PRIMATES IN SISS-GEO: POTENTIAL CONTRIBUTIONS OF MOBILE TECHNOLOGY, HEALTH SURVEILLANCE AND CITIZEN SCIENCE TO SUPPORT SPECIES CONSERVATION IN BRAZIL

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Abstract

The Information System on Wildlife Health (SISS-Geo) is based on citizen science and the use of mobile technologies, producing data and georeferenced alerts in real time for society, public health professionals, and conservation managers. From 2014 to 2020, the system recorded 4,909 non-human primates (NHP) in 23 states of Brazil. Joint action by the General Coordination for Surveillance of Arboviruses in the Ministry of Health (CGARB/DEIDT/SVS/MS), the SISS-Geo Platform, and state health departments in southern Brazil led to an increase of 1,141 % in the number of animals recorded since July 2016 with the spread of sylvatic yellow fever (YF). These sources reported the occurrence of 30 species, 14 of which are threatened with extinction, and 2,358 dead NHP, 75 % of which were *Alouatta guariba clamitans*. Despite the observed mortality, the limitations in records in areas distant from human presence and without collection of biological samples to confirm the cause of death prevent measurement of the real impact of YF on primates, which are vulnerable to a wide range of socio-environmental and climatic factors. The use of SISS-Geo by health professionals allowed more agile surveillance of epizootics and favored the application of various forecasting models for priority areas for NHP surveillance and human vaccination. Additionally, it provides information for various actions listed in the national plans for primate conservation, even though effective interventions against emerging infectious diseases are still not available for protecting NHP.

Keywords: Non-human primates, digital technology, epizootics, zoonoses, emerging infectious diseases, yellow fever.

Resumo

O Sistema de Informação em Saúde Silvestre - SISS-Geo foi desenvolvido nos preceitos da ciência cidadã e do uso de tecnologias móveis, produzindo dados de animais e alertas de anormalidades georreferenciados, em tempo real, para a sociedade e gestores de saúde e conservação da biodiversidade. De 2014 a 2020, o Sistema registrou 4,909 primatas não humanos (PNH) em 23 estados do Brasil. A ação conjunta da Coordenação Geral de Vigilância de Arboviroses do Ministério da Saúde (CGARB / DEIDT / SVS / MS), da Plataforma SISS-Geo e das Secretarias Estaduais de Saúde do Sul do Brasil levou ao aumento de 1,141 % no número de primatas não humanos (PNH) registrados desde julho de 2016, com a dispersão da febre amarela silvestre (FAS). Os dados apontam a ocorrência de 30 espécies de PNH, 14 das quais ameaçadas de extinção, e 2,358 animais mortos, 75 % dos quais *Alouatta guariba clamitans*. Apesar da mortalidade observada, as limitações de registros em áreas distantes da presença humana com a ausência de coleta de amostras biológicas para confirmação da causa da morte impedem a mensuração do real impacto da FAS nos primatas, vulneráveis a ampla gama de impactos socioambientais e climáticos. A utilização do SISS-Geo pelos profissionais de saúde permitiu a vigilância mais ágil das epizootias e favoreceu a aplicação de modelos de previsão e identificação de áreas de transmissão viral e prioritárias para vigilância de epizootias e vacinação humana. Além disso, forneceu informações para ações contidas nos planos nacionais para a conservação de primatas, embora intervenções eficazes contra doenças infecciosas emergentes ainda não estejam disponíveis para proteger os PNH.

Palavras-chave: Primatas não humanos, tecnologia digital, epizootias, zoonoses, doenças infecciosas emergentes, febre amarela.

Introduction

For hundreds of years, local populations have assisted researchers in fauna surveys (Miller-Rushing *et al.*, 2012). In recent decades, the inclusion of lay people or non-specialists in long-term studies for monitoring animals was established with the concept of citizen science and advances in digital technologies, and such participation became strategic for the acquisition of large amounts of data in a wide range of scientific areas (Pimm *et al.*, 2015; Smolinski *et al.*, 2017; Hecker *et al.*, 2018; Parsons *et al.*, 2018).

In Brazil, long-term species monitoring programs pose a challenge due to the large territory, socio-environmental differences, and budget constraints. Brazil has the highest primate diversity in the world, with 118 species, 41 of which are threatened (IUCN, 2020). Since the 1980s, important efforts for the conservation of critically endangered primate species have been made in the country by several national and international researchers and institutions. These efforts include the conservation programs of golden lion tamarin (*Leontopithecus rosalia)* (Kleiman *et al.*, 1986; Kierulff *et al.*, 2012) and Northern muriquis (*Brachyteles hypoxanthus*) (Strier and Mendes, 2011). More recently, National Center for Research and Conservation of Brazilian Primates (CPB) of the Chico Mendes Institute for Biodiversity Conservation (ICMBio) has implemented action plans for the conservation of primates in the Brazilian Amazon, Northeastern Brazil, and the Atlantic Forest, with the objective of expanding conservation actions, including the monitoring of more primate species. However, despite the high number of species threatened, long-term monitoring remains limited to relatively few species and areas.

Like other countries with extensive forested areas, Brazil faces the risk of emergence of zoonoses and the introduction of invasive exotic species that impact both humans and non-human primates (NHP) (Allen *et al.*, 2017; Estrada *et al.*, 2017, 2018). Examples include the Zika virus recently found in *Callithrix jacchus* in northeast Brazil (Terzian *et al.*, 2018) and the human herpesvirus in wild marmosets (Longa *et al.*, 2011). Although few studies have focused on the impact of yellow fever virus (YFV) on Platyrrhini species, primate population reduction temporally associated to YF has been historically reported in the Americas (Collias e Southwick, 1952; Rudran e Fernandez-Duque, 2003; Strier *et al.*, 2019), with the mortality in genus *Alouatta* most clearly documented (Possas *et al.*, 2018; Mares-Guia *et al.*, 2020). In South America, YFV has adapted to sylvatic mosquitoes (Culicidae) and to Platyrrhini primates. Considering the richness of NHP species in Brazil and their susceptibility to YFV (Vasconcelos, 2003; Chapman *et al.*, 2013; Marshall e Wich, 2016), it is fundamental to measure the impacts of YF on the various NHP species. The surveillance of zoonoses in primates requires systematic and accurate information on groups and species. The absence or inaccuracy of information leads to imprecision in risk analyses and limits the power of models for predicting and mitigating the occurrence of diseases and for planning conservation actions (Wolfe *et al.*, 1998; Chapman *et al.*, 2005; Gadelha *et al.*, 2018). The Brazilian government has relied on the monitoring of NHP epizootics as a strategy to identify risk areas and prioritize human vaccination since 1999 (Almeida *et al.*, 2014; Brasil, 2017a; Possas *et al.*, 2018), and from 2019 the SISS-Geo Platform was adopted as a georeferenced real-time monitoring tool by health professionals in an integrated surveillance effort of sylvatic zoonosis (Brasil, 2020a).

The Oswaldo Cruz Foundation (Fiocruz) is a health research institution of the Ministry of Health of Brazil with the mission of generating knowledge, research, solutions (vaccines, medicines, policies and good practices) and training professionals to prevent and control human health problems, including their relations with biodiversity, sustainability and socioeconomic conditions. According to its mission, Fiocruz understands the need for (and importance of) generating early alerts of health events in animals and humans with input from computational models for the identification of factors and areas at risk and vulnerable to the emergence of zoonoses. Fiocruz partnered with the National Laboratory for Scientific Computing (LNCC) to develop the Information System on Wildlife Health, or SISS-Geo (Chame *et al.*, 2019). With participation open to everyone, SISS-Geo integrates the concept of citizen science and the use of mobile digital technologies and algorithms that allow the generation of real-time alerts to stakeholders and decision makers to contribute with actions and policies in zoonosis surveillance and biodiversity conservation.

In this article we report the use of SISS-Geo in monitoring NHP in Brazil, especially in regard to the contributions through health surveillance and citizen science to support species conservation in Brazil. We highlight the use of SISS-Geo by the Southern states, the first region to adopt the tool as part of their epidemiological surveillance routine.

Methods

SISS-Geo is a free and collaborative platform available as smartphone apps and a Web system which receives records of animals from throughout the country. Records can be entered offline, with localization via GPS, and consist of two sets of information, those referring to the animal and to the recording location (Fig. 1) (Chame *et al.*, 2019). All records are audited and validated to the lowest possible taxonomic level. The current study drew on data referring to NHP recorded in SISS-Geo since the first record in June 2014, the year in which the system was launched. The annual period used is the monitoring period for YF in Brazil, ranging from July of one year to

June of the following year (Romano *et al.*, 2011; Brasil, 2019a), with peak occurrence (i.e., seasonal period) in the austral summer. For each annual monitoring period, we identified the total number of records of dead and live animals, by NHP family, genus, and species.

We compared the cumulative numbers and geographic distribution of the total records among three distinct periods (June 2014 to June 2016, July 2016 to June 2019, and July 2019 to June 2020), based on the increasing use of SISS-Geo for NHP surveillance. The period from 2014 to 2019 corresponds to the YFV dispersion from central Brazil to the southeastern region, heading south from 2019 to 2020. Efforts to sensitize the state health authorities and professionals to the use of SISS-Geo for YF surveillance were made during the Macro-regional Workshops on Integrated Yellow Fever Surveillance in Brazil and other technical events since 2017. The Southern Regional Plan for Yellow Fever Surveillance and Response, launched in 2019, was based on the use of SISS-Geo, and was successfully implemented as a pilot project by health professionals in the states of Paraná and Santa Catarina in epizootic surveillance. The Plan was established through cooperation among the Secretariat of Health Surveillance of the Brazilian Ministry of Health (SVS/MS), the respective State Health Secretariats, the São Paulo State Superintendency for Control of Endemics (SUCEN), and Fiocruz, and it involved training 100 health professionals in five meetings, thereby increasing data quality on surveillance of dead and sick NHP in southern Brazil. Using the automatic and real time alert tool in SISS-Geo, triggered whenever a dead or sick NHP is registered in SISS-Geo by any of its collaborators (health professionals or citizen scientists), an e-mail containing photographs, the precise location with links from Google Maps and the record data in SISS-Geo is sent to the federal, state, regional and municipal levels at the same time. This allows rapid and integrated action between different administrative levels with mobilization of teams to investigate the events, collect samples for laboratory diagnosis, and quickly vaccinate the human population in locations with reports of dead animals (Brasil, 2019a).

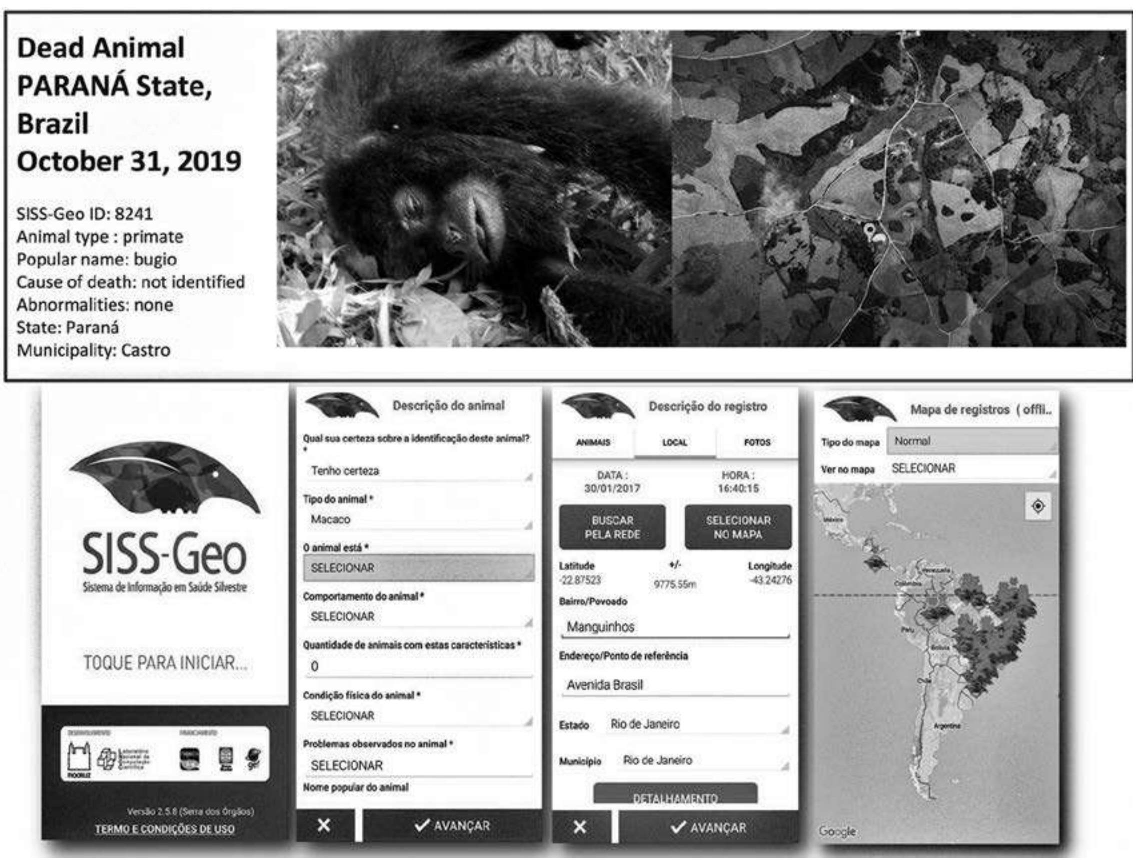

Figure 1. An example of a record in SISS-Geo and some screenshots of the app. More details in Chame *et al.*, 2019.

Results

SISS-Geo currently has 5,530 collaborators, out of which 526 (~10%) are either health professionals or health institutions. From this group, there are a total of 115 collaborators officially classified as: three health state secretariats, 38 state agencies, 73 municipality agencies and the federal coordination. The number of official accounts is going to grow considerably as SISS-Geo is expected to be embraced by other regions of the country as well.

NHP is the group with the most records (31 %) in the system. About 85 % of NHP records are submitted to the system without taxonomic identification and these are classified by internal auditors. Between June 8, 2014, when the first NHP was recorded in the system, and June 30, 2020, there were a total of 2,558 records of primates, with 4,909 animals observed in 23 states of Brazil. From these, 498 (10 %) NHP were unidentified by taxon and 928 (19 %) NHP were identified only at the genus level. In total 30 species were recorded, across 14 genera and five families. Fourteen of these species are threatened with extinction according to the International Union for Conservation of Nature (IUCN) (Table 1, Fig. 2). The records are concentrated in the states of Paraná (n = 978, 38 %) and Santa Catarina (n = 791, 31 %), reported by health professionals involved in the Southern Regional Plan for Yellow Fever Surveillance and Response, and in Rio de Janeiro (n = 555, 22 %), led by on-site activities by Fiocruz in communities around conservation areas. From June 2014 to June 2016, SISS-Geo recorded seven dead animals out of 75 NHP records. From July 2016 to June 2019, 53 % (362/685) referred to dead animals, while between July 2019 and June 2020, the proportion was 87 % (1567/1798) (Fig. 3). The most frequent genera recorded were *Alouatta* spp. (76 %, n = 1,778), of which 91 % (n = 1,623) were *Alouatta guariba clamitans*, and *Callithrix* spp. (10 %, n = 231). The increase of 1,141 % in the number of animals recorded in SISS-Geo since July 2016 resulted from the effort and sensitivity of the health surveillance system and the app use for YF, especially in southern Brazil (Fig. 4). As a result, the number of YF human cases within the more recent period (July 2019 to June 2020) (n = 19), when SISS-Geo was officially implemented for health services in southern Brazil, was lower compared to the period between mid-2014 to July 2019 when YF reached the southeastern region, causing the death of 2,259 people (Brasil, 2019b; 2020b).

Table 1. Non-human primates (NHP) recorded in SISS-Geo from March 2014 to June 2020. [CR] Critically Endangered, [EN] Endangered, [VU] Vulnerable, [NT] Near Threatened, [LC] Least Concern, [DD] Data Deficient, according to the IUCN (2020). Species organized according to Wilson e Reeder (2005). Taxonomy according to ITIS (2020).

Non-human primates (NHP)	**N records**	**N animals**	**N alive (% total animals)**	**N dead (% total animals)**
Callitrichidae				
Callithrix aurita (É. Geoffroy Saint-Hilaire, 1812) [EN]	4	8	6 (0.12)	2 (0.04)
Callithrix geoffroyi (Humboldt, 1812) [LC]	2	5	5 (0.10)	0
Callithrix jacchus (Linnaeus, 1758) [LC]	67	218	193 (3.93)	25 (0.51)
Callithrix kuhlii Coimbra-Filho, 1984 [VU]	1	1	0	1 (0.02)
Callithrix penicillata (É. Geoffroy Saint-Hilaire, 1812) [LC]	28	84	71 (1.45)	13 (0.26)
Callithrix hybrid	8	15	14 (0.29)	1 (0.02)
Callithrix sp. Erxleben, 1777	292	813	622 (12.67)	191 (3.89)
Leontopithecus caissara Lorini and Persson, 1989 [CR]	1	4	4 (0.08)	0
Leontopithecus chrysomelas (Kuhl, 1820) [EN]	4	11	11 (0.22)	0
Leontopithecus rosalia (Linnaeus, 1766) [EN]	16	79	76 (1.55)	3 (0.06)
Mico humeralifer (É. Geoffroy Saint-Hilaire, 1812) [DD]	16	35	34 (0.69)	1 (0.02)
Mico cf *melanurus* (É. Geoffroy Saint-Hilaire, 1812) [LC]	1	1	0	1 (0.02)
Saguinus bicolor (Spix, 1823) [CR]	2	2	1 (0.02)	1 (0.02)
Callitrichidae gen. sp.	23	45	27 (0.55)	18 (0.37)
Cebidae				
Cebus albifrons (Humboldt, 1812) [LC]	3	3	2 (0.04)	1 (0.02)
Sapajus apella (Linnaeus, 1758) [LC]	3	3	3 (0.06)	0
Sapajus cf. *flavius* (Schreber, 1774) [EN]	1	1	1 (0.02)	0
Sapajus libidinosus (Spix, 1823) [NT]	23	202	202 (4.11)	0
Sapajus nigritus (Goldfuss, 1809) [NT]	182	708	643 (13.1)	65 (1.32)
Sapajus robustus (Kuhl, 1820) [EN]	1	15	15 (0.31)	0
Sapajus sp. Kerr, 1792	20	72	63 (1.28)	9 (0.18)
Saimiri sp. Voigt in G. Cuvier, 1830	2	11	11 (0.22)	0

Continued on page 84

Table 1. *Continued from page 83*

Non-human primates (NHP)	N records	N animals	N alive (% total animals)	N dead (% total animals)
Cebidae gen. sp.	1	1	0	1 (0.02)
Aotidae				
Aotus azarae infulatus (Kuhl, 1820) [LC]	1	1	0	1 (0.02)
Pitheciidae				
Callicebus nigrifrons (Spix, 1823) [NT]	5	5	3 (0.06)	2 (0.04)
Callicebus sp. Thomas, 1903	3	3	0	3 (0.06)
Chiropotes albinasus (I. Geoffroy Saint-Hilaire and Deville, 1848) [EN]	1	3	3 (0.06)	0
Chiropotes satanas (Hoffmannsegg, 1807) [CR]	1	1	0	1 (0.02)
Pithecia irrorata Gray, 1841 [DD]	1	1	0	1 (0.02)
Plecturocebus hoffmannsi (Thomas, 1908) [LC]	4	4	4 (0.08)	0
Atelidae				
Alouatta belzebul (Linnaeus, 1766) [VU]	1	1	1 (0.02)	0
Alouatta caraya (Humboldt, 1812) [NT]	9	16	13 (0.26)	3 (0.06)
Alouatta guariba (Humboldt, 1812) [VU]	1	1	1 (0.02)	0
Alouatta guariba clamitans Cabrera, 1940 [VU]	1522	1921	156 (3.18)	1765 (35.95)
Alouatta nigerrima Lönnberg, 1940 [LC]	1	1	1 (0.02)	0
Alouatta ululata Elliot, 1911 [EN]	23	63	62 (1.26)	1 (0.02)
Alouatta sp. Lacépède, 1799	8	13	4 (0.08)	9 (0.18)
Ateles belzebuth É. Geoffroy Saint-Hilaire, 1806 [EN]	1	1	0	1 (0.02)
Ateles sp. É. Geoffroy Saint-Hilaire, 1806	1	1	1 (0.02)	0
Brachyteles arachnoides (É. Geoffroy Saint-Hilaire, 1806) [CR]	6	38	37 (0.75)	1 (0.02)
Unidentified NHP	268	498	261 (5.32)	237 (4.83)
Total	**2558**	**4909**	**2551* (51.97)**	**2358 (48.03)**

*65 of these reported as sick

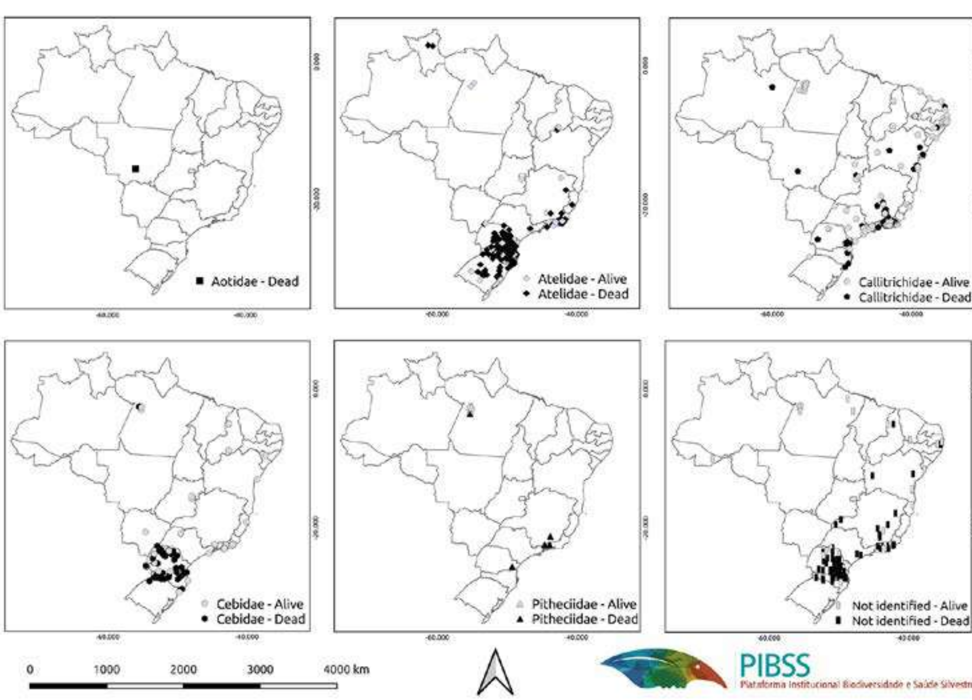

Figure 2. Records of non-human primates (NHP) in SISS-Geo by family (June 2014 - June 2020).

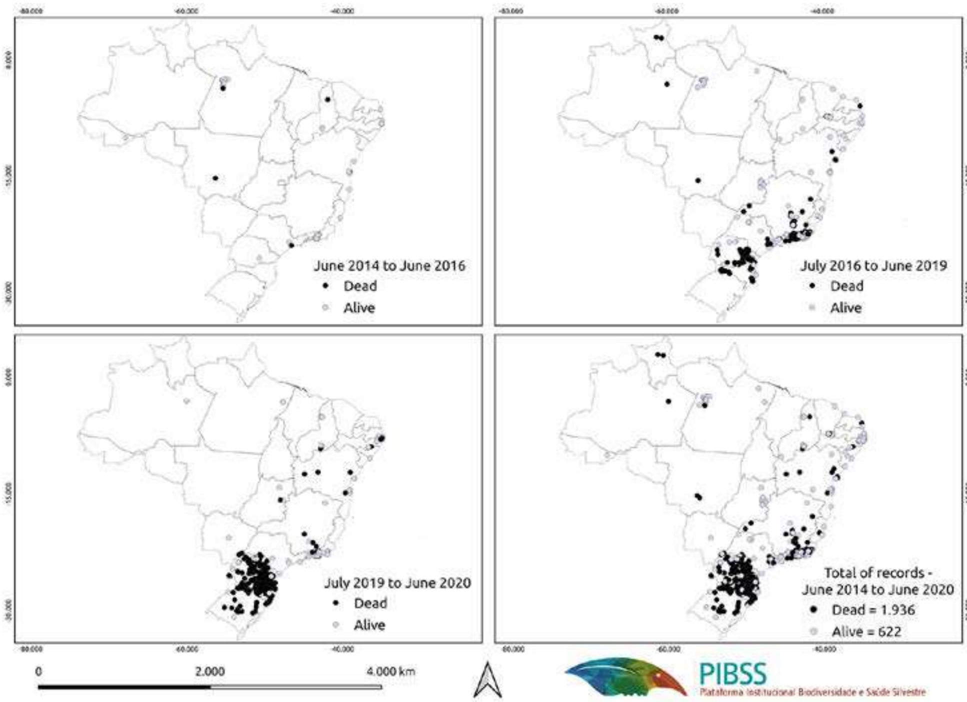

Figure 3. Records of non-human primates (NHP) in SISS-Geo. From left to right: records between 2014 (when SISS-Geo was launched) and June 2016; between July 2016 and June 2019 (when YF events took place in Southeastern region); from July 2019 to June 2020 (with the increase of records in Southern Brazil). The last image shows the total of records between June 2014 - June 2020.

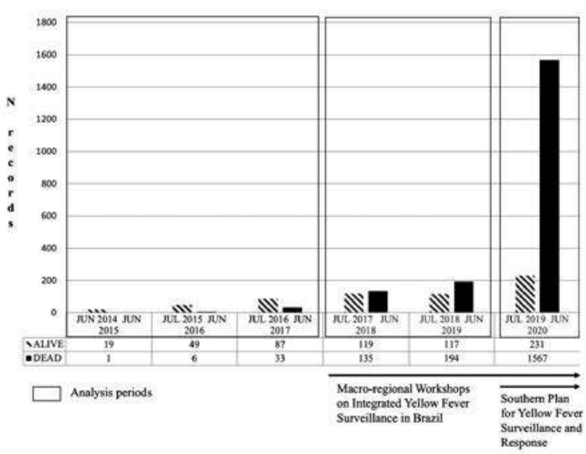

Figure 4. SISS-Geo records of live and dead non-human primates throughout the study periods and the effect of health surveillance initiatives in Brazil.

Discussion

Although the Ministry of Health's official system for reporting YF epizootics is the best overall database available thus far on NHP deaths from YF, reporting is known to be underestimated and biased toward information on dead animals in locations with human activities and by the increased surveillance impelled in areas with human casualties. From July 2014 to June 2020, the Ministry of Health recorded 22,495 dead NHP, of which only 1,827 had a confirmed diagnosis of YF. In Southern Brazil alone, 1,932 events were recorded involving the death of NHP, with 386 laboratory-confirmed epizootics (Brasil, 2019b; 2020b), most of them in the more recent period (2019/2020, 77 %) (Brasil, 2020b). Compared to the 2018/2019 monitoring period, these reports in SISS-Geo in 2019/2020 reduced by 83 % and 77 % the proportions of epizootics without genus/species identification and without geographic coordinates, respectively, in the national surveillance system database (info provided by CGARB/DEIDT/SVS/MS). The availability of information in real time, including images for taxonomic identification and geographic coordinates, in addition to epidemiological information (dead, alive or sick; health abnormalities; sex and age), now allows primatologists and epidemiologists to monitor NHP populations and to improve public health and conservation policies.

Yellow fever has occurred for centuries in the Americas and still poses challenges, since the intervals between outbreaks are apparently irregular and correlated with the ecology of NHP, mosquito vectors, and the virus itself, and with climatic and environmental drivers (Hamrick *et al.*, 2017; Hamlet *et al.*, 2021). There are few studies that have identified the presence of YFV in NHP, and they depend on various factors (Hollzmann *et al.*, 2010; Almeida *et al.*, 2014; Bicca-Marques *et al.*, 2017; Fernandes *et al.*, 2017), including the likelihood of finding dead or sick NHP; the local population's capacity to report information to health or environmental authorities; the fortunate presence of researchers and professionals associated with environmental actions in the area and referral to government systems that perform the diagnosis; the technical capacity of health services for proper investigation and collection of biological samples, necropsy procedures and collection of carcasses; and also laboratory capacity and the necessary equipment for logistics and transportation to the laboratories in the national reference network.

In certain situations, there is also a lack of infrastructure and mobilization of trained personnel to capture live animals in epidemiological and environmental impact studies, including animals in affected areas and/or those with increased relevance for health and conservation. Factors such as the short time window to collect viable viruses for diagnosis from carcasses and the differences in disease manifestation between NHP species (Vasconcelos, 2003) require planning complex strategies that generally require more resources. Timely information and georeferenced location play a crucial role for health surveillance and NHP conservation, since information about a dead or sick NHP triggers the prevention and control measures and makes possible the measurement of the number of individuals, and species affected by the virus, the definition of risk areas, and the evaluation of vulnerability, and favorability to transmission. An emblematic situation is the lack of data from Amazonia, where records of epizootics are scarce, despite NHP deaths witnessed by local residents, or reported by health professionals when YF human cases are detected. This fact may reflect low adherence by health services and professionals to recording NHP, both in SISS-Geo and in Ministry of Health records, since the impact of YF on the human population is low, given that the Amazonian population has been widely vaccinated for decades.

In this scenario, the number of dead animals recorded during YF outbreaks in Brazil is relevant to NHP species conservation, especially due to co-occurring extinction risk factors such as: increased fragmentation and habitat loss; population isolation; reduction in the number of individuals and species; and impacts from climate change (Wolfe *et al.*, 1998; Chapman *et al.*, 2005). Although studies refer to loss of individuals due to YF spatially and temporally associated to the seasonality of the transmission, few were supported by laboratory confirmation, and there are few data from on-going active research on free-living NHP in regards to the virus, making the identification of factors that favor its emergence even more difficult to ascertain (Moreno *et al.*, 2013; Almeida *et al.*, 2014; Bicca-Marques *et al.*, 2017; Fernandes *et al.*, 2017; Dietz *et al.*, 2019; Strier *et al.*, 2019).

Alouatta is known to be the genus most heavily impacted by the YFV, with entire groups decimated by the disease (Holzmann *et al.*, 2010; Almeida *et al.*, 2014). *Alouatta guariba clamitans* has been especially impacted, as a Vulnerable species (global-scope classification criterion (VU) - A4ce) (IUCN, 2012, 2020) for which we recommend updating the assessment of its conservation status due to its high mortality in the ongoing outbreaks (Brasil, 2021). Since July 2016, NHP from genera *Callithrix* (n=232, 10 % of the dead NHP during the period) and *Sapajus* (n=74, 3 %) were affected with dead individuals in sympatry with species at elevated risk for extinction such as *Leontopithecus* spp. and *Brachyteles* spp. This situation emphasizes the need to expand studies on viral circulation in *C. jacchus* and hybrids in their extended, invasive range, since their wide distribution and ecological plasticity may be significant in maintaining the virus (Abreu *et al.*, 2019; Mares-Guia *et al.*, 2020). Records of other genera and species are sporadic, we see the need for increasing participation of society to gather more data and to monitor the impact of YF to them.

The Southern Regional Plan for Yellow Fever, with the incorporation of SISS-Geo, allowed for confirmation of ecological corridors through which YFV has spread, based on the methodology proposed by the São Paulo State Superintendency for the Control of Endemics (SUCEN) (Fioravanti, 2018a, 2018b). SUCEN projected the probable functional corridors of virus dispersion between different forest fragments, determining the direction and velocity of the virus' spread, to help in designing and applying a human vaccination strategy with greater efficacy in the region (Brasil, 2019a). The methodology initially used georeferenced data with laboratory diagnosis on primates infected with YFV in the state of São Paulo obtained during the most recent outbreaks (2016-2019) in order to identify the spatial and temporal dispersion pattern of the virus between the forest fragments. The study shows the pattern of the virus' north-to-south shift at a mean daily velocity of approximately 2.7 km in hot months and approximately 0.5 km in cool months (Fioravanti, 2018a, 2018b). This allowed forecasting the dates and probable entry sites of the virus into other regions of the state of São Paulo, and these estimates determined the prioritization for surveillance and immunization activities in the identified areas (Fioravanti, 2018b). The data from the SISS-Geo platform provided key support for this study, as records (georeferenced, in real time, and validated by specialists) indicated the probable infection of NHP in other states of Brazil such as Paraná and Santa Catarina, thus allowing the expansion and updating of YF transmission corridors.

Conclusions

We emphasize the need for and benefits of continuous monitoring through the efforts of health surveillance services, not only useful for the protection of human life, but also to help with conservation actions towards maintaining NHP biodiversity. Among them, SISS-Geo provides: (i) data on the distribution of species, including endangered species, but especially for abundant species, which are rarely considered in zoonotic studies, but that can play an important role in the maintenance of pathogens of wide plasticity across hosts; (ii) records of living populations, especially those that may be in areas of silence for the occurrence of YF and other diseases; (iii) data on dead and sick animals which can help assess the risk of species extinction by YF; (iv) the occurrence of species groups in relation to environmental impacts, such as fragmentation and isolation and advances in habitat modifications, helping the maintenance and demarcation of new conservation areas; and (v) information that helps environmental education programs and society's engagement in participatory monitoring and conservation of NHP. Recent discussions evaluate the feasibility of the protection of threatened and captive animals through vaccination, and the monitoring of epizootics in NHP can be helpful to alert people about the transmission risk for specific groups and areas. These actions and effects can be significantly leveraged by integration of health, environmental and academic sectors and participation by citizen scientists, using digital tools and smartphones to increase the number of records and power to detect epidemiologically and environmentally relevant events. The high number of records of *Alouatta guariba clamitans* deaths highlights the importance of reassessing the status of the species in southern Brazil. The real-time georeferenced data allowed not only agility in collecting biological samples for confirmation of YF, but also helped to estimate YF transmission corridors and priority areas for intensification of surveillance and immunization actions, preventing YF outbreaks and human deaths in affected areas. As a result, the number of YF human cases in southern Brazil was significantly lower compared to the southeast region in 2019/2020 monitoring period. Inter-sector collaboration also resulted in integrated training for health and environmental managers and teams, including professionals working in conservation units. The basic SISS-Geo data are open and available at www.biodiversidade.ciss.fiocruz.br, and the complete database is available for institutional use in health, environment, and research.

Acknowledgements

Funding was provided by Oswaldo Cruz Foundation and Health Surveillance Secretariat/Brazilian Ministry of Health.

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