Journal of Medical Primatology

WILEY

ORIGINAL ARTICLE OPEN ACCESS

Assessment of the Risks of Zoonotic Infection at the Primatology Centre of the Interdisciplinary Medical Research Centre of Franceville in Gabon

Nzue Nguema Jean[1,2] | Otsaghe Ekore Désiré[1] | Dibakou Serge Ely[1] | Boundenga Larson[1,3] | Tsoumbou Thiérry-Audrey[1] | Moussadji Kinga Ivan Cyr[1] | Okomo Nguema Yasmine[1] | Mombo Landry Erik[2] | Pontier Dominique[4,5] | Ngoubangoye Barthélemy[1,3,4,5]

[1]Centre Interdisciplinaire de Recherches Médicales de Franceville (CIRMF), Franceville, Gabon | [2]Département de Biologie, Faculté Des Sciences, Université Des Sciences et Technique de Masuku (USTM), Franceville, Gabon | [3]Department of Anthropology, Durham University, Durham, UK | [4]CNRS, Laboratoire de Biométrie et Biologie Evolutive UMR5558, Université de Lyon 1, Villeurbanne, France | [5]LabEx ECOFECT, Eco-Evolutionary Dynamics of Infectious Diseases, University of Lyon, Lyon, France

Correspondence: Nzue Nguema Jean (nguemanzue14@gmail.com) | Ngoubangoye Barthélemy (genistha@hotmail.com)

Received: 6 January 2024 | **Revised:** 16 September 2024 | **Accepted:** 18 September 2024

Funding: This study was supported by Centre of the Interdisciplinary Medical Research Centre of Franceville (CIRMF, Gabon) and the LABEX ECOFECT (ANR-11-LABX-0048) of Université de Lyon, within the programme 'Investissements d'Avenir' (ANR-11-IDEX-0007) operated by the French National Research Agency (ANR) and by the RESPOND programme of the Université de Lyon (UDL).

Keywords: biosecurity | non-human primates | zoonoses | zoonotic risk

ABSTRACT

Background: Non-human primate (NHPs) conservation sites could be sites of exchange of pathogens involved in infectious diseases. It is important to assess the potential risks associated with this type of structure. The objective of this study was to carry out a risk assessment of the Primatology Centre housed in the Interdisciplinary Centre for Medical Research of Franceville (CIRMF).

Methods: A questionnaire was administered to the centre's staff to assess the risk associated with each workstation, followed by a review of the various pathogens identified in NHPs. The data were analysed using two diagrams: the Kiviat diagram and the Pareto diagram.

Results: Based on our results, a variety of pathogens such as viruses, bacteria and parasites, potentially transmissible to humans, were described in the NHPs at the Primatology Centre of CIRMF. The position most exposed to zoonotic risks was that of animal handlers.

Conclusion: The Primatology Centre of CIRMF is a potential transfer site for the transfer of zoonotic agents. To avoid the risk of parasite exchange between staff and animals, the implementation of biosecurity measures is essential.

1 | Introduction

The presence and operation of conservation sites, parks, zoos and sanctuaries that house monkeys lead to increased interactions and contact between humans and non-human primates (NHPs). These interactions may pose a zoonotic risk [1–3]. Currently, several primate species have been identified as potential reservoirs or intermediaries for pathogens that can be transmitted to humans [3]. Activities such as tourism, veterinary care and the habituation of NHPs are factors that contribute to exposure to certain pathogens [4]. This issue is particularly important for primatology centres, parks and zoos where direct interactions are numerous and frequent. Consequently, risk management in these specialised sites must take into account the risk of disease transmission between humans and primates [5].

The Interdisciplinary Centre for Medical Research of Franceville (CIRMF) is a research centre located in the south-east of the Haut-Ogooué province in Gabon. The centre conducts various studies on infectious diseases such as tuberculosis, syphilis, monkeypox virus and HIV. Many other studies focus on pathogen reservoirs (NHPs, bats, rodents, etc.) and transmission. The CIRMF also houses a Primatology Centre established in 1989 to help conduct studies on zoonotic pathogens and conservation.

The objective of this study was to conduct a biological risk assessment at the Primatology Centre of CIRMF and to make recommendations on potential biosecurity measures. The study aims to improve existing safety protocols and implement strategies to prevent disease transmission and ensure the general well-being of resident animals and staff working at the Primatology Centre of CIRMF.

2 | Materials and Methods

2.1 | Study Area

Since its creation in 1989, the Primatology Centre of CIRMF has served as an experimental platform. Biological protocols for medical research used primate species as experimental models. Since 2012, there has been no animal experimentation. The Primatology Centre of CIRMF has several facilities, including cage for gorillas, chimpanzees and other primate species. Additionally, there is a 4-ha fenced forest where around 200 non-human primates live (in enclosures), including mandrills (*Mandrillus sphynx*) and sun-tailed monkeys (*Cercopithecus solatus*). Although invasive animal experimentation ceased in 2012, these animals are still housed at the Primatology Centre of CIRMF for non-invasive studies (behavioural studies, parasitology, ecology, etc.). At the end of the experimental protocols, the old monkeys, no longer able to compete for food with other monkeys, were housed in dedicated buildings (retirement home). The centre periodically receives and houses primates seized by Gabon's Ministry of Water and Forests as part of health quarantines. Figure 1 shows an aerial view of the Primatology Centre of CIRMF.

Standard operating protocols aligned with the OSHAS (Occupational Health and Safety Assessment Series) 18001 framework have been implemented at the facility in which the staff consists of animal handlers, nurses, secretaries and veterinarians. Staff are responsible for the daily maintenance of the premises and animals in accordance with these standard protocols, under the direction of the unit heads. Individual experiments involving primates as experimental models also comply with standard operating procedures (SOPs) and are subject to prior approval by a national ethics committee. This committee is responsible for judging the appropriateness and scientific contribution of the desired study [6].

2.2 | Data Collection for Health and Safety Measures

Data collection for the infection risk assessment was based on health and safety measures, zoonosis identification and potential exposure. The assessment covered a number of the centre's activities (Figures 2 and 3), in accordance with the British Standard OHSAS 18001. The identification of zoonoses was based on two points: diseases detected in animals that could infect humans and vice versa. Two interviews were conducted, one with the

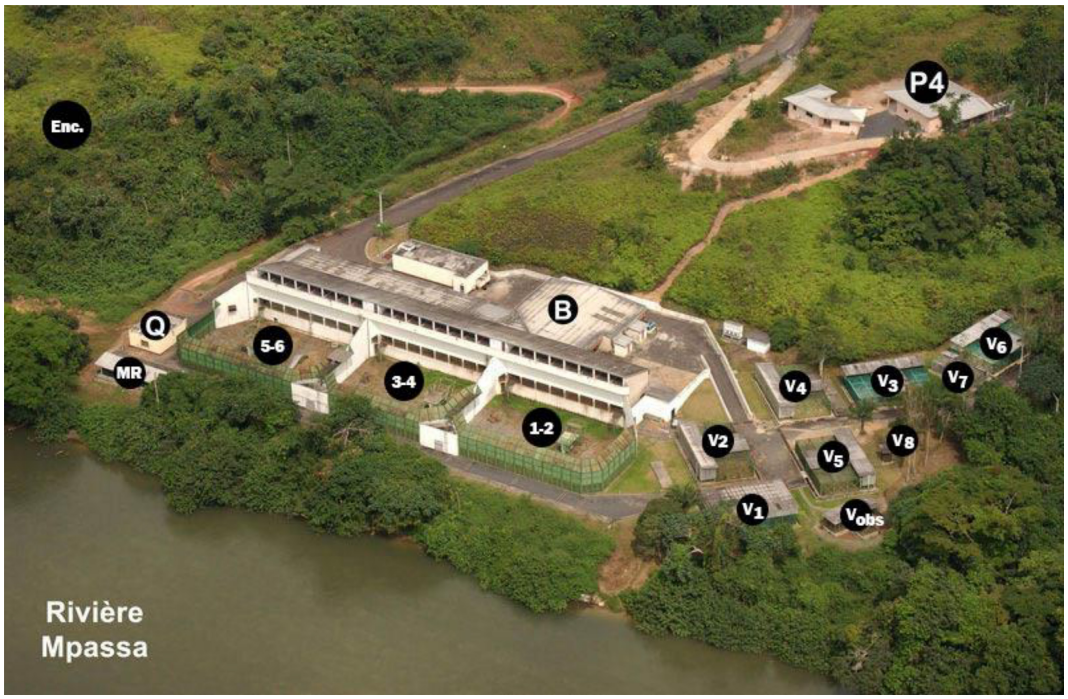

FIGURE 1 | Aerial view of the CIRMF Primatology Centre site. (1–6) Chimpanzee entertainment area; (V1–V8 and Vobs) cages of small monkeys; (Enc.) enclosures; (Q) quarantine building; (P4) high security laboratory; (B) premises of the Primatology Centre (treatment room, offices and kitchen); (MR) retirement home for old monkeys.

veterinarian at the Primatology Centre of CIRMF to identify diseases detected in animals and the other with CIRMF's occupational physician, who manages staff health without specifying the identity of the people concerned (due to medical confidentiality). Data on the clinical signs of diseases in humans were also provided by bibliographic research. Zoonotic risk points were identified by monitoring the centre's staff in their daily work. Tables 1 and 2 summarise the data from the interviews with physician and doctor and the literature review. This monitoring took place over a 2-month period from January 8, 2022 to March 8, 2022. The identification of activities was based on the a priori risk analysis method consisting of the following:

1. identifying hazards,
2. analysing the exposure process,
3. estimating risks,
4. classifying risks according to a risk score in order to prioritise actions.

2.3 | Reviewing Potential Pathogen Risks at the Primatology Centre of CIRMF

The PubMed database and Google Scholar were used to search for all publications related to the Primatology Centre of CIRMF.

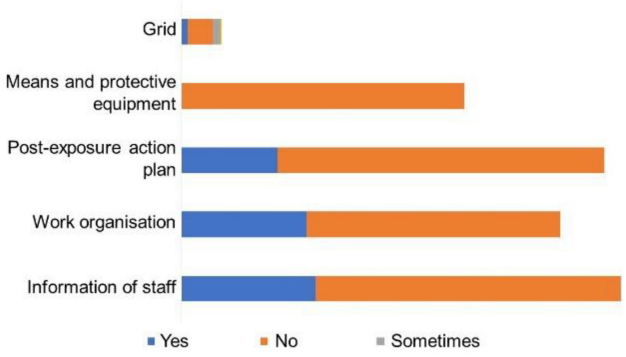

FIGURE 2 | COP health and safety assessment.

The following search terms were used to find the research articles: "Centre of Primatology + CIRMF", "Centre de Primatologie + CIRMF", "Search by specific author", "Centre of Primatology + Each pathogen family (Bacteria, Viruses, Parasites)". The articles selected for this study were those which met the following conditions: they had been carried out at the Primatology Centre of CIRMF (CDP) and had demonstrated circulating zoonotic infections in NHPs. When a study was not carried out at the CDP, it was automatically removed from the study. Other information was obtained from work carried out at the CDP but not yet published.

2.4 | Analysis

Relevant extracted data were then organised by pathogen name, pathogen type, potential spillover, apes affected and human symptoms.

2.5 | Kiviat Diagram and Pareto Chart

The data were analysed using two diagrams: the Kiviat diagram and the Pareto diagram. The Kiviat diagram is used to compare the exposure levels of different occupations to CDP. The principle is to represent and compare data on a two-dimensional plane. Each axis, starting from the same point, represents a quantified characteristic. This type of diagram facilitates the analysis and comparison of several sets of data [47]. The Pareto chart is used to identify 20% of the priority causes that will enable 80% of the risks to be eliminated. The principle is based on the analysis of data divided into categories in order to identify the root causes of a problem [48].

3 | Results

3.1 | Responsibilities and Level of Education of CDP Employees

A total of 27 employees were present at CDP at the time of our study. Twenty-one (78%) employees were male. The majority (62.96%) of the staff were employed as animal handlers and

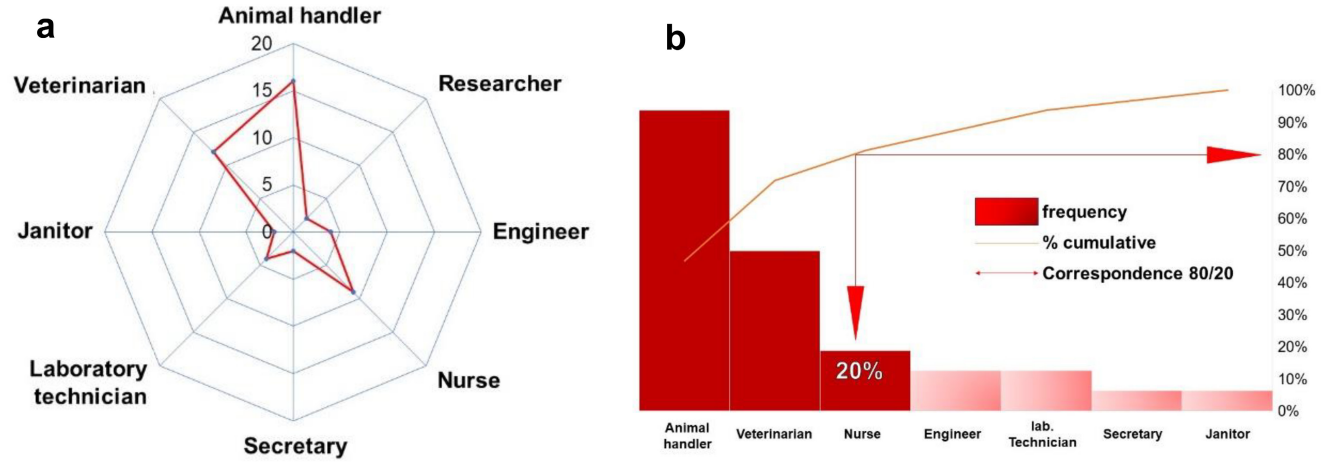

FIGURE 3 | The most exposed employees to potential zoonotic risks at the Primatology Centre of CIRMF. (a) Kiviat diagram highlighting the most exposed professions, (b) Pareto chart showing the priority items for risk treatment.

TABLE 1 | Diversity of potential zoonotic pathogens characterised in NHPs at the CDP.

Pathogens name	Pathogens type	Primates	Transmission mode (vectors)	References
Staphylococcus aureus	Bacteria	NHPs	Bite, direct contact	[7, 8]
Bartonella quintana	Bacteria	*C. cephus*	Vector born (lice)	[9]
Rickettsia felis	Bacteria	*C. cephus*	Vector born (fleas)	
Acinetobacter spp.	Bacteria	*P. t. troglodytes*, *M. sphinx*, *Macaca* sp.	Faecal–oral	N. Barthélemy and N. N. Jean, unpublished data
Yersinia spp.	Bacteria	*P. t. troglodytes*, *M. sphinx*, *Macaca* sp.	Faecal–oral	N. Barthélemy and N. N. Jean, unpublished data
Escherichia coli	Bacteria	*P. t. troglodytes*, *M. sphinx*, *Macaca* sp.	Direct or indirect contact, faecal–oral	N. Barthélemy and N. N. Jean, unpublished data
Klebsiella spp.	Bacteria	*P. t. troglodytes*, *M. sphinx*, *Macaca* sp.	Aerosols, body fluids	N. Barthélemy and N. N. Jean, unpublished data
Chlamydia spp.	Bacteria	*G. g. gorilla*, *P. t. troglodytes*	Direct or indirect contact	[10]
Pseudomonas spp.	Bacteria	*P. t. troglodytes*, *M. sphinx*, *Macaca* sp.	Faecal–oral	N. Barthélemy and N. N. Jean, unpublished data
Toxoplasma gondii	Parasite	*P. t. troglodytes*, *M. sphinx*, *G. gorilla*, *C. solatus*	Faecal–oral	[11, 12]
Plasmodium spp.	Parasite	*P. t. troglodytes*, *M. sphinx*, *C. torquatus*, *C. cephus*	Vector-borne (mosquitoes)	[13, 14]
Oesophagostomum spp.	Parasite	*P. t. troglodytes*	Soil	[15]
Trichuris spp.	Parasite	*A. solatus*	Soil	[16]
Hepatocystis spp.	Parasite	*M. sphinx*, *C. torquatus*, *C. cephus*	Soil	[13, 14]
Strongyloides spp.	Parasite	*A. solatus*, *M. sphinx*	Soil	[14, 17]
Ancylostoma spp.	Parasite	*M. sphinx*	Soil	[14]
Trichostrongylus spp.	Parasite	*M. sphinx*	Soil	
Balantioides coli	Parasite	*M. sphinx*	Soil	
Mammomonogamus spp.	Parasite	*M. sphinx*	Soil or indirect contact	[14, 18]
Pedicinus spp.	Parasite	*M. sphinx*	Faecal–oral	[14]
E. histolytica, *E. dispar*, *E. histolytica/dispar*	Parasite	*M. sphinx*, *A. solatus*	Faecal–oral, direct contact	[18]

(Continues)

TABLE 1 | (Continued)

Pathogens name	Pathogens type	Primates	Transmission mode (vectors)	References
Endolimax nana	Parasite	*M. sphinx*	Faecal–oral, direct contact	[18]
Simian foamy virus (SFV)	Virus	*M. sphinx*, *P. t. troglodytes*, *G. g. gorilla*, *Macaca* sp., *C. solatus*,	Bite, scratch, body fluid contact, sharp injuries	[6]
Simian immunodeficiency virus (SIV)	Virus	*P. t. troglodytes*, *M. sphinx*, *C. solatus*, *C. pygerythrus*	Body fluid contact and bite	[19–24]
Simian T-cell leukaemia virus (STLV-1)	Virus	*M. sphinx*, *M. fascicularis*, *C. pygerythrus*, *P. t. troglodytes*, *G. g. gorilla*	Unknown	[20, 23]
Hepatitis B virus	Virus	*P. t. troglodytes*, *G. g. gorilla*	Body fluid contact	[25]
SARS-COV2	Virus	*PNH*	Aerosol	[26]

most of the participants reported having completed a few years of education (Table 3). The results of the daily monitoring of employees at CDP indicate that among the centre's staff who are in contact with these animals, the animal handlers who care for them on a daily basis have a significantly higher frequency of contact than the other occupational groups (Table 3).

3.2 | Evaluation of Health and Security Measures

Daily monitoring of employees at CDP revealed that the majority of staff (animal handlers) were in regular contact with the animals. Figure 2 shows the current state of health and security measures at CDP. In most of the items assessed, there was a general failure to comply with health and security measures. The lack of resources and equipment and weaknesses in the areas of the OHSAS grid, the post-exposure action plan, work organisation and staff information were noted in our study.

3.3 | Potential Zoonotic Pathogens

By following our method of searching for articles on the various selected search engines and by applying our criteria for inclusion and estimation of the quality of the articles, we obtained 43 articles (including 5 unpublished works), of which only 28 were selected for inclusion in our analysis and allowed us to draw up Table 1.

Our literature search revealed a range of zoonotic pathogens, including 42.85% viruses, 10.71% bacteria and 46.44% parasites. The most common mode of transmission was the fecal-oral mode of transmission, but there are also some vector-borne diseases (Table 1).

Of the 21 pathogens or groups of pathogens identified as causing symptoms in humans, 60% (or 14 pathogens or groups of pathogens) affect the gastrointestinal tract, while the remaining pathogens or groups of pathogens affect the respiratory tract (10%), the urinary tract (10%) or cause general diseases (20%). Depending on the nature of the pathogen, different symptoms can be distinguished. These include general symptoms such as fever, diarrhoea and vomiting (e.g., symptoms associated with *Plasmodium* spp. and *Ancylostoma* spp.) and specific symptoms such as pneumonia, blood infection, urinary tract infection or endocarditis (e.g., symptoms associated with *Bartonella quintana* and *Acinetobacter* spp.). Additionally, there are pathogens that do not cause any of the above signs in humans (e.g., Simian immunodeficiency virus (SIV), Simian foamy virus (SFV) and Simian T-cell leukaemia virus (STLV-1)). Prevention of transmission of most of these pathogens can be avoided by using PPE, including masks and gloves when handling animals directly, but also when cleaning their facilities and maintaining good hygiene practices. Other strategies may also target the vectors of some of these pathogens.

3.4 | Highlighting the Most Exposed Employees

The Kiviat diagram (Figure 3a) reveals that the employees most exposed to zoonotic risks at the CDP were the animal handlers. According to this diagram, three professions are the most exposed among the eight represented: animal handlers,

TABLE 2 | Potential clinical manifestations linked to the presence of pathogens reported in NHPs at the CDP and their associated preventive methods.

Pathogens	Clinical symptoms in human	Target for prevention	References
Staphylococcus aureus	Pneumonia, bacteraemia, skin and soft tissue infections, Staphylococcal toxic shock syndrome	Personal protective equipment, minimise contact	[27]
Bartonella quintana	Fever, bacteraemia and endocarditis, trench lice-associated diseases, chronic bacteraemia	Vector-control measure	[28]
Rickettsia felis	Fever, headache, rash, gastrointestinal symptoms	Vector-control measure	[29]
Acinetobacter spp.	Pneumonia, bloodstream, urinary tract infection	Use PPE when handling primates and follow proper sanitation practices	[30]
Yersinia spp.	Fever, abdominal pain, diarrhoea	Maintain and enforce proper hygiene measures	[31]
Escherichia coli	Urinary tract infection, diarrhoea	Maintain good hygiene practices	[32]
Klebsiella spp.	Cough, fever	Maintain good hygiene practices	[33]
Chlamydia spp.	Pain when urinating, unusual vaginal discharge, pain in the belly or pelvis... (Female); pain when urinating, white, cloudy or watery discharge from the tip of the penis, pain in the testicles... (male)	Maintain good hygiene practices	[34]
Toxoplasma gondii	Muscle aches and pains, headache, fever, inflammation	Maintain and enforce proper hygiene measures	[35]
Pseudomonas spp.	Headache, diarrhoea, nausea, vomiting, cough, fever, difficulty breathing, pus, red eyes, swelling, sudden vision loss	Good hygiene practices to avoid infections	[36]
P. reichenowi, *P. gaboni*, *P. praefalciparum*, *P. adleri*, *P. falciparum*, *P. vivax-like*, *P. malariae-like*	Fever, chills, sweats, headaches, nausea and vomiting, body aches, general malaise	Elimination of vectors	[37, 38]
Oesophagostomum spp.	Mimicking an appendicitis, fever, vomiting, anorexia diarrhoea	Good hygiene practices to avoid infections	[39, 40]
Trichuris spp.	Gastroenteritis	Good hygiene practices to avoid infections	[39, 40]
Strongyloides spp.	Persistent diarrhoea, nausea and vomiting, weight loss, cough, fever, skin rash	Good hygiene practices to avoid infections	[39, 40]
Ancylostoma spp.	Nausea and vomiting, diarrhoea or constipation, loss of appetite, weight loss, anaemia, nutritional deficiencies	Maintain good hygiene practices	[39, 40]
Trichostrongylus spp.	Diarrhoea, abdominal pain and cramps, nausea and vomiting, weight loss	Maintain good hygiene practices	[39, 40]
Balantioides coli	Diarrhoea, abdominal pain and cramps, nausea and vomiting, weight loss	Maintain good hygiene practices	[39, 40]
Mammomonogamus spp.	Coughing in fits and starts, dry, persistent, unaffected by symptomatic treatment and antibiotic therapy	Good hygiene practices to avoid infections (The reproductive cycle is only very imperfectly known)	[41, 42]

(Continues)

TABLE 2 | (Continued)

Pathogens	Clinical symptoms in human	Target for prevention	References
Pedicinus spp.	Pruritus associated with scratching; lesions neck, thorax, waist and ankles	Inspections and treatments	[43]
E. histolytica, *E. dispar*, *E. histolytica/dispar*	Diarrhoea, which may be watery or contain blood and mucus, abdominal pain and cramping and fatigue	Maintain good hygiene practices	[44]
Endolimax nana	Gastointestianl infection such as diarrhoea, abdominal discomfort or flatulence	Maintain good hygiene practices	[39, 40]
Simian foamy virus (SFV)	No known clinical symptoms	Personal protective equipment, employ physical barriers	[45]
Simian immunodeficiency virus (SIV)	No known clinical symptoms	Personal protective equipment, employ physical barriers	[45]
Simian T-cell leukaemia virus (STLV-1)	No known clinical symptoms	Personal protective equipment, employ physical barriers	[45]
Hepatitis B virus	Loss of appetite and nausea, intermittent pain in the abdomen, severe tiredness, flu-like illness (with fever, headache and muscle aches), joint pain	Personal protective equipment, staff vaccination	[46]

TABLE 3 | Characterisation of the study population at the CIRMF's Primatology Centre.

Workstation	Number	Frequency (%)
Animal handler	17	62.96
Nurse	2	7.4
Janitor	1	3.71
Secretary	1	3.71
Laboratory technician	1	3.71
Engineer	2	7.4
Researcher	1	3.71
Veterinarian	2	7.4
Level of education		
Primary	1	4
Secondary	19	70
Tertiary	7	26

veterinarians and nurses (veterinary assistants). Researchers, laboratory assistants, secretaries and janitor were at lower risk of exposure (Figure 3a,b). When we apply Pareto's law to our results, we can see by transposing the data that nearly 40% of exposed professions (animal handlers, veterinarians and nurses) were associated with 80% of the risks (Figure 3b).

4 | Discussion

The aim of our study was to carry out a zoonotic risk assessment at the Primatology Centre of CIRMF in Gabon. This centre, which houses a diversity of primates, is concerned with their conservation and research is also focused on primate health and behaviour. In our work, the study cohort consisted of animal handlers, researchers, nurses and veterinarians. The majority (70%) of participants had completed secondary level education. Level of education could have an impact on knowledge of diseases that can originate from animals [49, 50].

Compliance measures play a central role in research establishments housing live animals, as they aim to protect workers from any potential danger. Close contact between humans and NHPs plays an important role in the emergence of infectious diseases [51]. One of the determining factors in the risk of infection is prevention and control [52], as it is impossible to completely isolate veterinarians, animal handlers, researchers and any other occupation that handles animals. Protected contact must be maintained to prevent any risk of zoonotic transmission. Our results highlight the importance of ongoing training, clear protocols and raising staff awareness on the need to prevent disease transmission in such a research establishment.

NHPs are considered reservoirs of potentially zoonotic bacteria [53]. These bacteria could be transmitted to humans and cause deadly infections in hosts [1]. The presence of antibiotic-resistant bacteria is another problem in NHPs linked to the spread of resistant bacteria [54]. The fecal–oral route of transmission is associated with the genera *Acinetobacter* spp. and *Yersinia* spp., while the presence of an intermediate vector is required for the species *B. quintana* and *R. felis* and direct or indirect contact is necessary for the species *E. coli* and *S. aureus* (Table 1). Antimicrobial resistance is another threat to both humans and NHPs at CDP [55]. High rates of antibiotic resistance have been reported in NHP-hosted Enterobacteria (Data awaiting publication) and cases of

transmission have been reported for multi-resistant *S. aureus* between humans and NHPs [7, 8]. Multi-resistant bacteria carried by monkeys can pose a risk to human health by crossing the species barrier. These observations highlight the need to implement and strict adherence to preventive measures aimed at protecting the health of staff and NHPs. The use of gloves, for example, can serve to prevent the transmission of pathogens during handling. Likewise, wearing masks can also prevent the risk of bacterial transmission of zoonotic diseases as tuberculosis.

Studies carried out at the CDP have reported the presence of a diversity of parasites (Table 1). Similar results have been reported in several park studies in Africa (Senegal, Republic of Congo, Djibouti, Algeria) in various NHP species [56]. At the CDP, Ngoubangoye [2] reported infections of NHPs by human *Plasmodium* [15]. This discovery raises fears of a possible transfer from monkeys to humans. In addition, a study by Narat et al. [56] in Congo reported cases of parasites in NHPs with zoonotic potential. All these studies confirmed the infectious risk associated with close contact with NHPs. Different modes of transmission have been reported, depending on the pathogen. For vector-borne parasites, effective control of disease vectors could play a role against certain pathogens such as *Plasmodium* spp. [1], the implementation of preventive measures to eliminate vectors (mosquitoes, flies, etc.) would make it possible to prevent risks linked to certain pathogens such as *Plasmodium* spp. (Table 1) but this control is complicated because the vectors (mosquitoes) are omnipresent due to the favourable forest environment. Soil-borne parasites are transmitted by eggs present in human or NHP feces, which contaminate the soil where sanitation is insufficient. Prevention mainly involves the availability of water (for cleaning cages), sanitation of the NHP feeding areas, the wearing of personal protective equipment (PPE) and strict compliance with animal hygienic conditions. These measures also apply to the prevention of risks due to pathogens transmitted via the fecal–oral route [16, 57].

Viruses are among the most frequently described pathogens in wildlife due to their major impact on public health. At the CDP, studies have detected Simian foamy virus (SFV) [58], Simian immunodeficiency virus (SIV) [20], hepatitis virus, Simian T-cell leukaemia virus (STLV) [22] and SARS-COV2 [26]. In 2017, 51 endemic or potentially endemic viruses were described in Gabon, including 22 zoonotic [59]. Transmission to humans could be reallocated by a variety of means. Because of the similarities between human and non-human lentiviruses, SIV and their susceptible NHP hosts have become the main models for studying the pathogenesis of these viruses and developing vaccines [60]. Although the risk of human infection with SIV is real [61], no transmission was observed between CDP staff and NHPs. The mode of transmission of SIV involves direct contact, primate's bites, sputum, fluids and wounds from sharp objects [19]. The SFV, a member of the spumavirus group from the family Retroviridea, have been described in several studies carried out in NHPs in Gabon [62]. Mouinga et al. [63] and more recently Gboyou et al. [6] reported that interspecies transmission of foamy viruses occurred among workers (animal handlers, veterinarians and researchers) in contact with NHPs in the CDP. However, the potential for SFV to become a human disease and spread among human populations following cross-species transmission is not yet fully understood [59]. These cases once again underline the need for workers in contact with NHPs to respect the recommended precautions when in contact with primate species or with material infected with these viruses. SARS-COV2 has been detected in the CDP in a captive sun-tailed *Cercopithecus* monkeys [26] likely due to a transmission from some of the CDP staff to this individual [64, 65]. This emphasises the urgent need of implementing measures to prevent the transmission of pathogens from humans to NHPs in close proximity to humans.

Among the main modes of transmission of these potentially zoonotic pathogens, the risk of contamination through direct contact (bites and aerosols) or indirect contact (e.g., from the ground or soiled fluids) is easy to control by wearing PPE and complying with sanitary procedures. For vector-borne pathogens such as *Plasmodium*, control seems much more complicated because the vectors (mosquitoes) are omnipresent due to the favourable forest environment. However, in order to safeguard workers from the bites of mosquitoes and other insect vectors, the distribution of repellents could be recommended.

In summary, this a priori risk analysis approach has enabled us to identify and assess potential zoonotic risks at the CDP. This work could help to prevent epidemics at the CDP and other facilities. Our findings highlight the urgent need to improve health, safety and prevention measures for staff—animal handlers, vets, nurses, but also laboratory technicians and researchers—who are at greater risk of exposure to pathogens. Although the CDP already has preventive measures in place, it would be desirable for management to clearly define an occupational health and safety policy. In addition, indicators and scorecards should be established and reviewed to achieve the desired health and safety performance, and equipment should be audited and maintained. Similarly, as a facility for potentially pathogenic biological agents, the COP should have a comprehensive set of biosafety measures developed in accordance with the biosafety management standards established by the Biosafety Committee. Still on the subject of prevention, the CDP should introduce a single occupational risk assessment document, prepared and updated annually by the head of the CDP or the risk prevention authority, which will facilitate the organisation of any prevention that may be required. In addition, as the provision of personal protective equipment (PPE) is not always effective, it is essential that management establish ongoing training programmes on the proper use and maintenance of PPE.

5 | Conclusion

Our study enabled us to characterise the zoonotic risks associated with the Primatology Centre of CIRMF. It emphasised the need to implement specific measures concerning the availability and use of personal protective equipment, improved hygiene, staff training and the need for health surveillance of staff and NHPs to minimise the risk of zoonoses. These measures remain essential not only for the protection of personnel and public health, but also for the conservation of habituated or non-habituated NHPs [66]. However, research into the mechanisms by which pathogens are transmitted between humans and NHPs must be continued in order to implement effective preventive measures in primatology centres.

Acknowledgements

We thank all the staff of the Primatology Centre of the Centre Interdisciplinaire de Recherche Médicale de Franceville (CIRMF). The CIRMF was supported by the Government of Gabon, Total-Fina-Elf Gabon and the Ministère de la Coopération Française.

Ethics Statement

The authors have nothing to report.

Consent

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

1. C. A. Devaux, O. Mediannikov, H. Medkour, and D. Raoult, "Infectious Disease Risk Across the Growing Human-Non Human Primate Interface: A Review of the Evidence," *Frontiers in Public Health* 7 (2019): 305, https://doi.org/10.3389/fpubh.2019.00305.

2. B. Ngoubangoye, "Recherche d'agents Infectieux Circulant Dans Une Communauté d'hôtes, Intérêt Pour La Conservation Des PNHs et Risque d'émergence de Maladies Zoonotiquesau Centre De Primatologie Du CIRMF et Dans Les Sanctuaires de PNHs (Au Gabon) Rimatologie Du CIRMF," (Gab. Université de Lyon, 2017).

3. B. Davoust, A. Levasseur, and O. Mediannikov, "Studies of Nonhuman Primates: Key Sources of Data on Zoonoses and Microbiota," *New Microbes New Infections* 26 (2018): S104–S108, https://doi.org/10.1016/j.nmni.2018.08.014.

4. M. Ramon, M. R. McLennan, C. R. Ruiz-Miranda, et al., "Infectious Diseases in Primates in Human-Impacted Landscapes," in *Primates in Anthropogenic Landscapes: Exploring Primate Behavioural Flexibility Across Human Contexts*, eds. T. McKinney, S. Waters, and M. A. Rodrigues (Cham, Switzerland: Springer, 2023), 139–160.

5. D. A. Travis, L. Hungerford, G. A. Engel, and L. Jones-Engel, "Disease Risk Analysis: A Tool for Primate Conservation Planning and Decision Making," *American Journal of Primatology* 68, no. 9 (2006): 855–867, https://doi.org/10.1002/ajp.20293.

6. M. Gboyou, J. Akpaki, B. Ngoubangoye, P. S. Kone, and R. B. Alambedji, "Descriptive Epidemiology and Phylogeny of Circulating Foamy Viruses at the CIRMF Primatology Centre in South East Gabon," *Heliyon*. Published ahead of print January 10, 2023.

7. M. Nagel, J. Dischinger, M. Türck, et al., "Human-Associated *Staphylococcus aureus* Strains Within Great Ape Populations in Central Africa (Gabon)," *Clinical Microbiology and Infection* 19, no. 11 (2013): 1072–1077, https://doi.org/10.1111/1469-0691.12119.

8. B. Ngoubangoye, D. Fouchet, L. A. Boundenga, et al., "*Staphylococcus aureus* Host Spectrum Correlates With Methicillin Resistance in a Multi-Species Ecosystem," *Microorganisms* 11, no. 2 (2023): 393, https://doi.org/10.3390/microorganisms11020393.

9. J. M. Rolain, O. Bourry, B. Davoust, and D. Raoult, "Bartonella Quintana and Rickettsia Felis in Gabon," *Emerging Infectious Diseases* 11, no. 11 (2005): 1742–1744, https://doi.org/10.3201/eid1111.050861.

10. A. Klöckner, M. Nagel, G. Greub, et al., "Chlamydia-Related Bacteria in Free-Living and Captive Great Apes, Gabon," *Emerging Infectious Diseases* 22, no. 12 (2016): 2199–2201, https://doi.org/10.3201/eid2212.150893.

11. J. P. Akue, N. E. Tomo, J. Badiambile, H. Moukana, R. A. Mbou-Mountsimbi, and B. Ngoubangoye, "Seroprevalence of *Toxoplasma gondii* and *Neospora caninum* in Non-Human Primates at a Primate Center at Franceville, Gabon," *Journal of Parasitology and Vector Biology* 10, no. 1 (2018): 1–7.

12. C. Poirotte, P. M. Kappeler, B. Ngoubangoye, S. Bourgeois, M. Moussodji, and M. J. E. Charpentier, "Morbid Attraction to Leopard Urine in Toxoplasma-Infected Chimpanzees," *Current Biology* 26, no. 3 (2016): R98–R99, https://doi.org/10.1016/j.cub.2015.12.020.

13. L. Boundenga, B. Ngoubangoye, I. M. Mombo, et al., "Extensive Diversity of Malaria Parasites Circulating in Central African Bats and Monkeys," *Ecology and Evolution* 8, no. 21 (2018): 10578–10586, https://doi.org/10.1002/ece3.4539.

14. A. Herbert, "Contribution à l'étude Du Parasitisme Chez Le Mandrill Au Gabon," (Université de Toulouse, Ecole Nationale Vétérinaire de Toulouse—ENVT, France, 2009).

15. B. Ngoubangoye, L. Boundenga, C. Arnathau, et al., "The Host Specificity of Ape Malaria Parasites Can Be Broken in Confined Environments," *International Journal for Parasitology* 46, no. 11 (2016): 737–744, https://doi.org/10.1016/j.ijpara.2016.06.004.

16. B. Ngoubangoye, L. Boundenga, S. E. Dibakou, et al., "Surgical Treatment of *Oesophagostomum* spp. Nodular Infection in a Chimpanzee at the CIRMF Primatology Center, Gabon," *Case Reports in Veterinary Medicine* 2021 (2021): 6617416, https://doi.org/10.1155/2021/6617416.

17. S. E. Dibakou, U. Maloueki, B. Ngoubangoye, et al., "Diversity of Gastrointestinal Parasites in Sympatric Mammals in Moukalaba-Doudou National Park, Gabon," *Veterinary World* 14 (2021): 3149, https://doi.org/10.14202/vetworld.2021.3149-3155.

18. J. M. Setchell, I. B. Bedjabaga, B. Goossens, P. Reed, E. J. Wickings, and L. A. Knapp, "Parasite Prevalence, Abundance, and Diversity in a Semi-Free-Ranging Colony of *Mandrillus sphinx*," *International Journal of Primatology* 28, no. 6 (2007): 1345–1362, https://doi.org/10.1007/s10764-007-9225-6.

19. D. Fouchet, D. Verrier, B. Ngoubangoye, et al., "Natural Simian Immunodeficiency Virus Transmission in *Mandrills*: A Family Affair?," *Proceedings of the Royal Society B: Biological Sciences* 279, no. 1742 (2012): 3426–3435, https://doi.org/10.1098/rspb.2012.0963.

20. M. C. Georges-Courbot, P. Moisson, E. Leroy, et al., "Occurrence and Frequency of Transmission of Naturally Occurring Simian Retroviral Infections (SIV, STLV, and SRV) at the CIRMF Primate Center, Gabon," *Journal of Medical Primatology* 25, no. 5 (1996): 313–326, https://doi.org/10.1111/j.1600-0684.1996.tb00023.x.

21. F. Liégeois, C. Butel, A. Mouinga-Ondéme, et al., "Full-Length Genome Sequence of a Simian Immunodeficiency Virus From a Wild-Captured Sun-Tailed Monkey in Gabon Provides Evidence for a Species-Specific Monophyletic SIVsun Lineage," *AIDS Research and Human Retroviruses* 27, no. 11 (2011): 1237–1241, https://doi.org/10.1089/aid.2011.0076.

22. M. Makuwa, S. Souquière, S. L. Clifford, et al., "Two Distinct STLV-1 Subtypes Infecting *Mandrillus sphinx* Follow the Geographic Distribution of Their Hosts," *AIDS Research and Human Retroviruses* 20, no. 10 (2004): 1137–1143, https://doi.org/10.1089/aid.2004.20.1137.

23. E. Nerrienet, X. Amouretti, M. C. Müller-Trutwin, et al., "Phylogenetic Analysis of SIV and STLV Type I in Mandrills (*Mandrillus sphinx*): Indications That Intracolony Transmissions Are Predominantly the Result of Male-to-Male Aggressive Contacts," *AIDS Research and Human Retroviruses* 14, no. 9 (1998): 785–796, https://doi.org/10.1089/aid.1998.14.785.

24. S. Souquière, F. Bibollet-Ruche, D. L. Robertson, et al., "Wild *Mandrillus sphinx* Are Carriers of Two Types of Lentivirus," *Journal of Virology* 75, no. 15 (2001): 7086–7096, https://doi.org/10.1128/JVI.75.15.7086-7096.2001.

25. M. Makuwa, S. Souquière, P. Telfer, et al., "Hepatitis Viruses in Non-Human Primates," *Journal of Medical Primatology* 35, no. 6 (2006): 384–387, https://doi.org/10.1111/j.1600-0684.2006.00163.x.

26. G. Maganga, B. Ngoubangoye, J. Koumba, et al., "Evidence of SARS-CoV-2 Infection in Pets, Captive Non-Human Primates and Farm Animals in Central Africa," *Asian Pacific Journal of Tropical Medicine* 15, no. 5 (2022): 232, https://doi.org/10.4103/1995-7645.345947.

27. G. C. Stewart, "*Staphylococcus aureus,*" (Boca Raton, 2005).

28. P. Brouqui, B. Lascola, V. Roux, and D. Raoult, "Chronic *Bartonella quintana* Bacteremia in Homeless Patients," *New England Journal of Medicine* 340, no. 3 (1999): 184–189, https://doi.org/10.1056/NEJM199901213400303.

29. K. E. Reif and K. R. Macaluso, "Ecology of *Rickettsia felis*: A Review," *Journal of Medical Entomology* 46, no. 4 (2009): 723–736, https://doi.org/10.1603/033.046.0402.

30. E. Bergogne-Berezin and K. J. Towner, "*Acinetobacter* spp. as Nosocomial Pathogens: Microbiological, Clinical, and Epidemiological Features," *Clinical Microbiology Reviews* 9, no. 2 (1996): 148–165.

31. E. Huovinen, L. M. Sihvonen, M. J. Virtanen, K. Haukka, A. Siitonen, and M. Kuusi, "Symptoms and Sources of Yersinia Enterocolitica-Infection: A Case–Control Study," *BMC Infectious Diseases* 10, no. 1 (2010): 122, https://doi.org/10.1186/1471-2334-10-122.

32. L. Cabrera-Sosa and T. J. Ochoa, "*Escherichia coli* Diarrhea," in *Hunter's Tropical Medicine and Emerging Infectious Diseases*, eds. E. T. Ryan, D. R. Hill, T. Solomon, N. E. Aronson, and T. P. Endy (Edinburgh, UK: Elsevier, 2020), 481–485, https://doi.org/10.1016/B978-0-323-55512-8.00046-6.

33. A. Kurup, Y. S. Wang, K. S. Heng, K. C. Tan, and C. H. Wong, "Four Cases of Necrotizing Fasciitis Caused by *Klebsiella* Species," *European Journal of Clinical Microbiology & Infectious Diseases* 23, no. 5 (2004): 403–407, https://doi.org/10.1007/s10096-004-1125-5.

34. R. Verhelst, H. Verstraelen, G. Claeys, et al., "Signs and Symptoms of Urethritis and Cervicitis Among Women With or Without Mycoplasma Genitalium or Chlamydia Trachomatis Infection," *Journal of Obstetrics and Gynaecology of Eastern and Central Africa* 23 (2004).

35. D. E. Hill, S. Chirukandoth, and J. P. Dubey, "Biology and Epidemiology of *Toxoplasma gondii* in Man and Animals," *Animal Health Research Reviews* 6, no. 1 (2005): 41–61, https://doi.org/10.1079/AHR2005100.

36. M. Kaluzna, J. Pulawska, and B. Meszka, "A New Bacterial Disease on Bluberry (*Vaccinium corymbosum*) Caused by *Pseudomonas* spp.," *Journal of Plant Protection Research* 53, no. 1 (2013): 32–36.

37. D. S. Nsagha, A. L. Njunda, H. L. F. Kamga, et al., "Knowledge and Practices Relating to Malaria in Ndu Community of Cameroon: Signs and Symptoms, Causes and Prevention," *Journal of Public Health and Epidemiology* 3, no. 6 (2011): 294–300.

38. T. D. Otto, A. Gilabert, T. Crellen, et al., "Genomes of All Known Members of a *Plasmodium* Subgenus Reveal Paths to Virulent Human Malaria," *Nature Microbiology* 3, no. 6 (2018): 687–697, https://doi.org/10.1038/s41564-018-0162-2.

39. M. Norhayati, M. S. Fatmah, S. Yusof, and A. B. Edariah, "Intestinal Parasitic Infections in Man: A Review," *Medical Journal of Malaysia* 58, no. 2 (2003): 296–305.

40. C. J. Kucik, G. L. Martin, and B. V. Sortor, "Common Intestinal Parasites," *American Family Physician* 69, no. 5 (2004): 1161–1169.

41. H. Y. Kim, S. M. Lee, J. E. Joo, M. J. Na, M. H. Ahn, and D. Y. Min, "Human Syngamosis: The First Case in Korea," *Thorax* 53, no. 8 (1998): 717–718, https://doi.org/10.1136/thx.53.8.717.

42. J. F. Magnaval and J. Magdeleine, "La Mammomonogamose Humaine," *Médecine Tropicale* 64 (2004): 21–22.

43. O. Chosidow, "Scabies and Pediculosis," *Lancet* 355, no. 9206 (2000): 819–826, https://doi.org/10.1016/S0140-6736(99)09458-1.

44. N. A. El-Dib, "Entamoeba Histolytica: An Overview," *Current Tropical Medicine Reports* 4, no. 1 (2017): 11–20, https://doi.org/10.1007/s40475-017-0100-z.

45. M. B. Gardner, M. P. Carlos, and P. A. Luciw, "Simian Retroviruses," in *AIDS and Other Manifestations of HIV Infection*, 4th ed., ed. G. P. Wormser (New York, NY: Raven Press, 2004), 195–262.

46. W. M. Lee and B. Hepatitis, "Virus Infection," *New England Journal of Medicine* 337, no. 24 (1997): 1733–1745, https://doi.org/10.1056/NEJM199712113372406.

47. S. Xu, M. Nixon, R. C. Wang, and M. Baldea, "Process Fault Detection Based on Time-Explicit Kiviat Diagram," in *Artificial Intelligence in Process Fault Diagnosis*, ed. R. J. Fickelscherer (Hoboken, NJ: Wiley, 2024), 131–159, https://doi.org/10.1002/9781119825920.ch6.

48. A. Grosfeld-Nir, B. Ronen, and N. Kozlovsky, "The Pareto Managerial Principle: When Does It Apply?," *International Journal of Production Research* 45, no. 10 (2007): 2317–2325, https://doi.org/10.1080/00207540600818203.

49. The Mountain Gorilla Veterinary Project 2002 Employee Health Group, "Risk of Disease Transmission Between Conservation Personnel and the Mountain Gorillas: Results From an Employee Health Program in Rwanda," *EcoHealth* 1, no. 4 (2004): 351–361, https://doi.org/10.1007/s10393-004-0116-4.

50. M. Ayim-Akonor, R. Krumkamp, J. May, and E. Mertens, "Understanding Attitude, Practices and Knowledge of Zoonotic Infectious Disease Risks Among Poultry Farmers in Ghana," *Veterinary Medicine and Science* 6, no. 3 (2020): 631–638, https://doi.org/10.1002/vms3.257.

51. C. L. Nunn and S. M. Altizer, "Sociality and Infectious Disease in Wild Primate Populations," *American Journal of Physical Anthropology* (2003): 160.

52. T. Qin, X. Ruan, Z. Duan, et al., "Wildlife-Borne Microorganisms and Strategies to Prevent and Control Emerging Infectious Diseases," *Journal of Biosafety and Biosecurity* 3, no. 2 (2021): 67–71.

53. L. Boundenga, P. Makouloutou-Nzassi, and B. Ngoubangoye, "A Review of Gabonese Gorillas and Their Pathogens: Diversity, Transfer and One Health Approach to Avoid Future Outbreaks?," *Frontiers in Parasitology* 2 (2023): 1115316, https://doi.org/10.3389/fpara.2023.1115316.

54. E. Baquero, M. Potapov, and R. Jordana, "New Species and Records of Entomobryidae and Orchesellidae (Collembola) From the East Caucasus (Russia)," *Zootaxa* 4991, no. 2 (2021): 247–270, https://doi.org/10.11646/zootaxa.4991.2.2.

55. M. B. Parsons, D. A. Travis, E. V. Lonsdorf, et al., "Antimicrobial Resistance Creates Threat to Chimpanzee Health and Conservation in the Wild," *Pathogens* 10, no. 4 (2021): 477, https://doi.org/10.3390/pathogens10040477.

56. V. Narat, J. Guillot, F. Pennec, et al., "Intestinal Helminths of Wild Bonobos in Forest-Savanna Mosaic: Risk Assessment of Cross-Species Transmission With Local People in The Democratic Republic of the Congo," *EcoHealth* 12, no. 4 (2015): 621–633, https://doi.org/10.1007/s10393-015-1058-8.

57. L. Boundenga, B. Ngoubangoye, N. Moukodoum, S. E. Dibakou, C. Moussadji, and J. P. Hugot, "Diversity of Parasites in Two Captive Chimpanzee Populations in Southern Gabon," *Infection, Genetics and Evolution* 91 (2021): 104807, https://doi.org/10.1016/j.meegid.2021.104807.

58. A. Mouinga-Ondémé, E. Betsem, M. Caron, et al., "Two Distinct Variants of Simian Foamy Virus in Naturally Infected Mandrills (*Mandrillus sphinx*) and Cross-Species Transmission to Humans," *Retrovirology* 7, no. 1 (2010): 105, https://doi.org/10.1186/1742-4690-7-105.

59. M. Bourgarel, N. Wauquier, and J. P. Gonzalez, "Emerging Viral Threats in Gabon: Health Capacities and Response to the Risk of Emerging Zoonotic Diseases in Central Africa," *Emerging Health Threats Journal* 3, no. 1 (2010): 7099, https://doi.org/10.3402/ehtj.v3i0.7099.

60. J. E. Schmitz and B. Korioth-Schmitz, "Immunopathogenesis of Simian Immunodeficiency Virus Infection in Nonhuman Primates," *Current Opinion in HIV and AIDS* 8 (2013): 273, https://doi.org/10.1097/COH.0b013e328361cf5b.

61. R. F. Khabbaz, W. Heneine, J. R. George, et al., "Infection of a Laboratory Worker With Simian Immunodeficiency Virus," *New England Journal of Medicine* 330, no. 3 (1994): 172–177, https://doi.org/10.1056/NEJM199401203300304.

62. S. Calattini, E. Nerrienet, P. Mauclère, M. C. Georges-Courbot, A. Saïb, and A. Gessain, "Natural Simian Foamy Virus Infection in Wild-Caught Gorillas, Mandrills and Drills From Cameroon and Gabon," *Journal of General Virology* 85, no. 11 (2004): 3313–3317, https://doi.org/10.1099/vir.0.80241-0.

63. A. Mouinga-Ondémé, M. Caron, A. Gessain, and M. Kazanji, "High Level of Inter-Species Transmission of Simian Foamy Virus From Non-Human Primates to Humans in Gabon, Central Africa," *Retrovirology* 8, no. S1 (2011): A229, https://doi.org/10.1186/1742-4690-8-S1-A229.

64. A. Tavera Gonzales, J. Bazalar Gonzales, T. Silvestre Espejo, et al., "Possible Spreading of SARS-CoV-2 From Humans to Captive Non-Human Primates in the Peruvian Amazon," *Animals* 14, no. 5 (2024): 732, https://doi.org/10.3390/ani14050732.

65. A. H. Pereira, A. L. Vasconcelos, V. L. Silva, et al., "Natural SARS-CoV-2 Infection in a Free-Ranging Black-Tailed Marmoset (*Mico melanurus*) From an Urban Area in Mid-West Brazil," *Journal of Comparative Pathology* 194 (2022): 22–27, https://doi.org/10.1016/j.jcpa.2022.03.005.

66. D. S. Azevedo, J. L. C. Duarte, C. F. G. Freitas, et al., "One Health Perspectives on New Emerging Viral Diseases in African Wild Great Apes," *Pathogens* 10, no. 10 (2021): 1283, https://doi.org/10.3390/pathogens10101283.