thanatosis antipredator display in Stenorrhina cf. degenhardtii. (c-d) Albinism and antipredator display in Dipsas sanctijoannis.

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