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Citizen Science for Monitoring Primates in the Brazilian Atlantic Forest: Preliminary Results from a Critical Conservation Tool

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Abstract: Citizen Science (CS) is a process that engages members of the public in the collection and interpretation of scientific data in collaboration with scientists. It is especially useful for monitoring biodiversity over extended periods and at larger scales than most researchers can cover themselves. Here we present preliminary insights from a project initiated to evaluate the potential of a systematic CS program to monitor primates in small fragments of Atlantic Forest surrounding the Reserva Particular de Patrimônio Natural Feliciano Miguel Abdala (RPPN-FMA), in Caratinga, Minas Gerais, Brazil. This region was near the center of a severe yellow fever outbreak that peaked in late 2016 and early 2017, which coincided with steep declines in the known populations of the four species of primates that occur sympatrically in the RPPN-FMA (*Alouatta guariba*, *Brachyteles hypoxanthus, Callithrix flaviceps*, and *Sapajus nigritus*). Nothing, however, was known about the status of these species in the surrounding forest fragments. To gain rapid insights into the status of primates in these fragments and at the same time to assess the feasibility of developing a more systematic CS program in the future, we visited 54 landowners within 6 km of the reserve, 49 of which agreed to participate by sharing their perceptions of primate presence or absence before and after the yellow fever outbreak, and in the subsequent potential recovery period. Consistent with the decline in primate populations in the RPPN-FMA and another region in southeastern Brazil, participants residing around the reserve perceived the greatest declines in populations of *Alouatta* and *Callithrix*, followed by *Sapajus,* with a comparatively small decline in *Brachyteles*. Participant perceptions, reflected in their monthly reports from June 2018 to June 2020, suggest that the presence of *Alouatta* (detected significantly more often by auditory cues) and *Callithrix* returned to pre-yellow fever levels, while that of *Sapajus* (detected more by visual cues) exceeded pre-yellow fever levels. The only species with seasonal variation in participant perceptions was *Callithrix*. Although systematic censuses are needed to calibrate participant reports, there is clear potential for the development of a more comprehensive CS program as part of conservation efforts to monitor primate species in this region.

Key words: Yellow fever, human communities, biodiversity, local resident perceptions, endangered species

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Introduction

Citizen Science (CS) is a process that engages members of the public in the collection and interpretation of scientific data in collaboration with scientists responsible for designing the study (Mohd Rameli *et al*. 2020). CS is particularly well-suited for monitoring patterns of species occurrence over longer time frames and over larger spatial scales than most individual investigators can cover (Bonney *et al*. 2009; Devictor *et al*. 2010; Danielsen *et al*. 2010; Hochachka *et al*. 2012; Bird *et al*. 2014). Despite recent discussions about whether and how criteria of scientific quality should be applied in CS projects (e.g., Auerbach *et al*. 2019; Heigl *et al*. 2019), there is growing recognition of the value of CS in biodiversity research (Horns *et al*. 2018; Wang *et al*. 2018; Schuttler *et al*. 2019).

Appreciation of CS peaked during the COVID-19 pandemic of 2020, when international travel bans and concerns for the health security of researchers, local human communities, and wildlife caused field research around the world to come to a sudden halt (Gillespie 2019; Gillespie and Leendertz 2020; IUCN-WHSG 2020; Lappan *et al*. 2020; Reid 2020; Trivedy 2020). Field studies that were entirely dependent on foreign researchers were effectively frozen in time (Morelli and Sposito 2020), whereas those with trained local participants who had access to the field sites could continue to function. The advantages of having personnel capable of sustaining ongoing data collection without travel during the COVID-19 pandemic brought the value of CS in biodiversity research into sharper perspective than ever before (Theobald *et al.* 2015; Benites *et al*. 2020). Nonetheless, it is essential that all safety protocols mandated during the pandemic (e.g., use of masks, social distancing, repeated washing of hands and other objects) should always be applied by all people in all contexts.

Here we present preliminary insights from a community-focused initiative to evaluate the potential for a systematic CS program to monitor primates in Atlantic Forest fragments surrounding the Reserva Particular de Patrimônio Natural Feliciano Miguel Abdala (RPPN-FMA), a private natural heritage reserve of approximately 1,000 ha in Caratinga, Minas Gerais, Brazil, where the Muriqui Project of Caratinga has been underway since 1983 (Strier and Mendes 2012). Past outreach programs there have focused on conservation education with school children and their families living in the agricultural matrix surrounding the reserve (e.g., Pontual *et al*. 2005; Strier *et al*. 2006). However, none of these prior efforts explicitly tapped into local residents' attention to the primates living in the forest fragments on or adjacent to their properties.

The stimulus for the present initiative traces back to the period between October 2016 and mid-2017, when this region of southeastern Brazil was hit by one of the most severe yellow fever (YF) outbreaks in history. YF is an arbovirus (genus *Flavivirus*) transmitted by mosquitoes (Silva *et al*. 2020). More than a third of the 777 Brazilians infected with yellow fever during this YF outbreak died (Faria *et al.* 2018) and at least 3,500 nonhuman primates were confirmed to have died from YF through April 2019 (Silva *et al*. 2020). Entire populations of brown howler monkeys (*Alouatta guariba*) in the states of Minas Gerais and Espírito Santo were entirely lost or reduced to a fraction of their original size (Mendes 2018). Virological analyses from skin and blood samples have also implicated YF as the source of mortality in other Atlantic Forest primates including marmosets (*Callithrix* spp.), titi monkeys (*Callicebus* spp.) and black capuchin monkeys (*Sapajus nigritus*) during the 2016–2017 outbreak (Fernandes *et al*. 2017; Figueiredo *et al*. 2018; Rezende *et al*. 2018). The Critically Endangered golden lion tamarin (*Leontopithecus rosalia*) was also severely affected (Dietz *et al*. 2019), and unusually high mortality was documented in two populations of northern muriquis (*Brachyteles hypoxanthus*) coincidental with the peak YF outbreak, implying that YF may have been the cause (Strier *et al.* 2017).

One of the muriqui populations that experienced high mortality (10%) during the peak of the 2016–2017 YF outbreak has been the subject of long-term demographic monitoring since the 1980s at the RPPN-FMA (Strier *et al*. 2018). The other three sympatric primates in this forest were even more severely affected, with populations of *Callithrix flaviceps* and *Alouatta guariba* estimated to have declined by as much as 90% and 80%, respectively, while the population of *Sapajus nigritus* is estimated to have declined by some 30–50% (Possamai *et al.* 2019).

The magnitude of the primate casualties coincidental with the 2016–2017 YF outbreak within the RPPN-FMA raised urgent concerns about the status of the much smaller populations of primates inhabiting some of the forest fragments surrounding the reserve, where we lacked the personnel and resources to conduct systematic surveys.

The quickest way to get insights into the status of the primates in these fragments is to ask the local residents. For example, interviews conducted by Gontijo (2019) with local residents in the central mountainous region of Espírito Santo following the same YF outbreak yielded estimates on population declines of *Alouatta guariba* (82.5%), *Callithrix* spp. (49.1%), *Sapajus nigritus* (23.7%) and *Brachyteles hypoxanthus* (19%) that permitted modeling of primate occupancy and extinction rates in the fragments. If volunteer residents in our region were similarly responsive, we could use the experience to assess whether a more systematic CS program for monitoring the primates in this agricultural matrix would be warranted.

Here, we first present our initial findings of local resident perceptions about the impact of the YF outbreak on primate presence. Then, using compiled monthly reports on the presence of primates from the same participants, we review their perceptions about the "recovery" of the primates. We were interested in whether resident proximity affected perceptions of primate presence during the three periods or over time, across seasons, or based on mode of communication during the recovery period, and whether the small, slower moving groups of howler monkeys and the small marmosets would be detected more often by auditory cues while the larger, more active groups of capuchin monkeys and muriquis would be more often detected by visual cues. Lastly, we evaluated the utility of CS as a tool for future primate monitoring and conservation in this region.

Methods

Study area and participants

This project was conducted in the rural community surrounding the RPPN-FMA, in the district of Santo Antônio do Manhuaçu, municipality of Caratinga, in eastern Minas

Gerais, Brazil (19°44'S, 41°49'W). Most of the fragments were located in Caratinga, but some were in the municipality of Ipanema. Most of the surrounding properties are less than 500 ha and all forest fragments monitored were at least 10 ha (Table 1). All properties were in a matrix of small forest fragments in different stages of regeneration (Brazil, Conama 1993) (Fig. 1).

From March to May 2018, 54 households outside of the borders of the reserve were visited by the project coordinator, Marcello S. Nery, or by his assistant, Roberto P. Paulino, both of whom were familiar to property owners in the region due to past or ongoing employment by *Preserve Muriqui*, the NGO that administers the reserve. The selection of which households to visit was made in large part based on the proximity of the properties to the reserve and on prior familiarity with the property owners.

Adults from 49 of the 54 households that were initially visited agreed to share their perceptions about primates in the forest fragments located on or in view of their properties. All 49 of these participating households (hereafter, volunteer participants) lived within 6 km from the reserve. All of the 49 participants were adults responsible for the house and 45 of the 49 (91.83%) were men. However, we do not have information about the level of participation of other members in these households or whether other individuals contributed to the monthly reports.

There was great variation regarding the size and location of the forest fragments upon which the participants were basing their perceptions of primate presence. Six fragments were monitored by 2–4 participants, resulting in a total of 35 different fragments among the 49 participants. Of these 49, one based their perceptions of primate presence on the border of the reserve itself, and 12 reported their perceptions based on four forested properties ranging from 15–320 ha that were continuous with the reserve but outside of its border. The remaining 36 participants reported their perceptions of primate presence referencing a combined total of 30 forest fragments ranging from 10 to 724 ha and separated from the reserve by 50 to 5,900 m (Fig. 1 and Table 1).

Because our priority here was simply to gain insights about primate populations from the perceptions of local residents, we did not consider either the characteristics of the forest fragments (e.g., size, distance to other fragments or the perimeter of the reserve) or the number of different participants referencing each fragment in our selection of participants. Indeed, the different numbers of participants reporting on each fragment resulted in variation in sampling intensity that would confound interpretations of perceptions of primate presence relative to fragment size. However, we recognize the importance of including these factors in any systematic CS project we may pursue in the future.

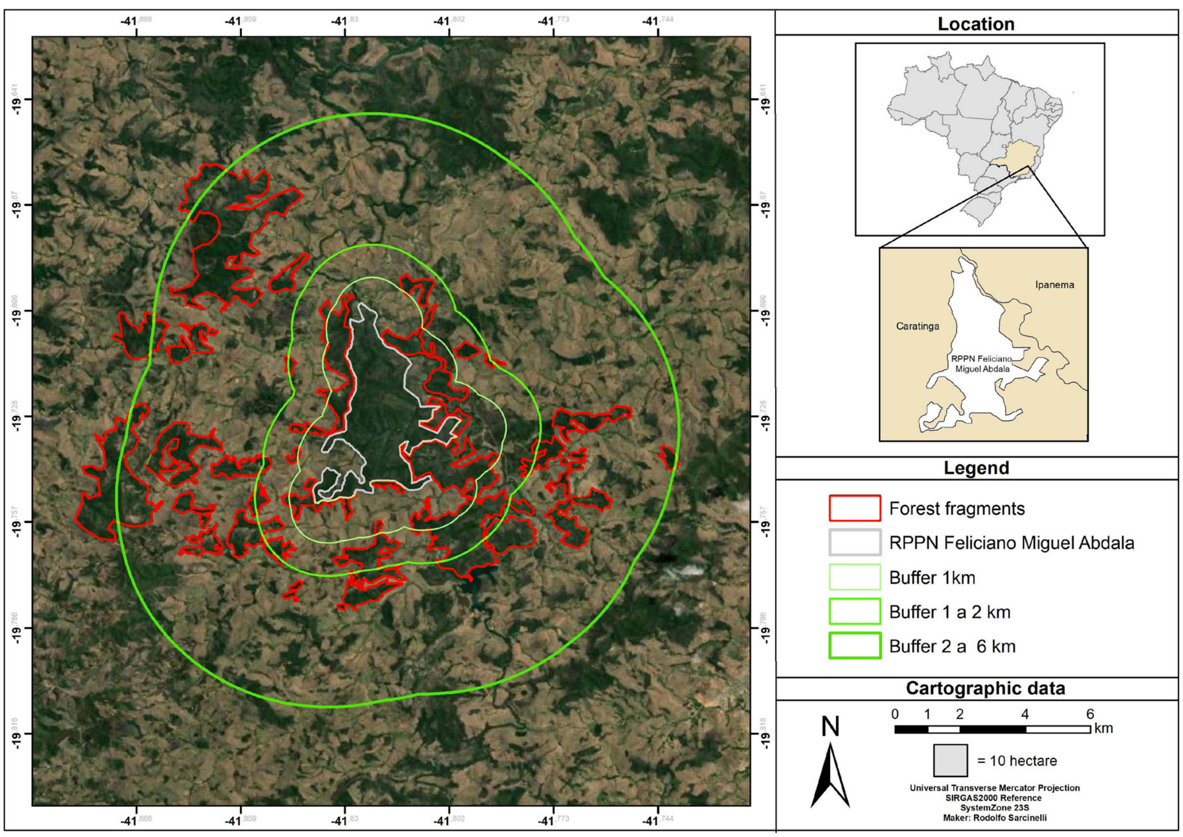

Figure 1. Location of the study area, Minas Gerais, Brazil. Shown here is the RPPN-FMA (at the center, white border) and the surrounding forest fragments with those referenced by participants in this study (red borders). Green lines, show the distance (Buffer category) between the participant's household and the nearest border of the RPPN-FMA, as described in the text.

Table 1. Forest Fragments (N = 35) and Participants (N = 49) surrounding the RPPN-FMA (municipalities of Caratinga and Ipanema, Minas Gerais, Brazil). Note that some fragments were registered at different distance categories by different participants.

Size (ha) of forest fragment (rounded to nearest ha)	Municipality	Location relative to reserve	Distance category	Number of participants reporting primate presence	Report of ≥1 primates
960	Caratinga	Actual Reserve	<1 km	1	Yes
15	Caratinga	Continuous	<1 km	1	Yes
62	Caratinga	Continuous	<1 km	1	Yes
200	Caratinga	Continuous	<1 km	4	Yes
"	"	"	1-2 km	3	Yes
320	Caratinga	Continuous	<1 km	2	Yes
"	"	"	1-2 km	1	Yes
10	Caratinga	Separate	1-2 km	1	Yes
10	Ipanema	Separate	>2 km	1	Yes
11	Caratinga	Separate	<1 km	1	Yes
11	Caratinga	Separate	1-2 km	2	Yes
13	Caratinga	Separate	>2 km	1	Yes
22	Ipanema	Separate	1-2 km	1	Yes
23	Ipanema	Separate	>2 km	1	Yes
30	Caratinga	Separate	1-2 km	1	No
36	Caratinga	Separate	1-2 km	1	Yes
41	Ipanema	Separate	1-2 km	1	Yes
42	Caratinga	Separate	1-2 km	1	Yes
44	Caratinga	Separate	1-2 km	1	Yes
47	Caratinga	Separate	1-2 km	1	Yes
49	Caratinga	Separate	>2 km	1	Yes
61	Ipanema	Separate	>2 km	1	Yes
72	Caratinga	Separate	>2 km	1	Yes
71	Caratinga	Separate	>2 km	1	Yes
77	Caratinga	Separate	1-2 km	1	Yes
83	Caratinga	Separate	1-2 km	2	Yes
"	"	"	>2 km	1	Yes
93	Ipanema	Separate	>2 km	1	Yes
104	Caratinga	Separate	>2 km	1	Yes
113	Ipanema	Separate	>2 km	1	Yes
119	Ipanema	Separate	>2 km	1	Yes
128	Caratinga	Separate	>2 km	1	Yes
137	Caratinga	Separate	<1 km	1	Yes
142	Caratinga	Separate	>2 km	2	Yes
182	Caratinga	Separate	>2 km	1	Yes
367	Caratinga	Separate	<1 km	1	Yes
"	"	"	1-2 km	1	Yes
"	"	"	>2 km	1	Yes
460	Caratinga	Separate	>2 km	1	No
724	Caratinga	Separate	>2 km	1	Yes

Data collection

Follow-up visits were made to all 49 properties in June 2018, during which time participants were asked about their perceptions about the presence of each of the four species of primates before the yellow fever outbreak (most of 2016), and after the yellow fever outbreak (March 2017 – March 2018).

Beginning with the June 2018 visits, participants were also asked to maintain monthly records of any primates they saw or heard in the forest fragments they could monitor from their properties. To facilitate their records, each participating household was provided with a specially designed calendar that included photos of each of the four primate species, following the style of other calendars used by residents in this community (Fig. 2). For each day of the month there was space for the participant to record each primate species seen or heard, as well as any additional information such as the number of individual monkeys, the number of occasions they were seen or heard that day, and the presence of infants or encounters with corpses, which could be indicative of an increase or decrease in the local population sizes, respectively.

Subsequent visits were made in August 2018 and then monthly from October 2018 through March 2020 to all 49 participants. Return visits were made if participants were not home at the time of the first visit each month. Due to COVID-19, from April – June 2020, all contacts were made by phone, using WhatsApp messaging. Thus, we obtained monthly records for a total of 23 months from June 2018 through June 2020 from the 49 participating households, with continuous monthly reporting conducted from October 2018 – June 2020.

Data analyses

All conversations with participants were tabulated. To evaluate the perceived impact of YF on the primates surrounding the reserve, we compared reports about the presence or absence of each species "Before" the YF outbreak (roughly through 2016), "After" the YF outbreak (e.g., March 2017 – March 2018), and during the current period of potential "Recovery," represented by any reported presence of a species during the period from June 2018 – June 2020. We used Sign-tests to evaluate changes in participants' perceptions of each species' presence during the periods Before versus After, After versus Recovery, and Before versus Recovery. It is important to note that reports during Before and After periods were based on participant retrospective considerations, whereas those from the Recovery period, which were based on participant perceptions of primate presence over a 2-year period, were likely to be more precise.

To evaluate whether proximity to the reserve affected participants' perceptions, we divided participants into three "residence proximity" categories based on the distance from their residence to the closest border of the reserve: <1 km (n = 13 participants); 1–2 km (n = 17); and >2 km (n = 19). The residence proximity did not always coincide with the distance between the reserve and the forest fragments about which the participants referenced in their reported perceptions of primate presence. We used Kruskall-Wallis tests to assess the effects of residence proximity on participant perceptions of primate presence during the three periods affected by YF, and on the number of months participants perceived each species as present during the recovery period. We used Steel-Dwass *post hoc* tests (the nonparametric equivalent of the Tukey's *post hoc* test, and which corrects for multiple comparisons in Jmp Pro 15) to assess

Figure 2. Cover and typical page of the calendar developed for participant records.

which distance categories were responsible for any differences detected.

We were restricted in our analyses of the presence or absence of primates and modes of detection during the Recovery period because only a few of the participants provided any additional information. We tabulated the number of monthly communications during the Recovery period in which each species was reported as present based on whether it was detected from Auditory cues (A) versus Visual cues (V). We used the Fisher exact test to determine whether detection mode differed across species.

Finally, to assess whether participant perceptions of primates during the Recovery period varied over time, across seasons, or based on mode of communication (in-person visits versus remote, WhatsApp contacts), we plotted the 49 participant perceptions by month, and divided the 23 monthly reports into three periods based on daylength, which varied from 13 hours in Summer (December–February) to 11 hours in Winter (June–August), with 12 hours during Spring and Fall (September–November and March–May, respectively; INMET 2020). We used Kruskall-Wallis tests with Steel-Dwass *post hoc* tests to compare the distribution of records of each species across daylength periods. We also compared the months in which communications were restricted to WhatsApp with the same months in the previous years. In all cases, we considered $p<0.05$ to be statistically significant.

Results

Perceived impact of yellow fever

The participants provided valuable information about their perceptions of the presence or absence of primates in the forest fragments surrounding the RPPN-FMA that would not have been possible to obtain in any other more efficient way. Two of the 49 participants (4.08%) reported they had no records of primates either Before, After, or during the Recovery period following the YF outbreak. Eighteen (36.74%) participants reported the presence of one species, 19 (38.78%) reported the presence of two species, eight (16.32%) reported the presence of three species, and two (4.08%) reported the presence of all four primate species (Table 2).

Before YF, *Alouatta* was reported either alone or with one or more other species by 46 of the 47 participants with any primate presence (97.87%), with the one exceptional case involving a report of *Sapajus* alone. After YF, 30 participants reported no primate presence. *Alouatta* was represented in only three of the 19 (15.78%) reports with one or more primates, while *Sapajus* was represented in 17 of the 19 (89.47%). By the Recovery period, *Alouatta* was once again present in 40 of the 47 (85.10%) reports, with *Sapajus* present in only 7 (14.89%) of these. Thirty of the 47 participants reporting primate presence included both *Alouatta* and *Sapajus* in the same fragments (Table 2).

Table 2. Perceptions of primate communities Before, After, and during the Recovery period following the 2016-2017 yellow fever (YF) outbreak.

Primate communities	N Before YF (%)	N After YF (%)	N Recovery (%)
None	2 (4.08)	30 (61.22)	2 (4.08)
Alouatta (Al) only	17 (34.69)	1 (2.04)	7 (14.29)
Brachyteles (Br) only	0	1 (2.04)	0
Callithrix (Cal) only	0	0	0
Sapajus (Sap) only	1 (2.04)	12 (24.49)	6 (12.24)
Al+Br	2 (4.08)	0	0
Al +Cal	4 (8.16)	0	3 (6.12)
Al+Sap	13 (26.53)	0	19 (38.78)
Br+Sap	0	2 (4.08)	1 (2.04)
Cal+Sap	0	1 (2.04)	0
Al+Br+Sap	2 (4.08)	1 (2.04)	4 (8.16)
Al+Cal+Sap	6 (12.24)	1 (2.04)	5 (10.20)
Al+Br+Cal+Sap	2 (4.08)	0	2 (4.08)
Total	49 (100)	49 (100)	49 (100)

Similar patterns are evident from the changes in participant reports of individual species Before and After the YF outbreak, and during the post-YF Recovery period. With the exception of *Brachyteles*, primate presence was perceived as being significantly higher Before YF and during the Recovery period than After YF (Fig. 3). Only *Sapajus* was perceived significantly more often during the Recovery period than Before the YF outbreak.

Residence proximity to the reserve tended to be associated with higher perceptions of primate presence across species and periods, but these effects were only statistically significant for *Sapajus* Before and After the YF outbreak and for *Callithrix* Before it (Fig. 4).

Detection mode and perceptions during the recovery period

A total of 782 reports of primates were obtained from the 49 participants during the 23-month post YF Recovery period. *Alouatta* accounted for 50.62% (n = 393) of the reports, *Sapajus* for 43.48% (n = 340), with *Callithrix* and *Brachyteles* accounting for only 3.71% (n = 29) and (2.56% (n = 20), respectively.

Consistent with our predictions, *Alouatta* and *Callithrix* were reported as being detected more often by Auditory cues than by Visual cues, but the difference was only significant for *Alouatta*; *Sapajus* and *Brachyteles* were detected significantly more often by Visual cues (Fig. 5).

The total number of months each participant reported primate presence varied from 0 to the maximum of 23 months for *Alouatta* (median = seven months) and *Sapajus* (median = two months), 0–6 months for *Callithrix* (median = zero months), and 0–4 for *Brachyteles* (median = zero months). We found no evidence that differences

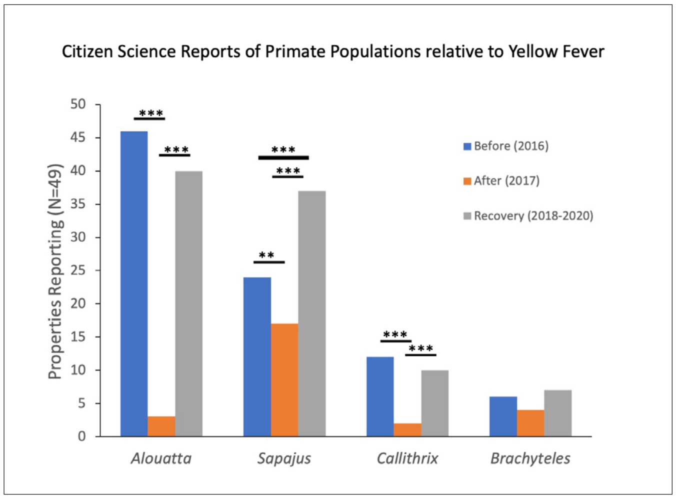

Figure 3. Perceptions of primate populations relative to the 2016–2017 yellow fever outbreak in the areas surrounding the RPPN-FMA, Caratinga, Minas Gerais, Brazil. The number of participants (N = 49) reporting the presence of each species Before the yellow fever outbreak, After the yellow fever outbreak, and during the subsequent Recovery period. Sign tests indicate significant differences with p<0.02 (**) and p<0.001 (***).

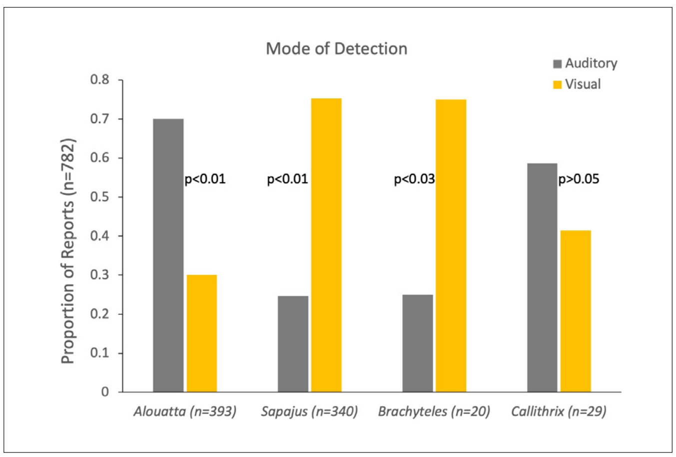

Figure 5. Modes of detection by species during the Recovery period. Proportions are based on the sum of the 49 participants' 23 monthly reports. Probabilities are shown for Fishers' exact tests.

in participants' monthly perceptions of primate presence varied with residence proximity to the reserve (Fig. 6).

There was substantial inter-monthly variation in the number of participants reporting primate presence during the post-YF Recovery period, but there was no consistent temporal pattern in participant perceptions (Fig. 7). The initial winter months of June – August 2018 included the highest frequencies of perceived presence for *Sapajus* and *Brachyteles*, and among the highest for *Alouatta* and *Callithrix*. However, perceptions of *Callithrix* peaked during the fall months of March – May 2019, and those of *Alouatta* peaked in March and April 2020. *Callithrix* was the only species for which the perceived presence varied significantly across seasons (H(2) = 6.36, p<0.05), with *post hoc* analyses revealing significantly lower frequencies during summer months and higher frequencies during winter months (p<0.04).

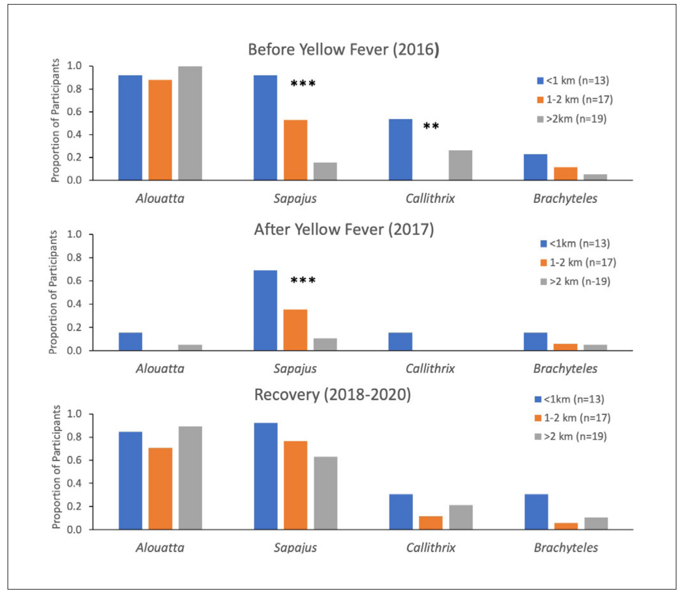

Figure 4. Effects of residence proximity to the reserve on perceptions of primate presence during each of the yellow fever periods. Proportions are calculated from the number of participants reporting primate presence during each period divided by the number of participants in each distance category. Asterisks show a statistical difference with residence proximity to the reserve Before YF for *Sapajus* (H(2) = 17.88, P = 0.0001, with *post hoc* Steel-Dwass test showing the difference between <1 km and >2 km at P<0.0001, and *Callithrix* (H(2) = 11.37, P=0.0034, with *post hoc* Steel-Dwass test showing the difference between <1 km and 1–2 km at P<0.003, and After YF for *Sapajus* (H(2) = 11.51, P<0.004, with *post hoc* Steel-Dwass showing the difference between <1 km and >2 km at P<0.003).

Participant contact mode (in-person visits versus remote WhatsApp) could not be compared for either *Brachyteles* or *Callithrix* because of the small number of reports. More participants, however, reported the presence of *Alouatta* and *Sapajus* in two of the three months they were contacted remotely compared to the same months when they were visited the previous year (Fig. 7).

Discussion

Perceived impact of yellow fever

Consistent with other findings about the effects of the 2016–2017 YF outbreak on primates in the RPPN-FMA (Possamai *et al.* 2019; Strier *et al.* 2018) and in the rural central montane region of Espírito Santo (Gontijo 2019), participants residing around the reserve perceived the greatest declines (p<0.001) in populations of *Alouatta* and *Callithrix*, followed by *Sapajus* (p<0.01) with a comparatively small decline in records of *Brachyteles*. However, in contrast to current estimates within the reserve (Possamai *et al.* 2019), the CS participants perceived recoveries of *Alouatta* and *Callithrix* that approximated their perceptions of these primates' presence Before YF, but perceptions of *Sapajus* recovery were significantly greater compared to their perceptions of presence Before YF (Fig. 3).

Although encouraging, these findings highlight the need for systematic censuses of primates in the forest fragments surrounding the reserve to validate the perceptions of our

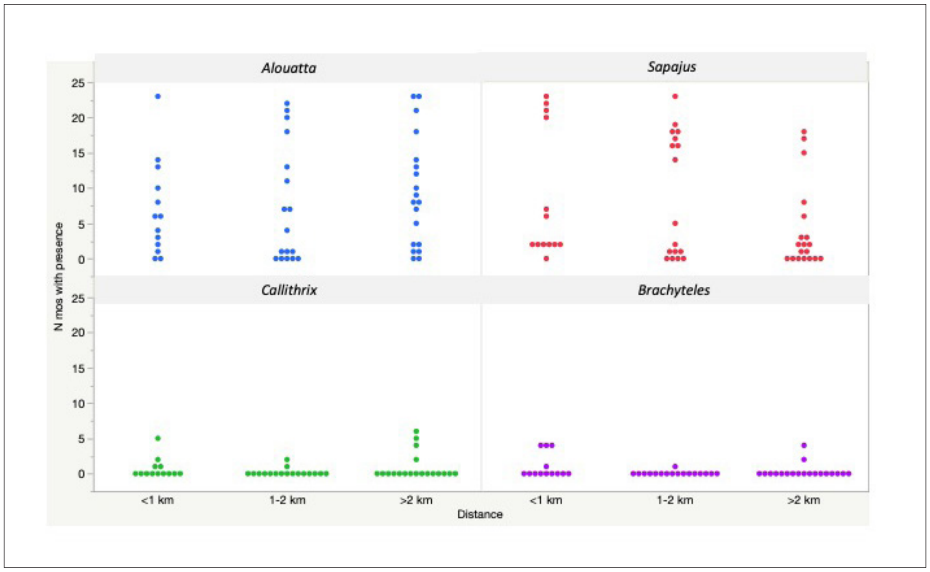

Figure 6. Number of months with primate presence did not differ by distance from the Reserve. Kruskall-Wallis tests H(2) *Alouatta* = 1.47, P = 0.48; H(2) *Sapajus* = 4.17, P = 0.12; H(2) *Callithrix* = 1.62, P = 0.45; H(2) *Brachyteles* = 4.32, P = 0.12.

participants. Indeed, because we standardized participant perceptions into present/absent alternatives, we cannot use these perceptions to assess whether *Alouatta* and *Callithrix* populations are recovering in these fragments or whether only solitary or small numbers of individuals remain. Similarly, although it seems unlikely that the increase in perceptions of *Sapajus* presence relative to *Alouatta* was solely a consequence of heightened attention that participants might have exhibited as a result of this project, there was no *a priori* reason for their interest to have been restricted to *Sapajus* alone. Thus, we need independent validation to fully evaluate the perceived shifts in the composition of local primate communities. Nonetheless, if validated, these results would raise the intriguing possibility that diseases such as YF, which are known to affect different species to different degrees (Santos *et al.* 2020), can contribute to variation and changes in primate communities. These community changes might have occurred if surplus *Sapajus* were able to expand into fragments that were occupied by *Alouatta* prior to the YF outbreak, and/or to colonize fragments or re-colonize the fragments faster than *Alouatta* or *Callithrix*.

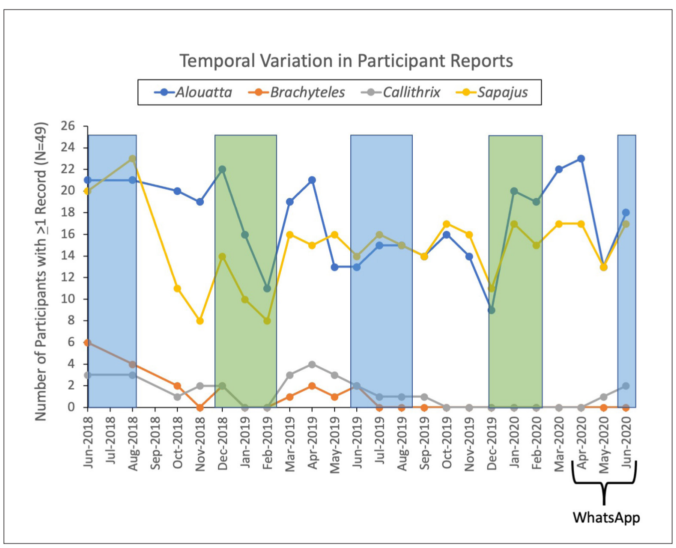

Figure 7. Temporal variation in participant perceptions of primate presence. Blue panels correspond to winter months, white panels to spring and fall months, and green panels to summer months. There were no seasonal differences in perceptions of primate presence for *Alouatta* (H(2) = 0.27, P = 0.87), *Sapajus* (H(2) = 4.71, P = 0.09), or *Brachyteles* (H(2) = 2.21, P = 0.33). *Callithrix* was perceived to be present at significantly higher frequencies during winter months than summer months, as described in the text.

Systematic monitoring efforts to obtain baseline population estimates could initially be implemented by biologists who are familiar with distinguishing the age-sex class characteristics of each of the species. Ultimately, however, the training of CS participants would provide a more efficient way to monitor changes in population sizes and composition (e.g., presence of infants) and to better understand the dynamics of primate communities within and among the forest fragments.

We cannot interpret the role that residence proximity to the reserve may have played in participant perceptions of primate presence because we did not control for characteristics of the forest fragments or for the number of different participants referencing each fragment in their reports. Such considerations will be necessary to include in any future CS program to permit quantitative analyses of forest fragment occupancy by primates than is possible at present.

Currently, we can only speculate about whether the reserve might serve as a "source" of colonizers of surrounding forest fragments, as least in the case of species such as *Sapajus* and *Callithrix*, which were significantly more likely to be perceived as present by the participants living closest to the reserve before the YF outbreak. Indeed, we cannot dismiss the possibility that *Sapajus* was more likely to be perceived compared to the other primates because of its more conspicuous behavior and greater affinity for exploiting cultivated foods such as sugar cane and corn (Hass and Printes 2014). Comparative assessments of population recoveries of these species within versus beyond the reserve are needed to evaluate this possibility. Although the large, protected forest fragment encompassed by the reserve is known to have supported high densities of all primate species in the past (Strier *et al*. 1999; Almeida-Silva *et al.* 2005), we do not yet know how perceptions of primate recovery in the surrounding community compare to population changes after YF within the reserve (Possamai *et al*. 2019).

Detection mode and perceptions of primate recovery

Participants reported perceiving the presence of *Alouatta* and *Callithrix* significantly more often based on auditory cues than on visual cues, whereas for *Sapajus* and *Brachyteles* these patterns were reversed. All four of these taxa are known for their complex vocal repertories. *Alouatta* is famous for its long-distance vocalizations used for intergroup spacing, especially during morning choruses and during intergroup encounters (Mendes 1989; Chiarello 1995; Oliveira 2002; Aguiar *et al*. 2003), while *Callithrix* is known for its high-frequency (hertz) vocalizations (Bezerra 2006) and for its use of frequent vocalizations for intergroup spacing and intragroup coordination (Barros and Yoshida 2009). By contrast, the large groups of both *Sapajus* and *Brachyteles* are also much more active, devoting nearly half of their days to traveling (Rimoli 2001; Gouveia 2009; Martins 2010) or traveling and feeding (Strier 1987).

Variation in participant reports of primate presence over the Recovery period did not correspond to their residence proximity to the reserve (see Fig. 6). This initially seemed surprising because we might have expected that residents in this agricultural community living closer to the reserve would be more aware of the long-term research and increasing ecotourism activities focused on primates there. Indeed, it seems that, at least within the 6-km radius of this project, a majority of participants shared a generally high level of interest in primates, regardless of their residential proximity to the reserve. This suggests that increased efforts to engage the surrounding community through education, visitation, and other events in the reserve would be welcome. Such activities could also help to minimize the decline in participant interest that has been documented in analyses of CS projects elsewhere (Theobald *et al*. 2015).

Seasonality in photoperiod, temperature, and rainfall are known to affect the activity patterns of primates and the availability of their food sources (Bicca-Marques and Fortes 2005), so we might have predicted that primate responses to these seasonal factors would affect the perception of participants about primate presence across different seasons during the recovery period. For example, we might have expected higher detection frequencies during the fall and winter months, when many trees lose their leaves in this semi-deciduous forest and primates would be more visible. This could potentially contribute to the more frequent reports of *Callithrix* during the winter versus summer months. Conversely, it is possible that longer daylight in the summer months affected the activities of our participants and thus increased their chances of perceiving primate presences during this season. Indeed, during spring and summer, when food availability is greater, *Alouatta* groups in the RPPN-FMA were more active and traveled more (Mendes, 1989). However, we found no increase in the perceived presence of *Alouatta* or other species during these seasons of greater food availability (see Fig. 7).

Potential for citizen science

Participant reports of their perceptions of primate presence were consistently high over the 23-month post-YF recovery period, indicative of the tremendous potential that CS could have in this region. Specifically, because the timing of the YF outbreak could not have been anticipated, there would have been no other way to obtain baseline information about the presence of the different primate species in the surrounding forests or about their status immediately after the outbreak. Thus, our study provides additional support for the potential value of CS in biodiversity research (Theobald *et al.* 2015), despite the limitations in our methods. For example, the monthly reports provided by the CS participants in our project permit us to identify which fragments should be prioritized in future ground surveys. Confirming the accuracy of the presence/absence reports will be a critical next step in this developing CS program, (Mohd Rameli *et al*. 2020). Moreover, confidence checks will permit us to improve our communication with the participants to minimize potential biases and maximize our ability to interpret the results (Bonney *et al*. 2009).

Despite the preliminary nature of our findings, three potential discoveries have emerged from this project that merit future consideration. First is the intriguing increase in the perceived presence of *Sapajus* relative to other primates and especially *Alouatta* during the recovery period compared to pre-YF outbreak. This unexpected finding raises fundamental questions about interspecific competition, species differences in colonization ability, and whether *Sapajus* are dispersing from the reserve or from other forest fragments in the region, each of which has implications for understanding the dynamic properties of Atlantic Forest primate communities.

A second intriguing finding is the perceived recovery of *Callithrix* to nearly its pre-YF presence. Although we lack information on whether the *Callithrix* reported by participants refer to individuals or reproductive groups, the recovery of *Callithrix* inside the reserve appears to be occurring more slowly (Possamai *et al.* 2019). This is unexpected, in that marmosets have twins twice a year and are rapid breeding r-strategists, colonizing their favored habitats—successional forest with dense understoreys (Rylands, 1996). Given the right habitat, they should recover faster than the other species. If remnant populations of *Callithrix flaviceps* can re-establish breeding groups in fragments outside the reserve, they may be vital for any conservation management plan for this Critically Endangered species.

Third is the novel discovery of an isolated female *Brachyteles hypoxanthus* in one of the forests monitored by one of the participants. Although other female muriquis known as individuals from the long-term study in the reserve have been sighted in forest fragments outside of the reserve, where they initially dispersed and have continued to reside (Tabacow *et al.* 2009; Strier *et al.* 2015), the report and subsequent confirmation of another solitary female (named "Cida," short for Ciência Cidadã, the Portuguese translation for Citizen Science) offers us another potential candidate for future translocation projects being conducted to save small muriqui populations elsewhere (Mendes *et al*. 2005; Barros *et al*. 2011; Tabacow *et al*. 2021).

While the perceptions of primate presence provided by the participants help us to prioritize which forest fragments merit systematic biological surveys, they also help to highlight methodological limitations that can be easily addressed in the future. For example, if we had selected participants based on their access to forest fragments with particular characteristics such as size, distance to the reserve, and degree of perturbation, we would have been able to interpret primate occupancy patterns in a way that our current, participant interest-based sample does not. Similarly, providing greater educational opportunities for participants, including more explicit training on how to distinguish age-sex class categories and assess population sizes would permit quantitative comparisons of the status of primates surrounding the reserve with assessments being conducted within the reserve (Bonney *et al.* 2009; Franquesa-Soler *et al.* 2020). Combining these improvements into a proper CS program would also help us to better understand the variables that contribute to successful or unsuccessful population recoveries in fragmented landscapes and provide perspectives into how to better manage existing fragments and improve connectivity among them to facilitate primate movement.

Finally, this project highlights the potential to increase community involvement in primate conservation and larger biodiversity objectives in this and other regions. The widespread use of cellular technology here not only facilitated our ability to contact participants remotely during the COVID-19 pandemic, but also offers promising potential for the development of primate monitoring applications, which would permit participants to more easily collect and upload data directly to a common database, as has already been implemented in other CS projects with great success (e.g., Plants: <https://plantnet.org/en>; Fish: <https://www.ictio.org/>; Birds: <https://ebird.org/averaves/home; <https://www.wikiaves.com.br/>; Fauna: <https://www.naturalista.mx>; <https://enciclovida.mx>; <https://www.inaturalist.org; http://a3p.eco.br/produto/sistema-urubu/>). Use of cell phones and Apps could also make CS attractive to the younger members of participating families instead of the adult members who participated here.

With increasing awareness about infectious zoonotic diseases such as the YF that stimulated this project, and subsequently COVID-19, there are new challenges to both human and animal health that require improved, innovative monitoring measures (Bengis *et al.* 2004). Citizen Science offers a promising pathway to increase community engagement in and support for scientific approaches to both health and conservation (Theobald *et al.* 2015). In addition, CS offers a way to increase public participation and support for government policies that favor biodiversity conservation (Viana and Queiroz 2020).

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