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Impacts of COVID-19 on Biodiversity Conservation and Community Networks at Kibale National Park, Uganda

Dipto Sarkar
Carleton University, Canada

Jan F. Gogarten
Universität Greifswald and Helmholtz Institute for One Health, Germany

Xiaofan Liang and Clio Andris
Georgia Institute of Technology, USA

Emmanuel Abwa Opito
Makerere University, Uganda

Kim Valenta
University of Florida, USA

Urs Kalbitzer
University of Konstanz and Max Planck Institute of Animal Behavior, Germany

Raja Sengupta
McGill University, Canada

Colin A. Chapman
Vancouver Island University, Canada; University of KwaZulu-Natal, South Africa; and Northwest University, China

Conservation, like all aspects of society, was severely affected by the COVID-19 pandemic. Although there have been projections and speculations about impacts on conservation plans and actions, data about the extent of these impacts are sparse. We contribute evidence from a research field site in Kibale National Park, Uganda. Our analysis shows that many of the fears concerning the negative conservation impacts of COVID-19 were borne out. Long-term research projects were disrupted, affecting employment opportunities in the park. These effects percolated into the local communities, which reported high levels of financial stress and other negative impacts, such as increased rates of teenage pregnancy. People who were permanently employed at the park reported lower levels of financial stress. Also particularly concerning was the increase in poaching in the park due to a lack of food security. This research highlights an important path toward resiliency for research stations in the face of global crises, but it requires changes in funding duration and scope from granting agencies and governments. Operating differently than ecotourism, research field stations provide unique opportunities to build resilient conservation instruments and the results of this research can help guide policies to make research field stations more resilient. **Key Words: biodiversity conservation, COVID-19 impacts, Kibale National Park, research field station, spatial social networks.**

The COVID-19 pandemic affected all aspects of human society and its endeavors; the natural world and its conservation were no exception. In the early days of the pandemic, researchers raised concerns about the impacts COVID-19 would have on biodiversity conservation plans, aims, policies, and practice (Hockings et al. 2020; McCleery et al. 2020; Neupane 2020; Cooke et al. 2021). These concerns focused primarily on decreases in funding to support conservation and their consequent impacts on the ground. Indeed, funding for conservation efforts declined because of reduced tourism

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revenue. A growing body of evidence has shown that loss of tourism revenue results in more illegal activities occurring within protected areas (Hockings et al. 2020; Lindsey et al. 2020; Smith et al. 2021). At the same time, resources that were typically earmarked for conservation were realigned toward public health and safety amid the pandemic. This reduced management capacity and was expected to result in future economic hardships for communities living near protected conservation areas (Bernstein et al. 2022). Limited resources for law enforcement patrols along with deteriorating economic situations in local communities were expected to result in increased human pressures on protected areas including poaching and habitat degradation (Hockings et al. 2020).

The COVID-19 pandemic also created new opportunities for conservation, though. Research showed that attributing the origins of the COVID-19 pandemic to human destruction of nature garnered higher support for biodiversity protection (Shreedhar and Mourato 2020). The pandemic also increased awareness about zoonotic disease spillover and that the postpandemic restructuring of society could be leveraged to benefit biodiversity through a better allocation of funding and support for preventing deforestation and regulating wildlife trade (Dobson et al. 2020; McCleery et al. 2020; Neupane 2020; Cooke et al. 2021; Bernstein et al. 2022). At the same time, the pandemic served as an important reminder of the interconnectedness of our world, raising the call for improving the health care access of populations in high-biodiversity areas as an important cornerstone of pandemic prevention efforts (Leendertz and Kalema-Zikusoka 2021).

We make a unique contribution by centering our research on a research field station instead of an ecotourism model. Five salient characteristics differentiate research field sites from ecotourism sites. First, the success of research field stations does not depend on flagship species, allowing for a broader view of conservation. Second, the community surrounding the research field station engages in conservation knowledge production exercise, linking the field site to the local community. Third, it creates opportunities for training and knowledge transfer and brings together generations of local and foreign researchers and conservation biologists, serving as a locus of knowledge production. Fourth, repeat visitors and the station's long-term presence fosters relationships between the community and researchers, which often leads to new social, education, health, and conservation initiatives. Finally, the visitations at research field stations are not as tightly tied to seasons and school holidays as tourism. Before the onset of COVID-19, research field stations supplemented governmental efforts to improve biodiversity protection outcomes while also improving community welfare (Struhsaker 2005; Michener et al. 2009; Baker 2015; Stevens and Gilson 2016; Tydecks et al. 2016; Kirumira et al. 2019; Sarkar, Andris, et al. 2019; Sarkar, Chapman, et al. 2019; Sarkar et al. 2022). The path forward for research field stations following the pandemic is still unclear, however.

In this study, we evaluate the pandemic's impact on biodiversity conservation and on local communities whose livelihoods depend on non-tourism-related conservation activities. We focus on the Makerere University Biological Field Station, a research field station in Kibale National Park, Uganda, and address the following research questions with help from the local communities:

1. How did COVID-19 affect the economic life of the communities living near the research field station? Did the impact differ if people are employed in the field station?
2. How did COVID-19 affect conservation research activities? What were the other impacts on conservation noted by the community?

We hope our results will guide future conservation efforts as well as in planning resilience into conservation efforts for future pandemics.

Methods

Study Site

Located in western Uganda, Kibale National Park (hereafter Kibale) is renowned as the primate capital of the world because it hosts thirteen species of primates, including the iconic chimpanzee (*Pan troglodytes*) and red colobus monkeys (*Piliocolobus tephrosceles*). The 795 km^2 park is predominantly a midaltitude moist evergreen forest. Between 1932 and 1993, Kibale underwent a transition from a forest reserve designed for sustainable timber extraction to a national park, which was firmly established in 1993 (Naughton-Treves 1997, 1999; Chapman and Lambert 2000). In the 1970s, 1980s, and early 1990s, the southern part of the park was degraded by agricultural encroachment, but following a resettlement program the forest has been actively restored (Omeja et al. 2012). Under the stewardship of the Uganda Wildlife Authority (UWA), Kibale is managed with a "parks and neighbors" strategy, where conservation research, community education and outreach, resource access agreements, and revenue sharing are vital components of management (Mugisha and Jacobson 2004; Jones 2006; Mackenzie, Sengupta, and Kaoser 2015). In Kibale, biodiversity protection goals need to be aligned with community welfare because of the high density of human population surrounding the park (approximately 229 people per km^2) and there are competing economic forces in terms of opportunities provided by tea and coffee plantations. Accompanied by continued human population growth, forest conversion and expanding crop production in the region poses additional challenges that conservation policies should address (Hartter et al. 2015). In Kibale, however, there is currently no evidence of the park boundary eroding and the abundance of many forest-dwelling species is increasing (Chapman et al. 2021; Sarkar et al. 2022) .

Research activity in Kibale intensified around 1970 with the work of Dr. Thomas Struhsaker. As research in the Kanyawara region increased, Makerere University overtook operations and led the expansion of the field station, which was officially named Makerere University Biological Field Station (MUBFS). The research station subsequently received funding from various sources including the Wildlife Conservation Society, the European Union (EU), the United States Agency for International Development (USAID), and the International Development Research Center (IDRC). Subsequently, two additional research sites began in Kibale: Ngogo and Sebatoli, which are also located in the northern region of the park and managed and maintained through the MUBFS. Kibale's history of human impacts in terms of commercial logging, agricultural clearing, and its conduciveness for working with the local communities has made the site a leading field station for conservation research in Africa (Box et al. 2008).

The Kanyawara site is the primary research site of MUBFS, hosting the administrative offices and much of the lodging capabilities, classrooms, library, dining facilities and kitchen, laboratory space, and medical facilities. In addition to research, several outreach and development projects focusing on education (Kasiisi Project), health (Kibale Health and Conservation Center, Mobile Health Clinic), and the reduction of encroachment (Kibale Snare Removal Project, Kibale Fuel Wood Project) are conducted through the research field station (Sarkar, Chapman, et al. 2019). Previous research has shown that many locals have benefited from employment opportunities provided through MUBFS in conjunction with development projects and research. Social networks spread the values of conservation and help improve people–park relationships (Chapman et al. 2015; Mackenzie, Sengupta, and Kaoser 2015; Project 2016; Kirumira et al. 2019; Sarkar, Andris, et al. 2019; Sarkar, Chapman, et al. 2019).

Study Design

To assess the impact of the pandemic on MUBFS and on the local community, we used a questionnaire that contained open-ended and multiple-choice questions. The questionnaire was adapted from Sarkar, Andris, et al. (2019) and Sarkar, Chapman, et al. (2019). The goal was to assess changes that occurred due to the COVID-19 pandemic, specifically the impact of lockdowns and decrease in foreign visitors (Table 1). A local field assistant who can speak the local languages administered the questionnaire between September 2021 and May 2022, adhering to the COVID-19-related restrictions implemented at the time (i.e., mask wearing and limited group size). The same field assistant administered the original questionnaire. Unlike the previous survey, all coordination was done remotely due to international travel restrictions.

The survey was first administered to field station employees (Tier 1 respondents), including administrative staff, field assistants, trail cutters, and cooks. The employees were contacted while they were at the MUBFS site with help from project managers and the administrative office. All surveys were administered using paper and pen and later transcribed by the field assistant. On average, the surveys took twenty minutes to complete and the respondents were compensated with a bag of sugar.

To evaluate how the economic benefits from the station spread through the community network, we used a snowball sampling strategy where individuals were asked to list people they had hired for various household and farming-related activities in the last year (Tier 2 respondents). The snowball sampling allowed us to the track the flow of economic benefits through the community and test if people who were connected economically even at a few degrees of separation to the field station were aware of conservation benefits and impacts. Each Tier 2 respondent was interviewed and asked the same questions, including who they hired for household and farm work. Each consequent level of the snowball sample was given an incremental number (i.e., Tier 2, 3, 4, and 5) enabling us to evaluate how perceptions change despite indirect links to the economic benefits emanating from the research field station. When an individual did not report hiring a person, unavailability, or unwillingness to participate, or if they lived too far from the field station for the field assistant to easily visit (four individuals), this individual acted as a terminal node in the network.

The final sample contained 195 people from twenty-five villages (including people who lived and worked at the field station site) within 12 km from the field station. To control for the self-selection bias of the snowball sampling method, we administered the survey to twenty-one randomly selected respondents, called control respondents (CRs), who were part of the network. To ensure that CRs were not connected to the research station, the CRs were asked if they were hired by anyone working at MUBFS (Tier 1) or by anyone who was hired by

Table 1. COVID-19-related questions added to the original survey of Sarkar, *Chapman, et al. (2019)*

Question	Format
Has your employment condition changed since COVID?	Multiple choice (reduced employment, increased employment, no change)
Please explain how your employment condition changed since COVID.	Open-ended
Has your financial situation changed since COVID?	Multiple choice (become worse, improved, no change)
How has your financial situation changed since COVID?	Open-ended
If your financial situation changed, when do you think things will be back to what it was?	Open-ended
In your opinion, what are the changes you notice in the park since COVID?	Open-ended
Do you think that the amount of poaching changed as a result of COVID?	Open-ended

MUBFS employees (Tier 2). All respondents were geolocated to their village of residence.

One key difference from the previous study was that the limitation on distance from the field station in which to conduct the survey was relaxed because we were uncertain about how the employment networks had been reconfigured due to COVID-19. We found that nearly all respondents were located within a 12-km buffer of MUBFS (only four respondents were located beyond this area) and consequently, this distance was selected as the new distance threshold, beyond which participation was excluded. As a result, those four more distantly located respondents were removed from the analysis to ensure consistency with the previous study where most respondents were located approximately 10 km from MUBFS.

The open-ended questions were coded to identify themes around conservation and community impacts, after multiple readings and iterations. Two passes through the entire data set were made to ensure all themes were captured. We generated frequency statistics from multiple-choice questions. Survey results were analyzed using a mixed-methods approach combining qualitative and geographic information systems (GIS) methods in R version 4.x and QGIS version 3.x. To compare the changes in response rates pertaining to different questions between the two time periods (pre- and postpandemic), Fisher's exact test and Wilcox rank sum tests were used.

Network Analysis

We created an edge list of the spatial social network data elicited from tiered respondents where each node represents an individual geolocated to their village and edges represent employer–employee relationships. The network consisted of thirty-two disconnected components, most with only a few nodes (—one to six). As many network metrics rely on shortest network distance calculation (e.g., closeness, betweenness), they require all nodes and edges to be part of the same connected component. Thus, we used the largest connected components with 145 nodes and 177 edges to ensure that all network metrics could be calculated. The network was analyzed in R using social network analysis metrics and spatial social network analysis to account for the spatial aspects of the network. Specifically, we calculated the degree of nodes, the distance of connections, proportion of inter- and intravillage connections, and the network flattening ratio. The network flattening ratio measures the spatial efficiency of the network. The flattening ratio provides a value between [0, 1] where low values indicate a spatially efficient network where people are connected to their spatially closest neighbor and high values indicate prevalence of distant connections. The before network contains 97 nodes and 108 edges. Although the before and during COVID-19 networks include different respondent populations and villages, we assume they are comparable while being vigilant about what outcomes might be an artifact of the difference in sampling. For robust comparison of inter- and intravillage comparison, we aggregated individual-level networks to the village level and only visualize spatial social networks between villages that have data in both the before and during COVID-19 data sets ($n = 11$).

Results

We first present the general characteristics of the survey followed by the impacts on the community and finally the impacts on conservation.

Table 2 shows the survey demographics by tier. Tier 1 employees worked as field assistants (thirty-six), as cooks and cleaners (fifteen), and as trail cutters (nine). Others (sixteen) worked as administrators, in security, and in various research projects. Employment duration ranged from two to twenty years, and the mean duration was approximately ten years. On average, each person in Tier 1 hired 3.2 people for household and farm work, which represents an increase from the average of 2.3 people reported in the previous survey. Overall, 35.6 percent of the people were hired for farm-related work and were hired frequently, often every few weeks. Most (82.8 percent) respondents lived within 6 km

Table 2. Demographics of survey respondents from communities adjacent to the Kibale National Park

	Respondent level					
Criteria	**Tier 1**	**Tier 2**	**Tier 3**	**Tier 4**	**Tier 5**	**CR**
No. of respondents	76	79	24	15	1	21
Sex (male [M], female [F], unknown [U])	F = 15 M = 61	F = 23 M = 55 U = 1	F = 13 M = 11	F = 9 M = 6	F = 1	F = 12 M = 9
Average household size	4.08	2.82	3.62	3.13	11.00	3.33
Average no. of livestock (cows, goats, pigs, chickens) per household	12.60	14.20	5.38	4.60	6.00	13.60
% of households with eucalyptus plantations	56.60	35.40	37.50	33.30	100.00	57.10
% of households with cash crop (sugarcane, tea, coffee)	42.10	24.10	37.50	33.00	0.00	61.90
Land tenure (%; I = inherited, B = bought)	I = 53.9 B = 61.8	I = 65.8 B = 27.8	I = 66.7 B = 37.5	I = 66.7 B = 33.3	I = 100.0	I = 57.1 B = 14.3
Employment (%; R = reduced; N = no change; S = stopped working)	R = 86.8 N = 11.8 S = 1.3	R = 91.1 N = 8.9	R = 83.3 N = 16.7	R = 86.7 N = 13.3	R = 100.0	R = 81.0 N = 14.3 S = 4.7
Finance (% R = reduced, N = no change)	R = 90.8 N = 9.2	R = 93.7 N = 6.3	R = 95.9 N = 4.1	R = 93.3 N = 6.7	R = 100.0	R = 90.5 N = 4.8

Note: CR = control respondent.

of the field station. Hiring was mostly local with 93.0 percent of Tier 1 employees living within 3 km of MUBFS.

Each Tier 2 employee on average hired 1.7 people. Some Tier 2 employees owned retail shops and hired help to run the shops. Tier 3 respondents worked as farmhands (e.g., digging, weeding, picking vegetables) and in other miscellaneous jobs, such as brick making, construction and repair, and house helpers. Each Tier 3 employee hired 1.8 other people for farming (weeding, digging) and household chores (fetching water and firewood). The same kind of jobs were performed by people hired by Tier 4 respondents.

There was an 81.9 percent drop in the number of researchers present at MUBFS between 2019 and 2020 and a 92.4 percent drop between 2019 and 2022. This corresponds to revenue generated from fees (for maintenance of the facilities and trails) from foreign researchers between these time periods (Figure 1). The number of foreign researchers visiting MUBFS in the second quarter of 2022 was also 67.4 percent lower than the second quarter of 2019. In the following section, we discuss the community and conservation impacts captured through the responses.

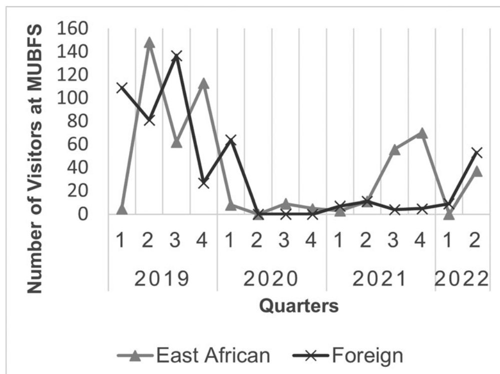

Figure 1. *Number of East African and foreign researchers visiting Makerere University Biological Field Station (MUBFS) per quarter. Fees for foreign researchers and assistants are UGX 900,000 (approximately US$250) and UGX 100,000 (approximately US$30), respectively, per quarter. The fees for East African students vary and services to them are often provided at cost.*

Changes in Employment and Financial Situation

As expected, the COVID-19 pandemic precipitated financial hardship for the community, with 86.5 percent ($n = 187$) of participants reporting a loss or reduction in employment and 92.2 percent ($n = 199$) reporting consequent financial hardships. This high rate of impact of the COVID-19 pandemic was felt rather uniformly across tiers (Figure 2), with no significant detected difference in the proportion of respondents facing employment reductions (Fisher's exact test, $p = 0.7086$) or financial hardship (Fisher's exact test, $p = 0.993$), when comparing the five tiers as well as the control group (Figure 2).

Although some Tier 1 employees had stable employment, many people were employed on a temporary basis as field assistants, trail cutters, and housekeepers. Consequently, the impacts were differentiated based on whether they continued working through COVID-19 or not. Unsurprisingly, people whose employment depended on other people rather than on the research station itself were more likely to report financial hardships (χ^2 $p < 0.05$). When disregarding those respondents with permanent contracts, though, there were similar levels of impacts reported throughout the tiers. The combination of employment loss and more free time led to Tier 1 respondents employing fewer people for home and farm work. The impacts of reduced hiring by Tier 1 respondents filtered down through the community. As noted in the prior study (Sarkar, Chapman, et al. 2019), employment for home and farm work follows friend and family ties, and people who were employed by friends rather than family reported greater impacts in employment (three people said explicitly their friends stopped hiring them). Economically, CRs were affected similarly to other respondents, as they also lost jobs, their income was reduced, and future plans were affected.

Figure 3 shows the employment networks generated through snowball sampling before and during the COVID-19 pandemic. In terms of the spatiality of employment, Tier 1 employees were located at a mean distance of 1.7 km from MUBFS, a statistically nonsignificant change from the prior survey (Wilcox rank sum test, $p = 0.59$). Overall, people were mostly hired from nearby villages (median $\text{distance}_{2021} = 577$ m, median $\text{distance}_{2019} = 682$ m, Wilcox rank sum test $p < 0.01$) for farm and household work. The network flattening ratio increased marginally compared to the prior study (0.32 now vs 0.21 previously, Wilcox rank sum test $p < 0.01$). The low flattening ratio value of the network indicates that even though most hiring was local, people located close to each other were not always connected. The slight increase in the flattening ratio coupled with the reduction in mean hiring distance indicates that some employers prioritized local hiring in response to lockdown-related restrictions on travel. This is also noted through the greater prevalence of intravillage hiring in the new network (Figure 3B). The switch to preferential local hiring also increased the size of the largest connected component, as more people were hired simultaneously for multiple jobs raising the mean degree of each node from 2.206 to 2.441, although this difference was not significant (Wilcox rank sum test, $p = 0.0573$).

There are several education and health-related projects run with the research field station as the focal point. These projects are supported through a variety of means including donor funding organized by researchers. These include the Kasiisi Project, the Kibale Health and Conservation Clinic, and the Kibale Mobile Clinic; all were halted during the lockdowns. The lockdowns affected both education and health outcomes of the communities. Several people (twenty) mentioned that children were not going to school, which had effects they perceived as very negative, for example, early pregnancies, greater rates of sexually transmitted disease, increased rates of domestic violence, and early marriage. Consistent with our previous study, several people cited generally having the health and education infrastructure as an advantage associated with the site.

Changes Regarding Conservation, Research, and People–Park Relationship

In terms of conservation, 38 percent ($n = 82$) of respondents noted that poaching had increased. The reasons cited were reduced presence of field assistants in the forest (22.6 percent, $n = 50$) and lack of money to buy food and meat leading to resorting to bushmeat (7.7 percent, $n = 17$). These views were informally supported by field assistants who observed new trails in the forest, dogs, and evidence of charcoal burning after they resumed their positions.

The long hiatus in working also meant that trails used for patrolling and surveys became overgrown and significant investments were needed to reopen them. Some primate groups that are observed for long-term monitoring were lost. Some field assistants noted that in the absence of regular contact some animals became more aggressive when they were once again observed. Between September 2021 and June 2022, there were two incidents of aggressive encounters between red colobus monkeys (*Piliocolobus tephrosceles*) and people and one instance of an aggressive encounter between a human and a baboon (*Papio anubis*).

In terms of community–park relationships, most people still saw value in the park and said that researcher presence helped form their views (14.7 percent, 84 responses). Many people also appreciated UWA's effort in managing the people–park relationship by providing access to firewood on weekends (fifty-four people). Consistent with prior studies, people who were associated with the park in some way (tiered respondents) showed greater engagement about park-related questions. For example, only two of twenty-one CRs identified a negative impact associated with the park compared to 73.4 percent of tiered employees and 71.4 percent of CRs said they did not know about COVID-19-related impacts on poaching.

Respondents reported awareness of disease transfer from wildlife to livestock more often during the survey that occurred during COVID-19 than the pre-COVID-19 survey (Figure 4A; Fisher's exact test, $p = 0.023$). In contrast, there did not appear to be a change in the reporting of disease transfer from wildlife to people between the two survey periods (Figure 4B; Fisher's exact test, $p = 0.25$). Before the COVID-19 pandemic, there was no difference in the reporting of disease transfer from wildlife to livestock (Figure 5A; Fisher's exact test, $p = 0.11$) or in the reporting of disease transfer from wildlife to people (Figure 5B; Fisher's exact test, $p = 0.76$) for individuals in the different survey tiers. In contrast, in the COVID-19 survey, there was a difference in the reporting of disease transfer from wildlife to livestock in the different survey tiers, with those with a more direct connection to work in the park reporting such disease transfer at a higher rate

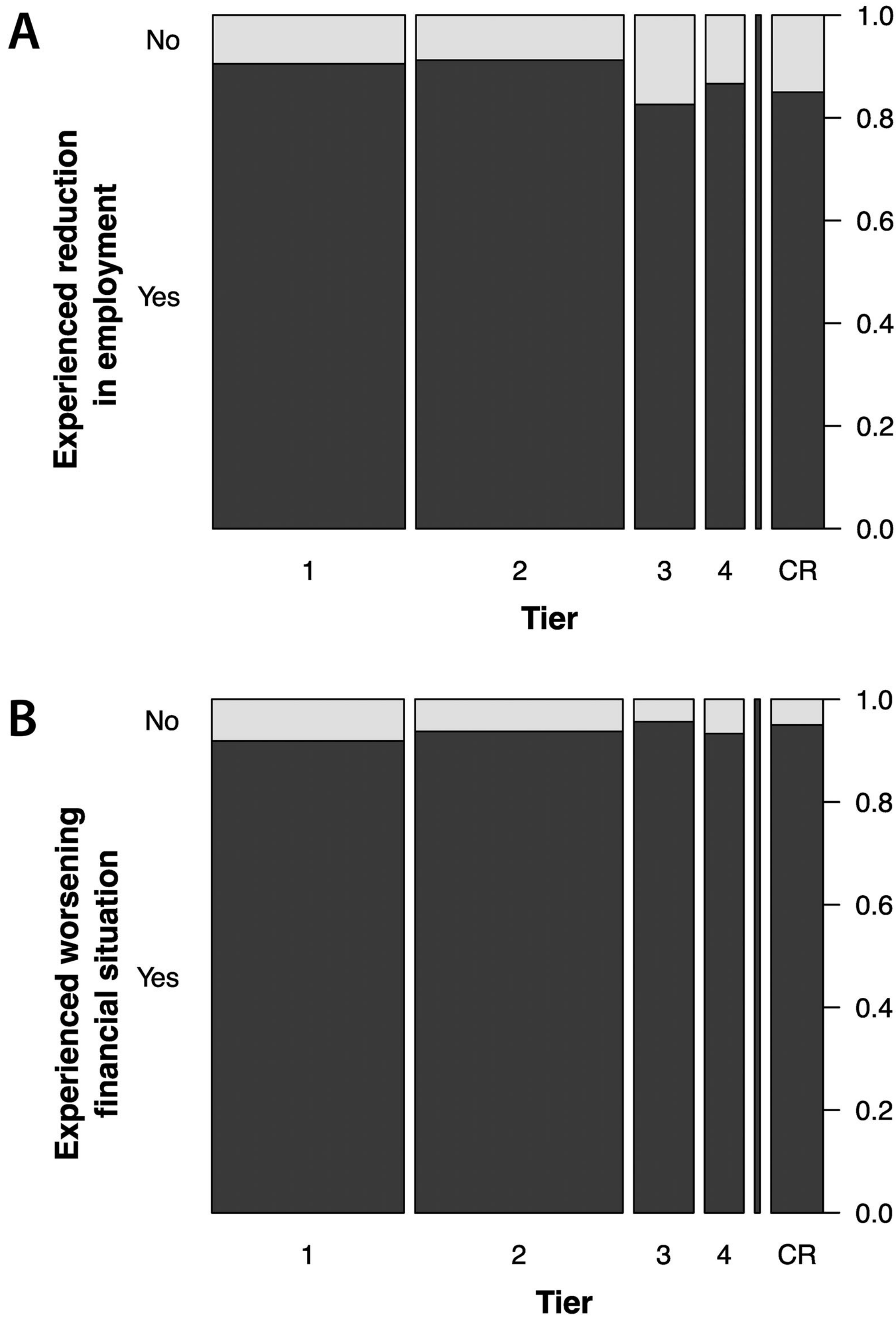

Figure 2. *Proportion of respondents within communities adjacent to the Kibale National Park reporting employment or finance related difficulty during the COVID19 pandemic. Note: CR = control respondent.*

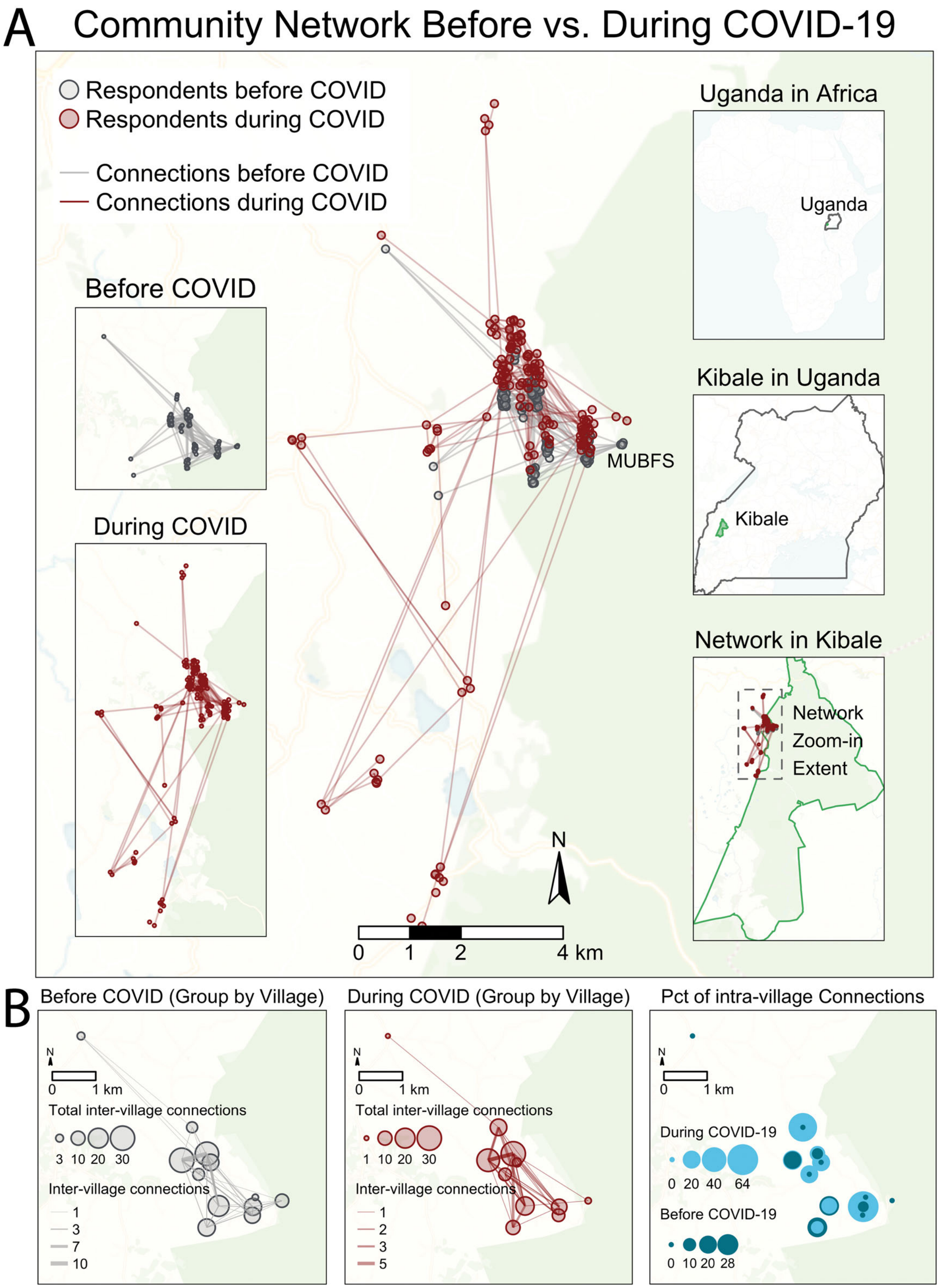

Figure 3. *(A) Hiring network emanating from Makerere University Biological Field Station before and during the pandemic. (B) The changes in intervillage and intravillage connections before and during COVID-19, grouped by villages. The villages are filtered by having data in both the before and during COVID-19 data sets.*

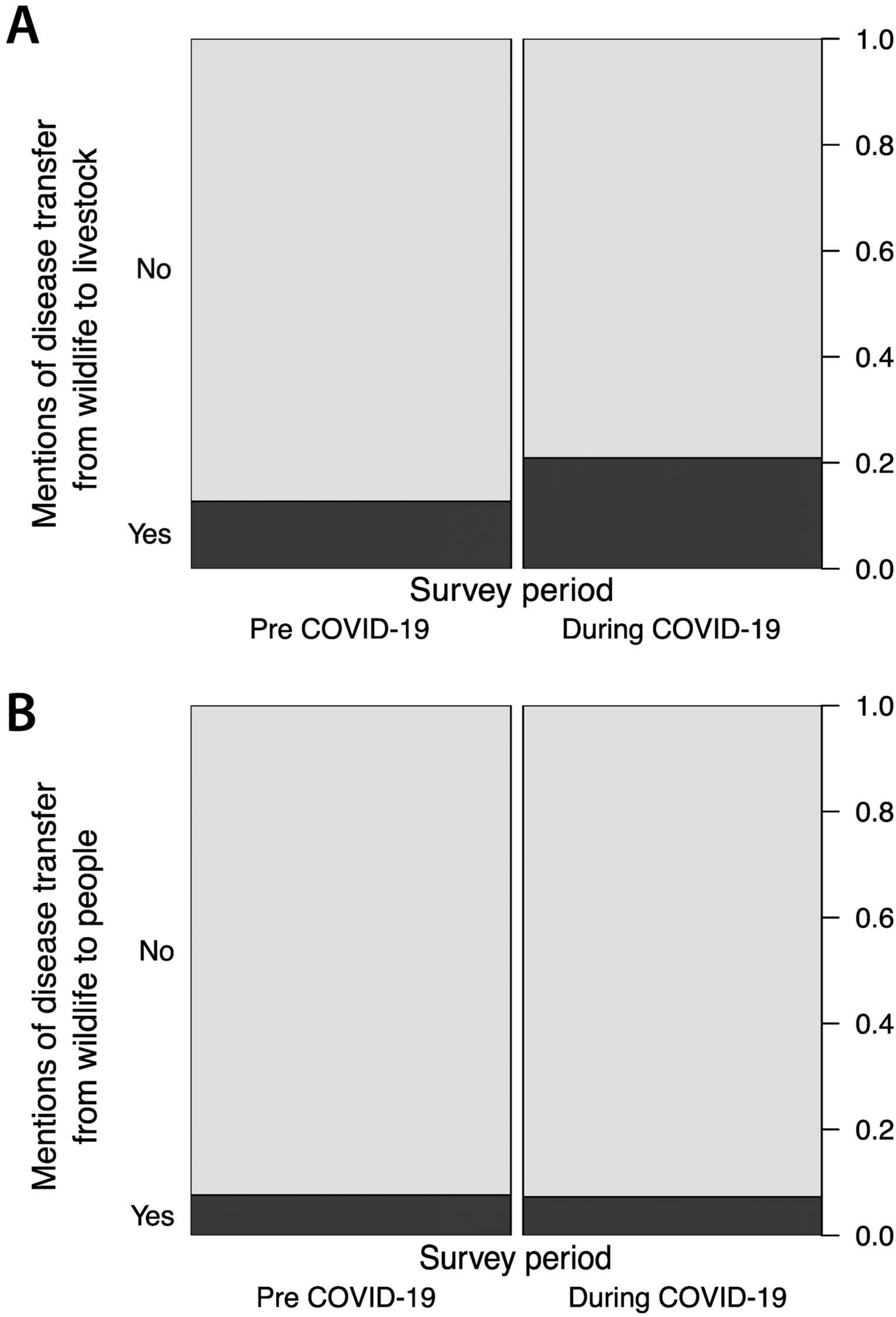

Figure 4. *Proportion of respondents mentioning (A) disease transfer from wildlife to livestock as a risk, and (B) zoonotic disease transfer as a risk. Results of the pre-COVID-19 survey are compared with the results from the survey made during the COVID-19 pandemic.*

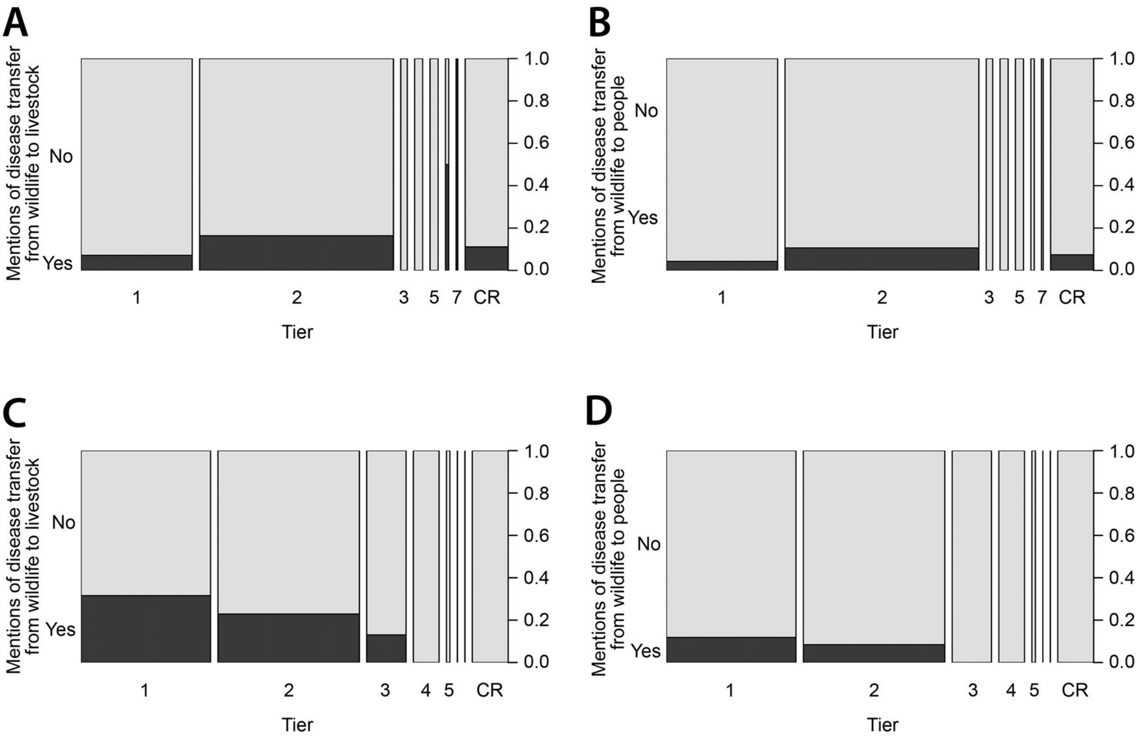

Figure 5. *Proportion of respondents in the different tiers prior to the pandemic that reported (A) disease transfer from wildlife to livestock as a risk or (B) disease transfer from wildlife to people as a risk, neither showing a detectable difference in the different tiers. In contrast, during the pandemic, the proportion of respondents reporting (C) disease transfer from wildlife to livestock as a risk varied significantly by tier, and a similar trend was observed in (D) the reporting of disease transfer from wildlife to people as a risk. Note: CR = control respondent.*

(Figure 5C; Fisher's exact test, $p = 0.0025$); a similar although not significant trend was observed in the reporting of disease transfer from wildlife to people (Figure 5D; Fisher's exact test, $p = 0.27$) respondents.

Discussion

The predicted negative conservation impacts of COVID-19 were borne out in Kibale, particularly the economic hardship experienced by communities. Such economic hardships were experienced throughout the world (Smith et al. 2021). Economic hardships appear to have forced communities to extract more bushmeat from the forest. People indicated that there were increased rates of illegal activities in the park as result of reduced patrolling efforts and people lacking other sustenance options. Prior research in this area had highlighted the need for integrating food security as part of conservation efforts to reduce bushmeat hunting (Sarkar et al. 2022). Our study supports this claim, as the economic hardships associated with the pandemic have exacerbated bushmeat hunting. The lower rates of patrolling done during the pandemic, however, imply that beyond peoples' accounts, evidence of the increased illegal activities will be hard to acquire. Our results also suggest that although there are several health, education, conservation, and livelihood supporting projects that run around the park, there needs to be a greater effort to support projects that provide protein supplies, such as poultry. The needs for food will increase with the a growing population around the park (Hartter et al. 2015).

Additionally, as noted elsewhere (Shreedhar and Mourato 2020; Leendertz and Kalema-Zikusoka 2021), subsequent to the COVID-19 pandemic there was a greater awareness of the risk of disease transfer from wildlife to the livestock and human community. Despite this, bushmeat hunting was perceived to have increased. Thus, faced with food insecurity, people appear to be ignoring this risk or perceiving the risk as low. This highlights the need for implementing a One Health approach at the policy level where human, animal, and environmental health are intrinsically linked (United Nations 2008).

All members of the community, including those not employed by the research station, reported similar rates of employment reduction and financial hardships. This perhaps suggests that employment at the research station was not uniquely vulnerable or resilient to pandemic-induced hardships. Rather, like in many parts of the world, a wide range of economic activities were affected by the pandemic. On the other hand, permanent employment associated with the research station provided a cushion against the sudden shock induced by the pandemic. At MUBFS, salaries of permanent staff are paid by Makerere University, but this just includes a few administrators, accountants, and the trail cutters. The bulk of the employment is temporary and when large field courses come to the field station the number of people working can triple. The funding from the field courses, researcher fees, and accommodations is what allows the field station to maintain its buildings and fund any needed improvements. Although we found that a vast majority of respondents in all tiers reported reductions in employment and financial hardships, we were unable to assess the severity of the financial hardship felt by people, and this represents a limitation of this study to incorporate into future studies as these economic shocks can have a long-lasting impact on the well-being of surrounding communities. Beyond having statistics for visitation, little is yet understood about community impacts due to COVID-19 in other models of conservation (e.g., areas relying heavily on ecotourism revenue). One example where we have access to relevant data provides a first insight; in Kanyanchu, the chimpanzee ecotourism site in Kibale, visitations in 2020 and 2021 were down by 81.2 percent when compared to 2018 and 2019. Comparing data on the community impacts would be valuable in understanding which models of revenue generation associated with conservation are more resilient in the face of uncertainty, such as resulted from the pandemic. Considering the differences in nature of activity, reason of visitation, and method of revenue generation between ecotourism and research field sites, however, we postulate that research field sites will be more robust. For example, lodges, restaurants, and craft shops represent a large proportion of economic activities surrounding the ecotourism site, and all of these are dependent on tourist visitations. Understanding the long-term impact of COVID-19 on communities living around protected areas remains an important conservation issue.

With respect to the secondary employment supported by employees of MUBFS, hiring mostly follows kinship and friendship lines. Because distance of travel was often noted as a barrier to employment, an optimized network, where people hire the spatially closest person would have mitigated some job losses and helped better isolate villages during the peak of the pandemic. The prior study, however, showed that distant hirings spread the benefits and knowledge originating from the park to a greater geographical area and thus had the potential to garner wider support for conservation. Thus, encouraging people to hire locally could have adverse impacts in terms of conservation.

Although the scientific consensus on the climate impacts of air travel is unanimous (Buxton et al. 2020; Neupane 2020; Cooke et al. 2021), the impacts of reduced travel on biodiversity protection plans require careful evaluation. Reduced carbon emission is undoubtedly good for the climate. The decreased visitation in protected areas might also be beneficial for some protected species (e.g., by reducing human-to-animal disease transmission risk or stress; Gillespie and Leendertz 2020; Bates et al. 2021). The ecotourism model that many protected areas rely on, however, is heavily predicated on income generated through tourism and requires a rethink with a particular perspective of building resilience (Prayag 2020). Lost revenue will not only affect the local communities, but also reduce funds for management and patrolling, resulting in higher levels of illegal activities and lingering long-term impacts (Cherkaoui et al. 2020; Smith et al. 2021). As demonstrated here, these same fears are borne out around a research station. For research stations, however, there is the potential to mitigate some impacts by having a larger number of field assistants hired as permanent employees. This will not only mitigate future financial stress, but also importantly lead to fewer disruptions in long-term monitoring while developing local expertise. This will require a change, though, in the science funding structure to allow longer grants, and mechanisms and monies to provide long-term support to field assistants located in foreign countries, even during a pandemic-related interruption.

The changes that the pandemic brought about will have positive and negative consequences for research. It might have provided an opening for local scientists to gain further stewardship of work in these areas. Without the participation of these local scientists, many research programs in the tropics would have been stalled for much greater periods. In situations where the research question required continuous monitoring for the application of appropriate statistics (e.g., climate change and phenological monitoring), such gaps could have resulted in the project failing to answer the question it was designed to address. Consequently, in the short term, this will also affect management decisions. For example, patrolling schedules to deter poaching as well as crop-raiding by animals that rely on animal monitoring data will be hindered. This highlights the importance of "in-house" research agencies for providing reliable evidence-based information for effective management (Roux et al. 2015; Roux et al. 2019). Most of the research funding for working in tropical conservation areas continues to come from high-income countries, however, and a large proportion of this disappeared during the pandemic. This meant that several research programs, including long-term monitoring projects, were paused. To overcome these challenges there could be greater investments in automated technologies that convert forests into technological sites of data production (Gabrys 2020), reducing the need for regular international travel. Without local consultation and stewardship, such efforts have the potential to disenfranchise communities and wrongly focus conservation as a technological optimization problem (Joppa 2015; Sarkar and Chapman 2021). Even before COVID-19, research field stations faced challenges to garner recognition, support, and funding from institutions (Baker 2015; Stevens and Gilson 2016; Tydecks et al. 2016). The idea of optimizing research-related activities by reducing travel and increasing technological interventions has clear potential to severely affect support for field stations. Field stations serve as a gathering place for scientists, students, and local citizens, leading to new scientific projects, discoveries, and the sharing of ideas among the different community members (Michener et al. 2009; Stevens and Gilson 2016; Sarkar, Chapman, and Sengupta 2021). Thus, the impacts of diminished support for field stations would reverberate through both the sciences and conservation.

Conclusion

This article provides insights into the impacts of the COVID-19 pandemic on biodiversity conservation by focusing on the MUBFS to assess how the pandemic affected local communities dependent on conservation research activities. By implementing a community survey closely mimicking a survey administered in the same location before the COVID-19 pandemic (2016–2017), we were able to compare the results from these surveys to generate a qualitative and quantitative glimpse into the hardships faced by this community due to the pandemic.

Research field stations play an important role in conservation. They serve as bases for long-term monitoring, provide meeting places for scientists, and provide innovative ways of involving the community in conservation. Even though there are estimated to be more than 900 biological field stations across the world, there is little commonality in their operations and funding (Baker 2015). Also, there is little public awareness about the important niche occupied by the research stations. In developing countries, the situation is exacerbated by the fact that a majority of the funding that flows into and through research field stations is dependent on foreign funding bodies and thus are more susceptible to global events and international relations. Thus, as vanguards of ecological, conservation, and climate research, field stations require better recognition and support. We hope our research will guide future conservation efforts in the ongoing COVID-19 pandemic, as well as planning resilience into conservation efforts for future global disruptions. ■

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ORCID

Dipto Sarkar http://orcid.org/0000-0003-2254-049X

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DIPTO SARKAR is an Assistant Professor in the Department of Geography and Environmental Studies at Carleton University, Ottawa K1S 5B6, Canada. E-mail: dipto.sarkar@carleton.ca. His research is focused on developing spatial analysis methods for modeling the efficacy of conservation plans and their impacts on park-adjacent communities.

JAN F. GOGARTEN is a research scientist at the Helmholtz Institute for One Health and the Applied Zoology and Nature Conservation research group at the University of Greifswald, 17489 Greifswald, Germany. E-mail: jan.gogarten@gmail.com. His interests are in understanding the factors influencing the distributions of animals and their microbes across landscapes and how to improve conservation outcomes.

XIAOFAN LIANG is a PhD Candidate at the School of City and Regional Planning at the Georgia Institute of Technology and an incoming City and Regional Planning Assistant Professor at Taubman College of Urban Planning and Architecture, University of Michigan, Ann Arbor, MI 48109. E-mail: xiaofan.l@gatech.edu. Her research interests include developing spatial social network metrics and visualizations to support urban planning practices.

CLIO ANDRIS is an Associate Professor in the School of City & Regional Planning and School of Interactive Computing at Georgia Tech, Atlanta, GA 30313. E-mail: clio@gatech.edu. Her research is focused on spatial social network analysis, GIScience, and geovisualization.

EMMANUEL ABWA OPITO is a PhD Candidate in the School of Forestry, Environment and Geographical Sciences, Makerere University, Kampala, Uganda. E-mail: emmanuelopito@gmail.com. His research interests include livelihoods, food security, biodiversity conservation, population dynamics of arthropods, and clean cooking energy.

KIM VALENTA is an Assistant Professor in the Department of Anthropology, University of Florida, Gainesville, FL 32603. E-mail: kimvalenta@ufl.edu. Her research focuses on the interactions between wild plants and animals.

URS KALBITZER is a Research Group Leader in the Department of Biology, University of Konstanz, Konstanz 78464, Germany, and the Department for the Ecology of Animal Societies, Max Planck Institute of Animal Behavior, Konstanz 78467, Germany. E-mail: urs.kalbitzer@uni-konstanz.de. His research aims to gain a comprehensive understanding of the impact of environmental factors on animal behavior and fitness with a focus on nonhuman primates.

RAJA SENGUPTA is an Associate Professor in the Department of Geography, McGill University, Montreal, QC H3A 0G4, Canada. E-mail: raja.sengupta@mcgill.ca. Hie research interest is in developing various spatial analysis approaches and agent-based modeling for better understanding complex biological and social systems.

COLIN A. CHAPMAN is a Professor of Biology at Vancouver Island University, Nanaimo, BC V9R 5S5, Canada. E-mail: Colin.Chapman.Research@gmail.com. His research focuses on how the environment influences animal abundance and social organization and given the plight of tropical animals, he has applied his research to conservation.