remote sensing

Article

Monitoring and Characterizing Temporal Patterns of a Large Colony of *Tadarida brasiliensis* (Chiroptera: Molossidae) in Argentina Using Field Observations and the Weather Radar RMA1

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Abstract: Migratory colonies of up to thousands or millions of Brazilian free-tailed bats (*Tadarida brasiliensis*) are present in temperate areas of America. The monitoring of these massive colonies is crucial to know their conservation status and to evaluate the important ecosystem services that they provide. The objectives of this study were to characterize and to monitor, with an interdisciplinary approach, one of the largest bat colonies in South America, located in La Calera (Córdoba, Argentina). This study includes eight years of field observations inside of their shelter and outside when the colony emerged. Moreover, these observations were complemented with one year of weather radar detections using the Radar Meteorológico Argentino 1 (RMA1). To determine if a detection is a true or false massive emergence of bats, an algorithm was designed. We observed that this large colony of *T. brasiliensis* is maternal and migratory, just like others in South and North America. This colony arrives in early spring and births occur two months later, migrations occur in early autumn, meanwhile the shelter is empty or inhabited only by a small group of individuals during the cold seasons. The colony was estimated at 900,000 individuals before births occurred. The radar detection was coincident with field observations, when a simultaneous emergence was observed, as well as in the monitoring throughout the year. This represents the first study made in South America using radar technology for monitoring a bat colony. We here demonstrate that RMA1 is a powerful tool for monitoring this colony in the long term, and even to alert possible changes in permanence in time or in the number of individuals.

Keywords: weather radar; bats; maternal colony; South America; Argentina; migration; aeroecology

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1. Introduction

Monitoring and characterizing of temporal and spatial patterns of animals with high mobility are necessary for their effective conservation [1–3]. These studies become more important when the species involved, such as bats (Mammalia: Chiroptera), provide ecosystem services [4]. These animals have long been postulated to play essential roles in agriculture because they can offer diverse benefits humans, i.e., suppression of arthropod pests, seed dispersal, and pollination [4–6]. For these reasons, bats can also be used as bio-indicators because they can reflect the status of plant populations [7]. Nonetheless, these animals have gained a bad reputation as potential sources of zoonotic diseases, such as rabies, severe acute respiratory syndrome (SARS), and ebola, and consequently they are often persecuted and killed [8,9]. However, the emergence of zoonotic diseases from bats seems also to be a consequence of anthropogenic modifications of natural environments [10]. Therefore, monitoring bat populations, and even more importantly, massive colonies in rural and urban systems, is crucial to know the conservation status of the species, study their behavior and ecology, analyze their efficiency as natural biological predators of agricultural pest insects, and to prevent diseases to humans [2].

The Brazilian free-tailed bat *Tadarida brasiliensis* (I. Geoffroy, 1824) (Chiroptera: Molossidae) is a medium-size species widespread in America from 46° North latitude to 52° South latitude [11,12]. This interesting species plays an important role in reducing populations of arthropod pests, thereby providing an important economic benefit to farmers [4,13]. Shelters are fundamental to bats because they are used for nesting, breeding, and interaction among individuals. This species uses a great variety of shelters, both natural (caves and hollow trees) and artificial (bridges, buildings, mines, tunnels, and culverts), in rural and urban environments, and they can take shelter solitarily, in small groups, or in large colonies of several millions of individuals [14]. Large colonies of this species have been reported at borders of their distribution, between the United States and Mexico in the northern hemisphere, and in Argentina, Brazil, and Uruguay at the southern hemisphere [15–20]. Those colonies are migratory and most of them are maternal. They are less common in South America than in North America where they have been very slightly studied [17,21]. Particularly in Argentina, there are three important known colonies: one at the Dam Escaba (Tucumán Province) in the northwest region, as well as two others in the central region at the Law Faculty, National University of Rosario (Rosario, Santa Fe Province) [17], and La Calera (Córdoba Province) in a limestone mining deposit.

There is an important potential in using radar technology for biological studies, quantifying animal movements, analyzing population densities and diversity, as well as for studying species phenologies across a wide range of spatial, temporal, and climatic scales [22,23]. This type of remote sensing tool is useful for studying birds, insects, and bats which fly in large groups at high altitudes [24–31]. It has been previously shown that weather radar detects movements of bat colonies, including *T. brasiliensis* [26,30–33]. These observations also show interactions between these highly mobile predators and their migratory insect prey [34]. Nevertheless, all known studies using radar technology on *T. brasiliensis* have been made in North America. Due to the size of the colony from La Calera, it can be detected by the weather radar "Radar Meteorológico Argentino 1" (RMA1) when bats emerge to forage. To complement information provided by the RMA1 with observations collected at the field could be extremely valuable to understand some behavioral aspects of this colony. Having better knowledge about these large colonies is fundamental to evaluate the ecosystem service that they can provide and most importantly to implement conservation strategies [35]. The aim of this study is to characterize and to monitor the colony of *T. brasiliensis* present in the locality of La Calera using field observations and weather radar detection with RMA1.

2. Materials and Methods

2.1. Study Area

The colony of *Tadarida brasiliensis* is housed in tunnels of the old and abandoned concrete factory "Hercules" (see Figure 1), inside a limestone mining deposit, in La Calera, Córdoba Province, Argentina

(31.319S, 64.332W). The surrounding landscape is a semiarid savanna with typical vegetation of Chaco Serrano and Espinal [36]. The average monthly rainfall is 70 mm, with markedly summer distribution (140 mm). The average annual temperature is 17 °C, with a maximum annual average of 24 °C and a minimum annual average of 11 °C.

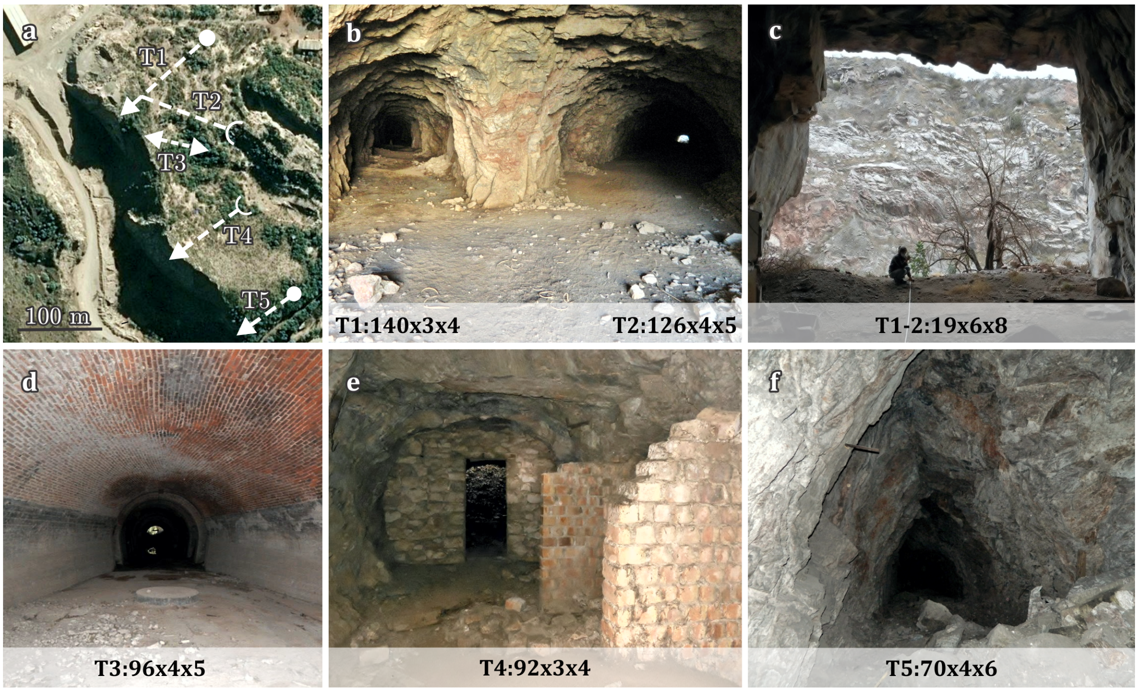

Figure 1. (**a**) Position of the tunnels (T) inside the old concrete factory. The ends of each tunnel are marked to denote whether they are open (arrowhead), partially obstructed (semicircle), or completely obstructed (full circle). (**b**,**d**–**f**) Each tunnel and their dimensions in metres (length, height, width). (**c**) Section of the tunnels that connects T1 and T2, and their dimensions.

2.2. Characterization and Monitoring of the Colony

All tunnels were surveyed to record their geographic positions and dimensions (summarized in Figure 1a). Bats were captured and identified following Barquez and Díaz [37], by direct observations, photographs, and even traces (feces). The tunnels were visited 24 times from 2012 to 2019 in order to determine the composition of the colony, and periods of permanence and migration. The observations were made inside and/or outside the tunnel when the colony emerged.

The presence of the colony was verified and the following stages of bat-life were identified by observation: newborn pups (with no flying ability and hairless), young individuals (erratic flight and gray hair), and adults (normal flight and brown hair). Photographs with metric reference were taken before that births occurred, to obtain a preliminary estimation of the size of the colony. The number of individuals in a known area was counted and this value was extrapolated to the total area occupied by the colony [18]. Outside of the shelter, the onset time of the emergence was recorded as that when bats starting to emerge in large numbers [38], and it was compared with sunset time. The ending time of emergence was registered when the massive emergence was interrupted and bat emergence was observed in isolated groups. As additional data, birds of prey were recorded hunting the bats during the emergence. It is worth highlighting that no anesthesia, euthanasia, or any kind of animal sacrifice were used in this study.

2.3. Radar Meteorológico Argentino 1 (RMA1)

A weather radar is an instrument used to detect and characterize storms and other meteorological phenomena. The radar antenna emits pulses of radiation to targets under observation which intercept and scatter part of the pulse energy. This received signal or echo is amplified, digitized, and processed in the radar receiver, so it can be displayed and recorded. The time elapsed between the emission and the back-scattered signal reception is used to determine the target range since the pulses move at the speed of light [39]. The RMA1 is a C-band polarimetric Doppler radar located at the campus of the National University of Córdoba, Argentina (31.441S, 64.191W). The radar emits both horizontal (H) and Vertical (V) polarizations simultaneously, allowing the calculation of 3D fields of several variables or parameters: horizontal (Z_H) and vertical reflectivity (Z_V) factors in dBZ (decibels of Z), radial velocity (V_D), spectral width (W), differential reflectivity (Z_{dr}), differential phase (ϕ_{dp}), specific differential phase (K_{dp}), and correlation coefficient (ρ_{hv}). The coverage radius of successive volumes is 240 km [29].

2.4. Radar Sampling Data

Bat observations using RMA1 were made from July 2018 to June 2019. During this period, radar strategies with a gate resolution of 450 m and 15 elevation angles were used for detection. The sampling time interval used was from 20 to 22 h Local Time (LT), generating on average 14 samples per day, collecting between 400 and 450 images monthly. The shelter of the colony is approximately 19 km away from the radar and at an azimuth of 316 degrees. Figure 2 shows the elevation profile of the terrain through a vertical slice in the azimuthal direction of the shelter and different elevation angles recorded by the radar plan position indicators (PPIs).

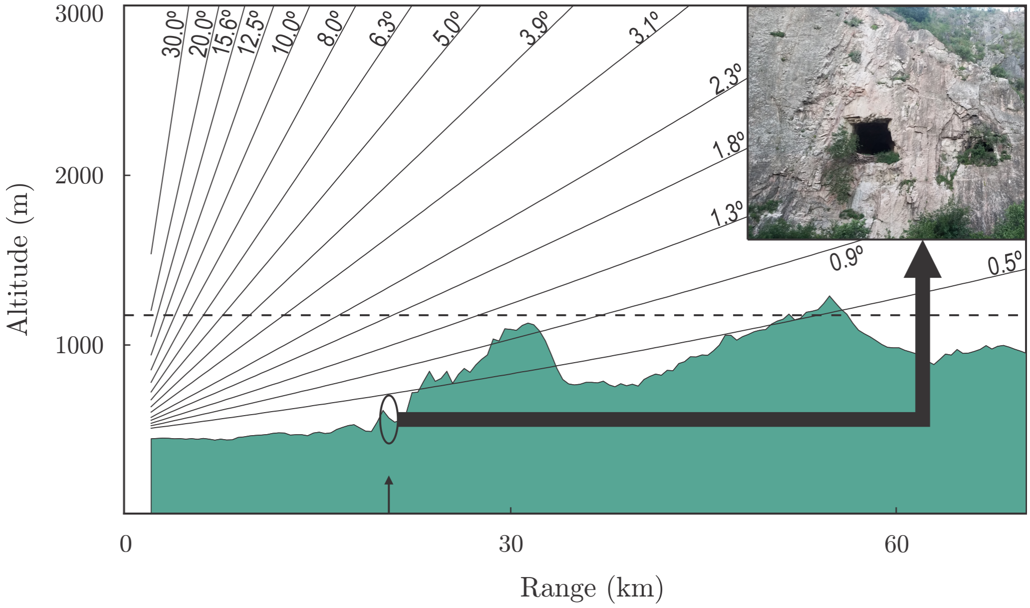

Figure 2. Description of the elevation profile of the land in the direction of the shelter, this last marked with an arrow and an oval. The elevation angles of the radar are described in solid black lines and a photograph of the outside of the common portion between tunnels 1 and 2 is shown. The horizontal black dashed line shows the height at which the observation is made (see intersection with plan position indicators (PPI) 4 (line 1.8 degrees).

The data sampling area was determined by taking the event that occurred on 15 December 2018, as the reference pattern. The sampling area is set between azimuths 305 to 328 and between 13 km to 21 km away from the radar, as shown in Figure 3. This figure shows in both images the horizontal reflectivity factor Z_H, associated with PPI 4, of the colony for 15 December 2018, at 20:39 LT. The image in the left panel shows data before filtering, while the right panel shows data after filtering as explained below.

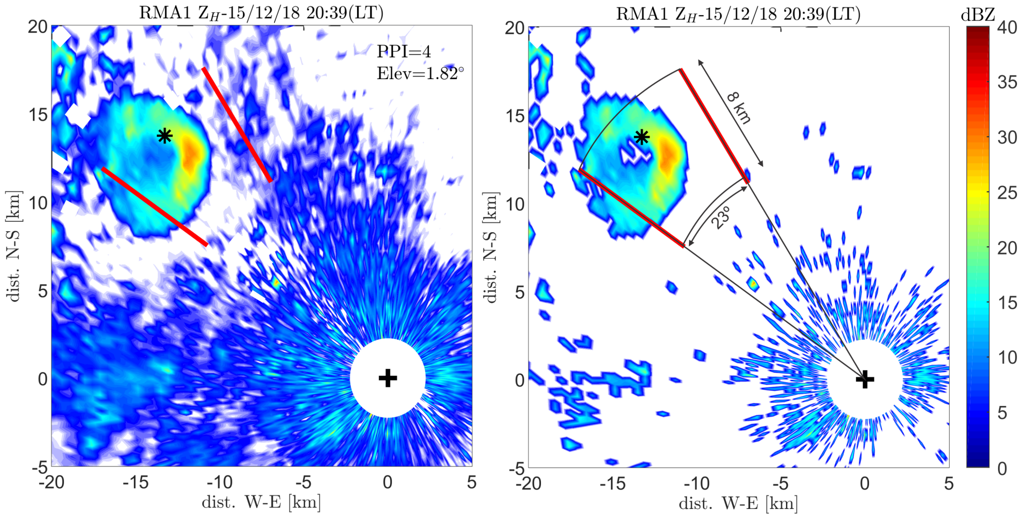

Figure 3. Horizontal reflectivity factor Z_H, associated with PPI 4, of the colony for 15 December 2018, at 20:39 LT. The image in the left panel shows the data before being filtered. The image on the right panel shows the filter applied to the data. Symbols indicate the position of the radar (plus) and the shelter of the colony (asterisk) and red lines delimit the sampling area.

2.5. Bat Detection

The method used to determine when a valid detection occurs is based on an algorithm that has to take into account three main factors: clutter echoes, meteorological echoes, and weak echoes.

The analysis performed on 15 December 2018, shows that the maximum reflectivity factor is close to 30 dBZ for both the vertical and horizontal channels, as can be seen in Figure 4. This figure also exposes the level of noise floor that may contain the information associated with detection. This criterion determines the first stage of the detection algorithm and is based on filtering the Z_H and Z_V data (if $Z_{H,V} > 40$ dBZ, $Z_{H,V}$ = NaN and if $Z_{H,V} < 10$ dBZ, $Z_{H,V} = 0$).

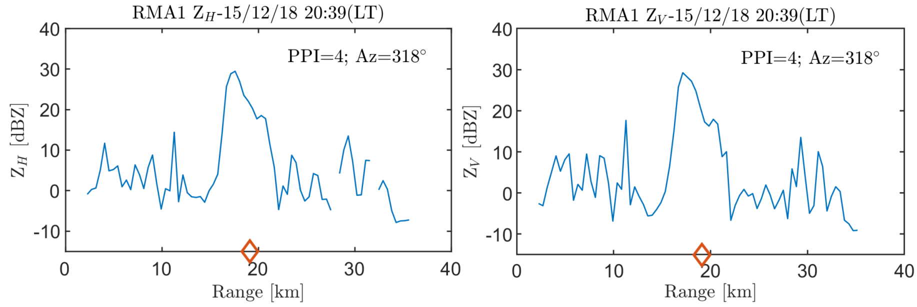

Figure 4. Reflectivity factor for both the horizontal (Z_H) and vertical (Z_V) channels as a function of distance to radar (range) for azimuth of 318°. The red rhombus marks shelter position.

The difference of Z_H and Z_V (in linear scale) whose relation is called Z_{dp} was used to eliminate meteorological echoes. This factor was very useful to discriminate precisely, due to the characteristics that bats have when way out, the difference between a meteorological and non-meteorological echo. The Z_{dp} factor for a meteorological echo will always be positive due to the characteristics of the hydrometeors that are in the atmosphere at heights to which the observation is performed. For the particular case of bats, the Z_{dp} factor, within the area of analysis, shows a mixture of values between positive and negative, as can be seen in the right panel of Figure 5. Using this concept, a series of filters were created to validate a detection. The diagram in the left panel of Figure 5 shows the designed algorithm, `Filter_1`, applied in the sampling zone after calculating Z_{dp}. In this filter, it is established that all values between -1 and 1 are not significant for detection and therefore are replaced by NaN values. `Filter_2` analyzes the density of negative points inside the sample, and if this value is less than 5% of the sample it is defined as false (take into account that during the emergence of the colony, $Z_{dp} < 0$). `Filter_3` takes the difference between maximum and minimum values of the sample and compares it with the threshold obtained from the reference sample (15 December 2018). If this value is above the specified threshold, it is differentiated as a false detection because it is considered like meteorological data. `Filter_4` analyzes the amount of NaN elements in the sample and if these exceed 90%, it is defined as false detection. When detection is true, the maximum value of the variable Z_v within the sample is assigned to that instant.

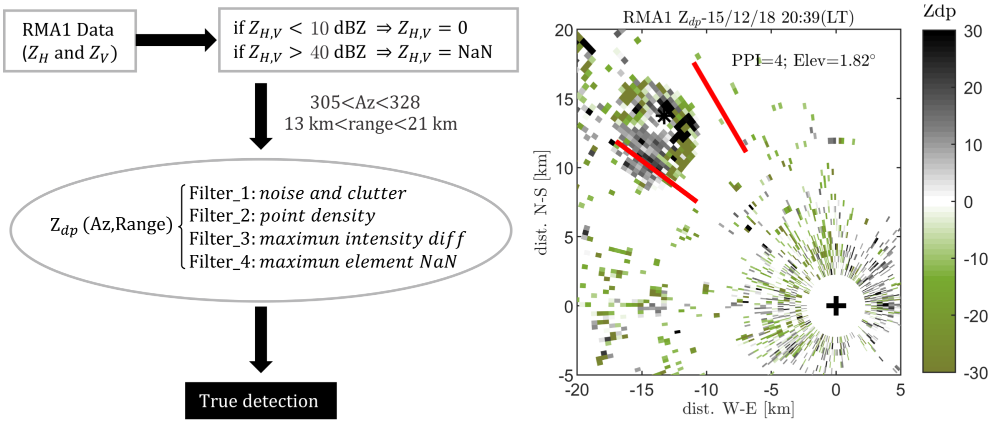

Figure 5. Sequence of filters that determine the algorithm used to validate a detection in the left panel. The right panel shows the behavior of the variable Z_{dp} for a valid detection.

The behavior of the algorithm in the case of a sample contaminated by a storm is shown in Figure 6. This figure shows how regions with higher values than 40 dBZ in the storm are eliminated. The remaining values are used to calculate Z_{dp}. This variable is presented in the right panel of Figure 6. Here, most of the values that agree with the storm are always positive, however, within the sampling area there are some negative values that, depending on its characteristics, the algorithm will decide if the observation corresponds to a valid detection.

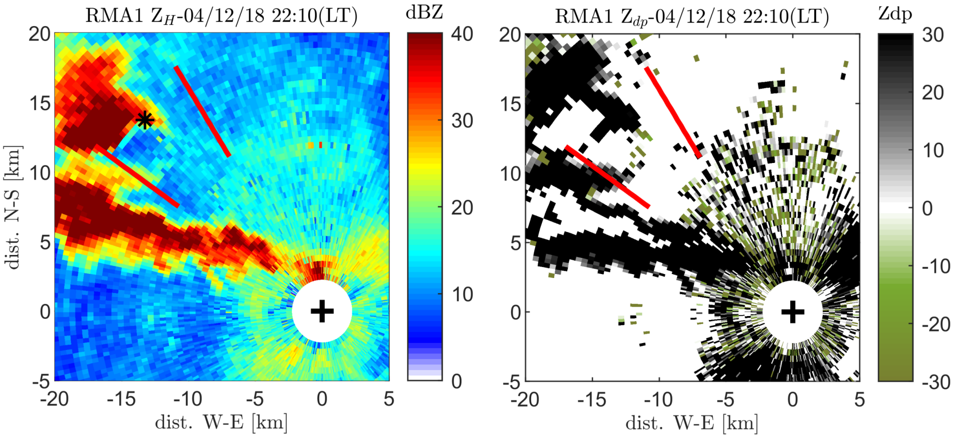

Figure 6. Storm detected on 4 December 2018 close to the observation area of the colony. The right panel shows the intensity of it using Z_H for the PPI 4, while the left panel shows the output of the data after using the detection algorithm.

3. Results

3.1. Characterization and Monitoring of the Colony

The bats observed in the five tunnels belong to four species, including that of the large colony of *Tadarida brasiliensis*. This colony was housed in tunnel 2 where the floor was covered by a thick layer of guano. In tunnel 1, despite being connected to tunnel 2, no individuals were observed but a few deposits of guano were observed. Tunnel 3 was inhabited by one to 62 individuals of *Histiotus* sp. (Vespertilionidae), one or two individuals of *Myotis dinellii* (Vespertilionidae), and an individual of *Desmodus rotundus* (Phyllostomidae). In tunnel 4, visited only once, two individuals of *M. dinellii* and one *T. brasiliensis* were observed. Finally, in tunnel 5 there were 10 to 15 individuals of *D. rotundus* and the typical feces of hematophagous bats were observed.

Seasonal variations were observed in the colony of *T. brasiliensis* due to migration and births that occurred during their permanence in the shelter (Figure 7a–f). This colony arrived in early spring, between September and October. From the time of arrival until mid-November only adults were observed. Newborn pups were observed from late-November to mid-December, indicating that births occurred approximately two months after the arrival (i.e., the colony arrived in October but newborn pups were observed only by mid-December). It is worth noting that newborn pups were observed forming groups among adults (Figure 7c). The newborns were small, hairless, and incapable of flight (Figure 7e), but 45 days later were bigger with their bodies partial or totally covered with greyish hair, and capable of an erratic flight (Figure 7f). The large colony was recorded until mid to late April and since May after migration the number of individuals was considerably reduced. Finally, until the return of the colony, either no individuals or a small group of approximately 500 to 1000 individuals were observed (Table 1). The colony size was estimated at about 900,000 individuals and occupied an area of 450 m^2 before the births occurred (October 2013).

Figure 7. Colony of *Tadarida brasiliensis*. (**a**) Aspect of the shelter after migration (13 May 2014) and (**b**) after the return (30 November 2017), (**c**) bats crowded, the pale colored sector belongs to a group of newborn pups (30 November 2017), (**d**) group of adults (9 December 2014), (**e**) a newborn (30 November 2017), (**f**) two juveniles with different degree of hair coverage (January 27, 2014), (**g**) the emergence of the colony from the common portion of tunnel 1 and 2 (7 December 2018), (**h**) mass emergence as a continuous serpentine stream (21 January 2012). (Photo credits: S. Villalba—a, d, and g; L. Boero—b, c, e, and f; V. Damino—h).

Table 1. Detail of the field observations between 2012 and 2019.

Date	**Observation Inside of the Colony Shelter**	**Observation Outside of the Colony Shelter (Emergence). LT = Local Time**	**Observations in Other Tunnels (T). Species (n° Bats)**
21 January 2012	Full colony	Onset time = 19:50 LT Sunset time = 20:22 LT End time = 20:35 LT	-
06 July 2012	Without bats	-	-
23 July 2012	500–1000 bats	-	T3 = Without bats T5 = *Desmodus rotundus* (small colony)
11 July 2013	More than 500 bats	-	T5 = *D. rotundus* (10)
15 August 2013	Without bats	-	T5 = *D. rotundus* (15)
13 September 2013	Without bats	-	T3 = *Histiotus* sp. (9), *Myotis dinellii* (1) T4 = *M. dinellii* (2), *Tadarida brasiliensis* (1) T5 = *D. rotundus* (15)
24 October 2013	Full colony. Adults. Colony size estimation	-	-
12 December 2013	Full colony. Adults and newborns	Onset time = 20:35 LT Sunset time = 20:14 LT End time = 21:17 LT	-
27 January 2014	Full colony. Adults and young	Onset time = 20:23 LT End time = 21:27 LT	-
26 February 2014	Full colony	-	T3 = *Histiotus* sp. (62), *M. dinellii* (2)
13 March 2014	Full colony	Onset time= 19:58 LT Sunset time = 19:35 LT End time = 20:40 LT	-
26 March 2014	Full colony	Onset time = 19:45 LT Sunset time = 19:19 LT End time = -	-
15 April 2014	Full colony	Onset time = 19:10 LT Sunset time = 18:55 LT End time = 20:00 LT	-
30 April 2014	Full colony	-	-
13 May 2014	Partial colony (less than 25%)	-	T3 = *Histiotus* sp. (2), *M. dinellii* (1)
22 September 2014	Full colony. Adults.	-	T3 = *Histiotus* sp. (1), *M. dinellii* (1)
09 December 2014	Full colony. Adults and young	Onset time = 20:30 LT Sunset time = 20:12 LT End time = -	-
15 April 2015	Partial colony (less than 50%)	-	-
05 May 2015	Partial colony (less than 25%)	-	-
11 November 2016	Full colony. Adults.	-	T3 = *Histiotus* sp. (40)
02 February 2017	Full colony. Adults and young	-	T3 = *Histiotus* sp. (2), *M. dinellii* (1)
30 November 2017	Full colony. Adults and newborns	-	T3 = *Histiotus* sp. (23), *D. rotundus*(1)
07 December 2018	-	Onset time = 20:30 LT Sunset time = 20:11 LT End time = 21:35 LT	-
03 April 2019	Full colony	-	-

The colony emerges massively as a continuous serpentine stream which borders the mountain (Figure 7g,h), and then, it becomes more diffuse, with less group integrity. The onset time of emergence was between 19:10 to 20:35 LT, starting 4 to 26 min after sunset except once being registered 32 min before sunset. The emergence lasts approximately 50 min, a period of time in which different birds such as owls (*Tyto alba*), peregrine falcons (*Falco peregrinus*), and red falcons (*Falco sparverius*) are waiting for the emergence to hunt the bats. Table 1 shows the details of field observations and seasonal variations of the colony population and their composition are summarized in Figure 8.

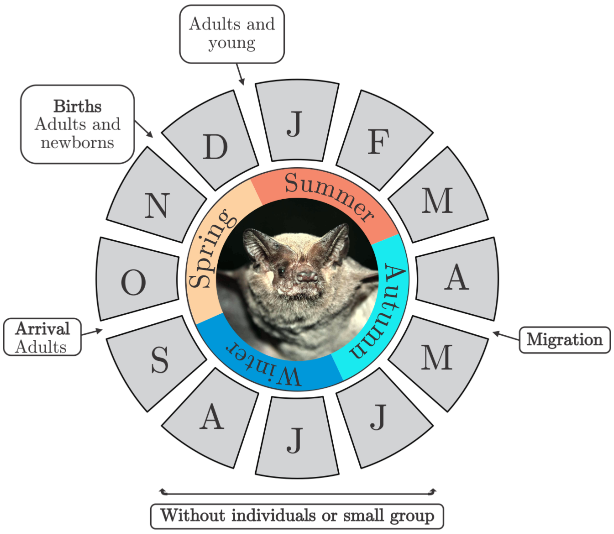

Figure 8. Activity cycle of the colony of *T. brasiliensis* through out the year. (Photo credits: R.M. Barquez).

3.2. Radar Bat Detection

To analyze the behavior of the bat colony located in La Calera, an analysis of RMA1 data was carried out from July 2018 to June 2019 in a two-hour interval, from 20 to 22:00 LT. An example of radar detection can be seen in Figure 9. This figure refers to the detection made on 7 December 2018, and shows that the emergence is recorded at 20:34 LT and continued throughout the sampling interval. The colors of the image refer to the echo intensity received by the targets (horizontal reflectivity factor Z_H) and show how the intensity and shape of the echo changes during the colony emergence. This factor refers to the echo intensity received by the radar being directly proportional to the size of the targets and the number of individuals [29,40].

To achieve a record that allows daily monitoring of the colony, the maximum value of Z_V is taken within the sampling area defined in Figure 3 and that value is labeled to see its temporal evolution, as can be seen in Figure 10. The data observed and processed are shown in an interval that goes from 1 December to 8 December 8 2018, between 20 to 22 h (LT).

A monthly follow-up can be carried out taking the maximum value of Z_V of each daily observation, as shown in Figures 11 and 12. The first of these figures contains the months from July 2018 to December 2018 and shows that there is no activity of the colony during the winter months, while the activity begins in mid-September. The months of November and December show a consolidated activity around 30 dBZ. The second of these figures, Figure 12, shows the behavior from the months of January 2019 to the month of June 2019. The first four months of this figure show the same behavior as the last months of Figure 11, with an average of Z_V that remains around 30 dBZ. This figure shows that the detection of the colony begins to decline from May to June.

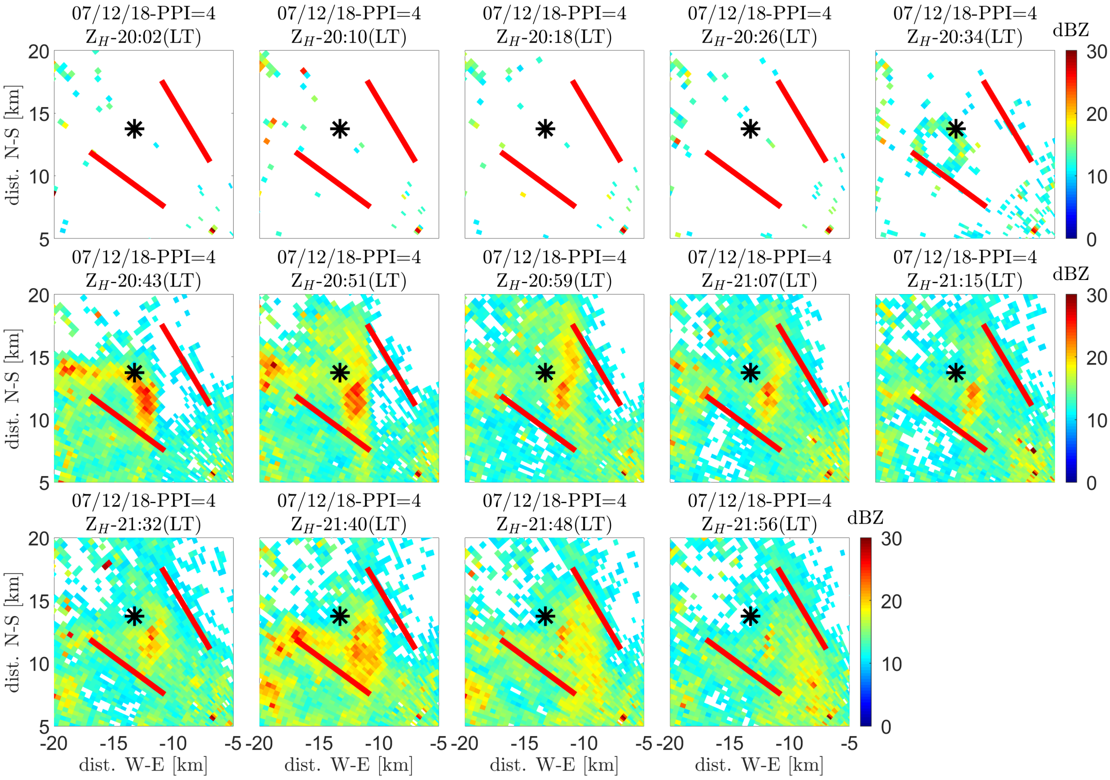

Figure 9. Temporal sequence of the horizontal reflectivity factor associated with the PPI 4 for 7 December 2018, between 20 to 22 LT.

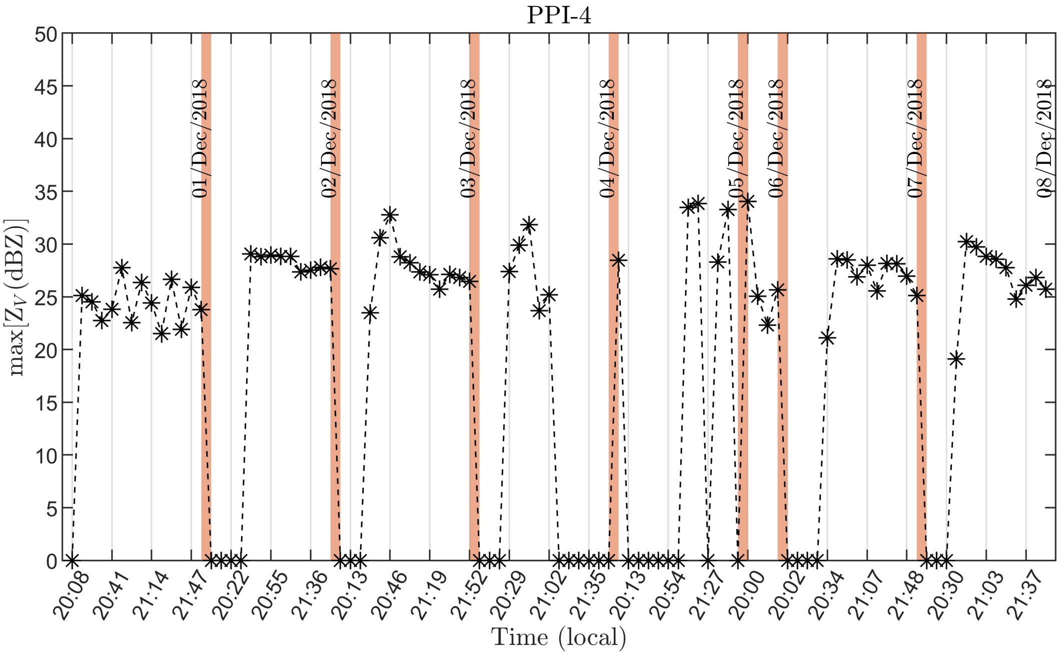

Figure 10. Maximum variability of Z_V within the sampling interval between 1 December 2018, to 8 December 2018.

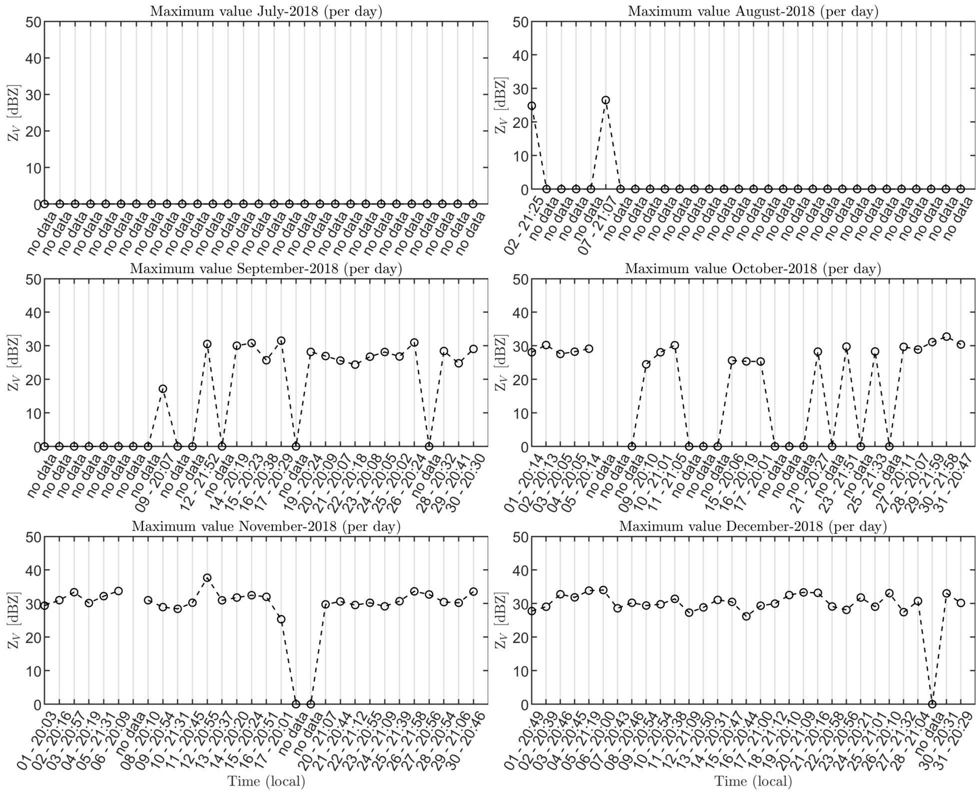

Figure 11. Maximum value Z_V reflectivity factor taken per day of observation. The registered period goes from July 2018 to December 2018.

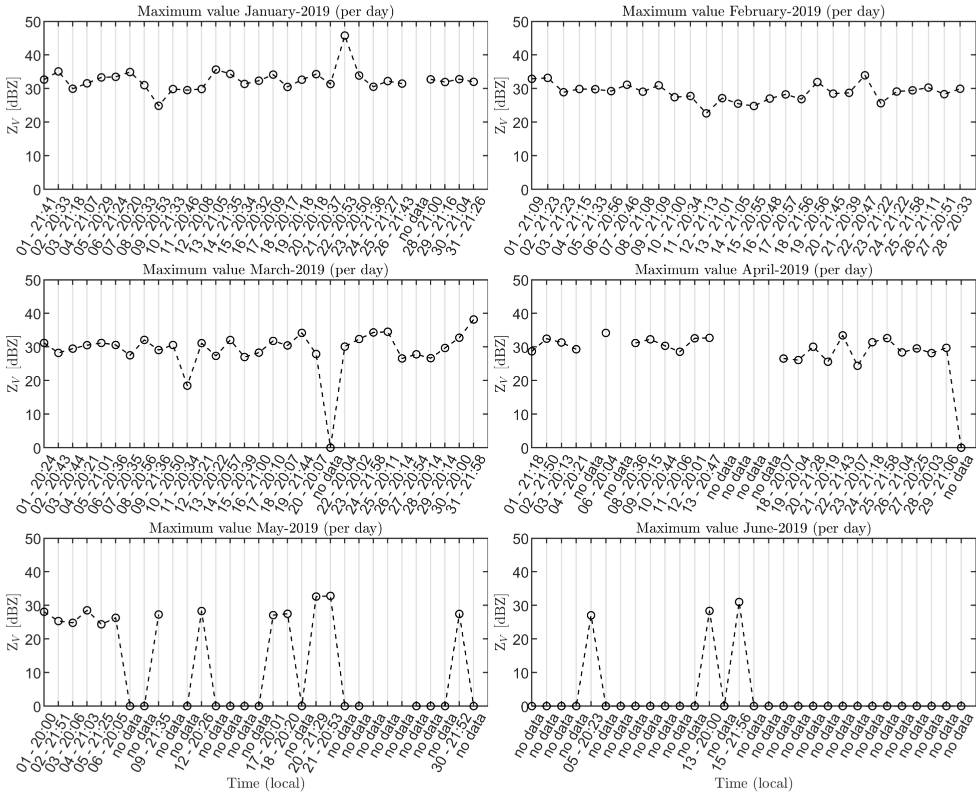

Figure 12. Maximum value Z_V reflectivity factor taken per day of observation. The registered period goes from January 2019 to June 2019.

4. Discussion

The large colony of *Tadarida brasiliensis* from La Calera roosts only in tunnel 2 but occasionally occupies part of tunnel 1. The other tunnels are occupied by *Histiotus* sp., *Myotis dinellii*, and *Desmodus rotundus*, which roost solitary or in small colonies [41]. It is known that shelters used by large colonies of *T. brasiliensis* are particular and have a large enough surface for millions of bats to hang, as well as spacious rooms, considerable height, and large entrances allowing a massive rate of emergence [14]. Also, this species seems to avoid wet shelters [14]. Tunnel 2 is the largest and has a large entrance (Figure 1c) that falls into a ravine without obstacles, unlike the entrance of tunnel 5, which is at the ground level and surrounded by vegetation. Moreover, tunnel 2 consists of a single large passage, unlike tunnel 4 which has subdivisions that interrupt the flow of bats. It also has less incidence of light than tunnel 3, and less humidity than tunnel 1, which has more water infiltration.

In South America, the largest known colony of *T. brasiliensis* is located at the Dam Escaba (Tucumán, Argentina), and is estimated in tens of millions of individuals, although it recently suffered a drastic decline [19,42] due to significant changes in the shelter with the argument of "relocating" the colony (see [43]). Another known large colony is present in the Law Faculty at Rosario (Santa Fé, Argentina), originally composed of 64,000 bats which roost in the ceiling of the building [17], but reduced to half after a fire in the building in 2003. Moreover, in Porto Alegre (Rio Grande do Sul state, Brazil) and several departments of Uruguay there are buildings which have colonies from 1000 to 10,000 individuals [20,44]. In La Calera we estimated 900,000 individuals in the colony, which allows us to confirm that is the second largest known colony known of *T. brasiliensis* in South America. Nevertheless, this estimation was performed before births occurred. For this reason, we believe that the colony is even larger if newborns and young are considered.

The colony of La Calera is maternal and migratory, as are others in South America and numerous in North America. These kind of colonies are only present in temperate zones, from 27°S to 31°S latitudes [16,17,20,42] and 25°N to 38°N [35], despite the fact that *T. brasiliensis* is more widely distributed in America. The annual activity cycle of all these colonies are seasonally similar, with arrival to the shelters in early- to mid-spring, births in late spring, and migrations in late summer or early autumn, showing patterns of gradualness until the shelters are empty or just inhabited by a small group of individuals that remain during the cold seasons, as is shown in Figures 7, 8, 11, 12 and Table 1 [15–18,20,30]. There is no information about migratory routes in the South American colonies, unlike in North America where it is known that they migrate towards lower latitudes [45,46], reaching distances of up to 1800 km [47]. These pulses of migrations in coordination with the reproduction of this species are associated with environmental factors and food availability [16,48].

Tadarida brasiliensis is known to be seasonal monoestrous [49,50] with females giving birth to a single pup which, in the large maternal colonies, are placed in creches with thousands of other infants, while females roost separately [15–17]. We have observed these creches in La Calera (Figure 7c). The lactating females return to the creche twice a day to nurse [15], and are able to discriminate their own pup by means of location memory, pups vocalization, and olfactory cues [51,52]. On the other hand, observation on the growth of newborns in La Calera coincides with those reported for others colonies in both hemispheres, where the young of five to six weeks have hair, a size similar to that of adults, and already begin to fly [15–17,48]. Two weeks after the first flights, young bats are weaned and begin to emerge outside their shelters to satisfy their nutritional needs independently [53].

The massive emergence of the colonies of *T. brasiliensis* are either diffuse, where there is little group integrity, or serpentine, where the bats fly in a column [54]. In La Calera, most of the time the emergence was serpentine, contrary to what it was observed in several caves in Texas state (USA) [54] and in El Salitre cave, Hidalgo state (Mexico) [55]. The time of emergence is mainly correlated with the sunset, but also varied according to the energetic demands for reproduction of the cohort, differences in climate, and prey availability [38,53]. We observed that the onset time of emergence varied seasonally according the sunset. On the other hand, energy requirements could also influence onset time of emergence, i.e., the earliest emergence observed in January (Table 1) could be lactating females that, having higher energy demands, emerge earlier [53,56]. Numerous birds of prey take advantage of massive emergences of *T. brasiliensis* to hunt [14,15], and the species observed around the colony of La Calera are known predators of *T. brasiliensis* [17,57,58].

Detections made by RMA1 showed important similarities with those made in the field on the same day. In 7 December 2018, the time of emergence was at 20:30 LT (Figure 7g and Table 1) and the radar detection was at 20:34 LT (Figure 9 and Figure 10). At that moment, the intensity of the echo was lower (horizontal reflectivity factor Z_H) and more concentrated in the surrounding area of the shelter than in subsequent detections (Figure 9) when it became more intense and disperse. This could have happened because most of the bats emerged and dispersed out of the shelter. On the other hand, the end time of the emergence was registered at 21:35 LT, while the radar detection continued at 22:00 (final of sampling interval), where the intensity of the echo was more concentrated away from the shelter. The spatial pattern shown by the RMA1 could be explained by the foraging activity made by this species around 50 km [32]. Moreover, radar detections throughout the year agree with the activity cycle of the colony of *T. brasiliensis* obtained by field observations and with records for other similar colonies, in temperate zones from South and North America (mentioned above). True radar detections started in early-September, 2018 and remained continued until April 2019, coinciding with the observed periods of permanence of the colony. Despite the continuous detections during this period, some intermittence was shown, manly in October 2018. In the case of radar detections in May 2019, it was not possible to confirm whether the radar detected the colony that postponed its departure; or the small group that is usually find in that month (Table 1); or, if they are false detections, due to the lack of simultaneous field observation. For the same reason, in the isolated detections of August 2018 and June 2019, we cannot confirm if it is the small permanent group or false detections. With respect to the analysis using Z_{dp}, it agrees with the conceptual model proposed by Mirkovic et al., [33]. We also found negative values such as Z_{dr} during the emergence of the colony.

Large migratory and maternal colonies of *T. brasiliensis* must be a priority for conservation plans since they present potential threats and, at the same time, provide important ecosystem services [35,42,59]. Some threats for this species are mortality caused by wind turbines installed in their migration routes, as well as disturbances that alter the few shelters used by these large maternal colonies [4,9,18,42,60]. These colonies provide an important ecosystem service in the area within 50 km of the shelter [59]: one million lactating females of *T. brasiliensis* can consume eight tons of insects each night, including pest species of crops [4]. Currently, *T. brasiliensis* is a protected species by the Convention on the Conservation of Migratory Species of Wild Animals (CMS, Appendix I—Adheres National Law of Argentina 23,918). Added to this, based on proposals from PCMA (Programa de Conservación de Murciélagos de Argentina—Bat Conservation Program of Argentina), the three large colonies known in Argentina have been recognized as SICOMs (Sitio de Importancia para la Conservación de Murciélagos—Sites of Importance for Conservation of Bats), by the RELCOM (Red Latinoamericana para la Conservación de los Murciélagos—Latin American Bat Conservation Network) [61]. Particularly, the colony of La Calera and its habitats are protected by a Provincial Resolution (R-2541/12) [41]. Despite this legal protection, it is necessary to continue monitoring the colony in the long term to assess its conservation status and to alert for possible changes in the permanence of the colony or in the number of individuals. Radar technology is a very powerful tool to carry out this task [30] and, in this case, the RMA1 is reliable for monitoring the colony of La Calera.

5. Conclusions

The colony of *T. brasiliensis* present in La Calera represents the second largest known colony of bats in South America, with 900,000 individuals. We confirmed that this colony is maternal and migratory, as well as that it is present in the warm seasons and absent or reduced during cold seasons, similar to other large colonies detected in temperate areas of America. It was characterized using ecological and behavioral aspects related to the kind of shelter, presence of creches, growth of the newborn, emergence of the colony, and predators. It is important to reinforce and deepen all subjects included in this preliminary study.

The observations made by RMA1 show this instrument is not only useful for meteorological detection but also for biological targets. Detection of an emergence was proven to be accurate as compared with simultaneous field observations. Also, the observation made by this radar agree with field observations when the activity cycle of the colony of *T. brasiliensis* through the year is considered. The algorithm generated to determine if a detection is a true or a false emergence of bats was consistent, most of the time, with what was expected according to field observations. However, this needs to be checked with more simultaneous field observations because there are some false detections during the period of permanence and some true detections during the period in which the colony is absent or markedly reduced. For this reason, we consider that more years of analyses with the inclusion of statistical analysis are needed.

This represents, to our knowledge, the first study made in South America using field observations together with radar technology to obtain complete information about a bat colony. We here demonstrate that RMA1 can be a powerful tool for monitoring a colony at a long term, and even to alert possible changes in the permanence of the colony or the number of individuals. This monitoring would allow researchers to reinforce the conservation strategies for the colony. Moreover, this is an initial step to stimulate further studies which may allow scientists to know which variables determine the daily activity pattern (onset time of the emergence and return), as well as the annual activity cycle (permanence and migrations), estimate the population number through radar data, and to have a better knowledge about the ecosystem service provided by the colony to the surrounding farmers.

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