Economic pressures of Covid-19 lockdowns result in increased timber extraction within a critically endangered region: a case study from the Pacific Forest of Ecuador

Jacquelyn M. Tleimat1,2, Sarah R. Fritts2, Rebecca M. Brunner3,4, David Rodriguez2, Ryan L. Lynch4, Shawn F. McCracken1,4

1 Department of Life Sciences, College of Science and Engineering, Texas A&M University – Corpus Christi  
2 Department of Biology, College of Science and Engineering, Texas State University – San Marcos  
3 Department of Environmental Science, Policy, and Management, College of Natural Resources, University of California – Berkeley  
4 Third Millennium Alliance

Correspondence: Jacquelyn M. Tleimat, Department of Life Sciences, College of Science and Engineering, Texas A&M University – Corpus Christi, Corpus Christi, TX, U.S.A.

jackietleimat@gmail.com

**Abstract**

Although the COVID-19 lockdowns in 2020 had some environmental benefits, the pandemic’s impact on the global economy has also had conservation repercussions, especially in biodiverse nations. Ecuador, which is heavily reliant on petroleum, agricultural exports, and ecotourism, experienced a rise in poverty in response to pandemic shutdowns. In this study, we sought to quantify levels of illegal timber extraction and poaching before and after the start of COVID-19 lockdowns throughout two protected areas (Reserva Jama Coaque [JCR] and Reserva Bosque Seco Lalo Loor [BSLL]) in the endangered Pacific Forest of Ecuador. We analyzed chainsaw and gunshot acoustic data recorded from devices installed in the forest canopy from December 2019 to March 2020 and October 2020 to March 2021. Results from generalized linear mixed effects models indicated less chainsaw activity before lockdowns (𝛃post.lockdown = 0.571 + 0.196 SE, p-value = 0.004), although increased average rainfall also seemed to negatively affect chainsaw activity (𝛃avg.rainfall = -0.005 + 0.001 SE, p-value < 0.001). Gunshots were too infrequent to conduct statistical models; however, 87% of gunshots were detected during the ‘lockdown’ period. Observational data collected by rangers from these protected areas also noted an increase in poaching activities beginning mid to late 2020 and persisting into 2021. These results add to the steadily growing literature indicating an increase in environmental crime, particularly in biodiverse nations, catalyzed by COVID-19-related economic hardships. Identifying areas where environmental crime increased during pandemic lockdowns is vital to address both socioeconomic drivers and enforcement deficiencies to prevent further biodiversity loss and disease outbreaks and to promote ecosystem resilience. Our study also demonstrates the utility of passive acoustic monitoring to detect illegal resource extraction patterns, which can inform strategies such as game theory modeling for ranger patrol circuits and placement of real-time acoustic detection technologies to monitor and mitigate environmental crimes.

Keywords: COVID-19 repercussions, environmental crime, anthropause, deforestation, passive acoustic monitoring

**Introduction**

In March 2020, the SARS-CoV-2 outbreak led to lockdowns that drastically reduced human travel and economic activity (Bates et al. 2020), which inadvertently impacted wildlife and their habitats. One of the most publicized effects was increases in wildlife in urban and periurban areas from novel sightings (Silva-Rodríguez et al. 2021) to increased sightings of ‘avoidant’ species (Wilmers et al. 2021; Rutz et al. 2020). Outside of urban areas, reported decreases in human activity in several natural areas positively impacted some species due to reduced disruption during reproduction events (Schofield et al. 2021; Corlett et al. 2020; Rutz et al. 2020). Additionally, decreased vehicular traffic on roads and waterways temporarily decreased air and water pollution in many places (Faridi et al. 2021; Bao and Zhang 2020; Dantas et al 2020; Kerimray et al 2020; Saraswat and Saraswat 2020) and reduced wildlife-vehicle collisions (Bíl et al. 2021; LeClair et al. 2021; Shilling et al. 2021). Collectively, this period of lockdowns was termed by researchers as the ‘anthropause’ (Rutz et al. 2020). The dominating narrative of the ‘anthropause’ seems to be focused on the effects of decreased human interaction on the environment and speculations on how resource extraction may change in response to these drastic changes.

However, not all countries experienced a uniform decline in human-nature interaction; increases in environmental crime due to lockdowns was reported in several countries (Price 2020). For example, spikes in poaching were reported more frequently (Aditya et al. 2021; Koju et al. 2021; Rahman et al. 2021; Price 2020), a greater emphasis was placed on wildlife trade (Morcatty et al. 2021), and satellite imagery revealed an increase in deforestation across several tropical countries (Spring 2020; Brancalion et al. 2020) facilitated by higher unemployment – especially of park rangers. Unfortunately, much of these data were confined to news reports which limits the ability to understand true trends given the historic underreporting of environmental crime (Barclay and Bartel 2015) coupled with lowered employment of park rangers during this period. To fully assess the impact of the ‘anthropause’, it is evident that the evaluation of datasets from countries that were financially impacted the most by the pandemic are a necessity.

The economy of Ecuador, a megadiverse country in South America, was largely driven by petroleum, agriculture, and ecotourism before the COVID-19 pandemic; thus, it was severely impacted by lockdowns as oil demand and tourism declined (Heritage Foundation 2022; Lara 2022). In fact, GDP decreased nearly 8%, resulting in the poverty threshold currently encompassing 30% of Ecuador’s population (ECLAC 2021), which exacerbated economic inequality and the consequent social issues. This economic crisis coupled with declines in ability to enforce human restrictions within protected areas (Price 2020) likely motivated individuals to seek illegal resource extraction as a source of income, especially when presented with the emerging market created by the boom in wind energy. Specifically, increases in wind energy created an increase in demand for balsa wood (*Ochromoa pyramidale*), which comprises ~2.3% of a typical wind turbine blade by weight (Liu and Barlow 2016), and then a concomitant rise in balsa prices. Job insecurity and loss, decreased ability to protect forests, and increase in demand of wind energy, together, have created a dynamic that benefits individuals who pursue illegal logging. Although reports have been made on the drastic increase in illegal logging as of 2020, the Amazon has been the primary focus (Baquero 2021) despite the existence of logging throughout Ecuador (Tomaselli 2019).

The Pacific Forest of Ecuador is a greatly imperiled ecoregion (Dodson and Gentry 1991) that has lost 98% of its primary forest, largely due to slash and burn agriculture (Haro-Carrión and Southworth 2018). Export of timber such as teak, balsa, and gmelina (Tomaselli 2019) has further contributed to this deforestation. From 2018 – 2020, the amount of advertising along Manabí Province roads for balsa purchasing increased noticeably (Pers. Obs.). Yet, despite the increased market for balsa and massive deforestation, this area of Ecuador has largely been ignored on reports of logging in the country. As such, there have been no quantitative reports on how the lockdowns have impacted timber extraction in Manabí Province despite being at the heart of the Tumbes-Chocó-Magdalena biodiversity hotspot (Mittermeier et al. 2011). Our objective was to compare chainsaw and gunshot activity in a protected area in the Pacific Forest of Ecuador before and after the start of COVID-19 lockdowns by using passive acoustic devices that were opportunely installed months prior to the start of the pandemic. We hypothesized an increase in chainsaw and gunshot activity after the start of the COVID-19 lockdowns, likely due to the ensuing economic crisis. This case study will add to the growing literature analyzing the effects of lockdowns on environmental crime and aid in directing appropriate conservation action. In the face of the COVID-19 pandemic, a shift in conservation efforts towards a multidisciplinary approach (e.g., ‘One Health’) where human, environmental, and wildlife health are intrinsically linked (Zinsstag et al. 2005; Zinsstag and Tanner 2008) are essential to mitigate future disease outbreaks.

**Methods**

This study was located in the Pacific Forest of Ecuador within the Hacienda Camarones Key Biodiversity Area (HCKBA), located approximately 11 km south of the equator in the Manabí Province. The HCKBA encompasses 4,000 ha and includes Reserva Jama Coaque (JCR; -0.116128, -80.124546), Reserva Bosque Seco Lalo Loor (BSLL; -0.077115, -80.153496), and the Three Forest Conservation Corridor which consists of the forested ridgeline between the two ecological reserves. The climate is defined by a marked dry season from June through December and an intense rainy season from January through May (Dodson and Gentry 1991).

We monitored chainsaw and gunshot activity throughout the HCKBA using eighteen AudioMoth (version 1.1, Open Acoustic Devices, United Kingdom) passive acoustic devices systematically mounted in the canopy (Min: 4 m, Max: 29.5 m, Avg: 16.6 m). In the canopy of each tree, we secured an AudioMoth that was set to record 10 minutes every hour between 0600 – 1900 hrs. We completed establishment of the canopy stations on 5 January 2020 and data collection for this analysis on 25 March 2021.

We identified illegal activity using parameters that reflect vibrations created by chainsaws and gunshots identified in the literature and adjusted based on populated results in Kaleidoscope Pro (version 5.19, Wildlife Acoustics). We used the following parameters for chainsaws: 80 – 550 Hz frequency range, 0.5 – 20 s vocalization length, and 0.45 s maximum inter-syllable gap (Matache et al. 2020). For gunshots we used 200 - 2500 Hz frequency range, 0.001 - 0.75 s vocalization length, and 0.01 maximum inter-syllable gap. We manually identified sound waves that populated within the specified parameters. We created a proxy of chainsaw activity by creating a daily history of detected/non-detected status. We did the same for gunshot detections.

We conducted a generalized linear mixed effects model using the ‘glmmTMB’ package (Brooks et al. 2017), given the response variable (daily history of chainsaw activity coded as ‘1’ for detected, ‘0’ for non-detected) was non-normally distributed and the mix of fixed and random effects. We used two time periods related to COVID-19 lockdowns: pre COVID-19 lockdowns defined as December 2019 – April 2020 and during/post-COVID-19 lockdowns defined as October 2020 – March 2021 (these periods defined given the lack of data from May 2020 – early October 2020) as a categorical independent fixed effect, average monthly rainfall (mm) as a continuous fixed effect, and canopy station as a random effect. We included average monthly rainfall as it was likely to impact the ability to run a chainsaw. We compared a Poisson distribution to a zero-inflated Poisson distribution using the lowest AICc to determine which best fit the data. We compared the best model to a null model using an ANOVA to ensure that variables explained variation in the dataset. We used a Wald test from the package ‘Activity’ (Rowcliffe et al. 2014) to compare the hourly chainsaw activity patterns between the time periods (i.e. whether peak times shifted). We conducted analyses in R version 4.1.1 (R Team 2021; Rstudio 2021). We generated a heatmap of change in chainsaw frequency in response to lockdowns using QGIS (version 3.14, QGIS Development Team).

**Results**

Chainsaw noises were detected across 14 canopy stations over 174 days: 40 days ‘pre-lockdown’, and 134 days ‘during/post-lockdown’. Gunshots were detected across 5 canopy stations over 8 days, 7 in the ‘post-lockdown’ period and 1 in the ‘pre-lockdown’ period. Gunshots were not used in any further analysis given the low detection.

The number of chainsaw days varied between the time periods and based on rainfall (Chisq = 221.270, df = 3, p-value < 0.001). Based on AICc values, the best fit distribution for the GLMM was Poisson with log link distribution with the next AICc best model having Δ2.004. During the ‘post-lockdown’ period, there was 0.571 greater log count of expected chainsaws than the ‘pre-lockdown’ period (Figure 2) meaning there was a 3.724 greater chainsaw counts during the ‘post-lockdown’ period compared to the ‘pre-lockdown’ period. A one unit increase in average rainfall was associated with a 0.005 unit decrease in the expected log count of chainsaws (Figure 2). There was high variance between sites (1.957 + 1.399 SE), which is unsurprising given chainsaws were not detected at 23% of sites (Figure 1).

The activity curves based on bootstrapped data of each COVID-19 period did not differ based on a Wald test (Diff: -0.001, SE: 0.037, p-value: 0.975), indicating no change in time of day in chainsaw activity as a result of the COVID-19 lockdowns (Figure 3). The activity curve illustrates a daily peak in chainsaw activity 0900 hr – 1400 hr. Although the passive acoustic devices only recorded from 0600 – 1900 (during daylight hours), no chainsaws were detected before 0800 or at the 1900 hr, so it is unlikely we failed to capture other hours of chainsaw activity.

**Discussion**

Illegal extraction of timber resources by chainsaws within a protected area of the endangered Pacific Coastal ecosystem of Ecuador increased during and following COVID-19 lockdowns. This pattern is supported by the increased law enforcement seizures of illegal balsa throughout Ecuador with a spike of 180% from 2019 to 2020 (Coba 2021); though this rise was largely attributed to the balsa boom (Baquero 2021), the economic crisis undoubtedly contributed to this spike in illegal balsa harvesting. Similarly, agricultural expansion and increases in illegal mining in neighboring Brazil and Colombia resulted in greater illegal resource extraction during and after COVID-19 lockdowns (Iglesias 2020; Duque 2020). Our results also seem to suggest rainfall influenced chainsaw activity (Figure 2); however, this is likely an artifact of the sampling design given we did not have the data to compare many low rain months before lockdowns. Our study was conducted in response to a unique opportunity (i.e., a global pandemic affecting humans), and thus on a limited scale, yet it provides quantitative evidence that these resource extraction patterns were associated with COVID-19 lockdowns.

Even though limited data on gunshots were available throughout the protected areas we sampled, it is noteworthy that 87% of gunshot detection days were during the ‘post lockdown period.’ Rangers from BSLL have noted an increase in poaching activity as of October 2020, and similarly, increased poaching has been noted by JCR rangers as of summer of 2020 (Figure 4). Both security trail cameras and visual observations by rangers detected more frequent foot traffic in JCR (Pers. Comm.). Unfortunately, thorough records were not maintained until the increased traffic was observed for baseline comparison, but these records are now consistently maintained to monitor changes in foot traffic.

Patterns of illegal activity within the HCKBA will continue to be monitored with passive acoustic devices, especially following the implementation of shared agroforestry practices with local landowners to assess their effectiveness in reducing illegal resource extraction. Our results suggest that sites at the borders of property lines experienced the greatest increase in chainsaw activity (Figure 1), indicating boundary lines should be patrolled more frequently. Spatial and temporal data from this study will be used to strengthen game-theory models to inform patrolling regimes of the park rangers. Additionally, the temporal data from this study provides a potential guideline for surrounding reserves on ‘peak’ extraction times (0900 - 1400 hr) to aid in guiding their own patrol regimes.

Previous studies have demonstrated the effectiveness of using passive acoustic devices to monitor poaching activity and illegal vessel activity and adjust on the ground patrolling efforts (Astaras et al. 2020; Kline et al. 2020), and our study indicates these devices are also useful to monitor chainsaw activity. Given the limited number of gunshots detected, further research on appropriate recording intervals and live monitoring technology is needed to optimize gunshot detection. Still, with the cost effectiveness of passive acoustic devices, we would recommend this method to other protected areas as a means to identify peak extraction times, activity hotspots, and set a chainsaw activity baseline to compare after logging regulations or patrolling regimes are changed (Astaras et al. 2020).

It is vital that further investigation on the impacts of COVID-19 lockdowns on environmental crime continue, particularly in regions of high biodiversity, as disease outbreak and pandemic events are on the rise (Lindahl & Grace 2015; Myers & Patz 2009) and this information can help create safeguards to prevent similar environmental repercussions. Regions of high biodiversity, such as the Pacific Forest of Ecuador and the Amazon, have a greater potential for zoonotic spillover events (i.e., pathogen transmission from wildlife to humans), after a contact event (Daszak et al. 2000), compared to regions like the USA or Europe. For one, these biodiverse regions have high pre-existing pathogenic diversity, which increases the probability of a pathogen with epidemic potential existing, and second, rising human-wildlife interaction in these areas increases potential for contact events (Ellwanger et al. 2020). Although there are high standing levels of pathogen diversity in these regions, the maintenance of biodiversity supports a healthy ecosystem, in large part by keeping vector populations under control (Keesing et al. 2010); these controls are thrown out of equilibrium by deforestation and other such anthropogenic disturbances allowing vectors and pathogens to spread and occupy new niches (Johnson et al. 2015; Pongsiri et al. 2009; Aguirre and Tabor 2008). Often these anthropogenic disturbances leave forests in small, fragmented patches that may lead to higher risk of spillover through the creation of independent ‘co-evolutionary’ units, thus driving greater pathogen diversity (Zohdy et al. 2019). To protect the health of human populations and prevent further wide-spread pandemics, ecosystem health needs to be preserved and a key element of that is restricting environmental crime.

A growing number of researchers are calling to change to a ‘One Health’ perspective of conservation as continued environmental degradation presents a clear threat not only to wildlife, but to human health as well (Kadykalo et al. 2022; Halabowski and Rzymski 2021; Kideghesho et al. 2021; Koju et al. 2021; Manenti and Hymas 2021; Rahman et al. 2021; Scanlan 2021; Zahawi et al. 2021; Beirne 2020). In this paper, we call for greater documentation of habitat loss and modification, particularly in highly biodiverse areas. Areas where environmental crime is increasing should be identified to investigate and understand the main contributors; areas where logging industries are the main cause should trigger effective changes in regulations, however in other cases, economic safety nets and regenerative harvesting practices (such as agroforestry) should be established to protect struggling communities to remove the need for illegal resource extraction. While many researchers have called upon increased surveillance and stricter regulation on the logging industry, we believe it is also imperative to identify the socioeconomic drivers of environmental crime and seek solutions that eliminate the need for this source of income.

**Acknowledgements**

We would like to extend our thanks to the funders that made this research possible; Texas State University Research Enhancement Program, Texas A&M University - Corpus Christi, Rufford Foundation Small Grants, The Van Tienhoven Foundation, The Explorers Club (Mamont Scholar Grant), IUCN – Netherlands, and Saving Nature. To the field team that helped place and maintain the devices; Rebecca Davis, Moises Tenorio, Sixto Lopez, Matthew Parker, and Nicolas Betancourt, a huge thank you. We thank the team at Third Millennium Alliance for logistical coordination, providing lodging, and access, and thanks to Bosque Seco Lalo Loor and the Loor Family, Dany Murillo, and Edilberto Marquez for granting our team permission to place canopy stations on their properties.

**Author Contributions**

**Jacquelyn M Tleimat:** Conceptualization (equal); Data curation (lead); Formal analysis (lead); Funding acquisition (equal); Investigation (equal); Methodology (supporting); Validation (lead); Visualization (lead); Writing- original draft (lead); Writing- review & editing (supporting). **Sarah R. Fritts:** Funding acquisition (equal); Project administration (supporting); Supervision (equal); Validation (supporting); Resources (equal); Visualization (equal); Writing- original draft (equal); Writing- review & editing (equal). **Rebecca M. Brunner:** Conceptualization (supporting); Funding acquisition (equal); Resources (equal); Writing- original draft (supporting); Writing- review & editing (equal). **Ryan L. Lynch:** Conceptualization (supporting); Funding acquisition (equal); Project administration (equal); Investigation (equal); Methodology (equal); Resources (equal); Visualization (supportingl); Writing- original draft (supporting); Writing- review & editing (equal). **David Rodriguez:** Funding acquisition (equal); Project administration (supporting); Supervision (equal); Resources (equal); Writing- review & editing (equal). **Shawn F. McCracken:** Conceptualization (equal); Funding acquisition (lead); Project administration (lead); Supervision (lead); Investigation (equal); Methodology (equal); Validation (supporting); Resources (equal); Formal analysis (equal); Visualization (equal); Writing- original draft (equal); Writing- review & editing (lead).

**Competing Interests Statement**

Authors declare no competing interests

**Data Accessibility Statement**

The data from this manuscript will be made available on Dryad

**Literature Cited**

Astaras, C., Linder, J. M., Wrege, P., Orume, R., Johnson, P. J., & Macdonald, D. W. (2020). Boots on the ground: the role of passive acoustic monitoring in evaluating anti-poaching patrols. *Environmental Conservation*, *47*(3), 213–216. https://doi.org/10.1017/S0376892920000193

Aditya, V., Goswami, R., Mendis, A., & Roopa, R. (2021). Scale of the issue: Mapping the impact of the COVID-19 lockdown on pangolin trade across India. *Biological Conservation*, 257, 109136. https://doi.org/10.1016/j.biocon.2021.109136

Aguirre, A. A., & Tabor, G. M. (2008). Global factors driving emerging infectious diseases: Impact on wildlife populations. *Annals of the New York Academy of Sciences*, 1149(1), 1–3. https://doi.org/10.1196/annals.1428.052

Baquero, D. C. (2021). *Mongabay. Indigenous Amazonian communities bear the burden of Ecuador’s balsa boom.* Retrieved from: <https://news.mongabay.com/2021/08/indigenous-amazonian-communities-bear-the-burden-of-ecuadors-balsa-boom/> Accessed on October 25, 2021.

Bao, R., & Zhang, A. (2020). Does lockdown reduce air pollution? Evidence from 44 cities in northern China. *Science of the Total Environment*, 731, 139052. https://doi.org/10.1016/j.scitotenv.2020.139052

Barclay, E., & Bartel, R. (2015). Defining environmental crime: The perspective of farmers. *Journal of Rural Studies*, 39, 188–198. https://doi.org/10.1016/j.jrurstud.2015.01.007

Bates, A. E., Primack, R. B., Moraga, P., & Duarte, C. M. (2020). COVID-19 pandemic and associated lockdown as a “Global Human Confinement Experiment” to investigate biodiversity conservation. *Biological Conservation*, 248, 108665. https://doi.org/10.1016/j.biocon.2020.108665

Beirne, P. (2021). Wildlife trade and COVID-19: Towards a criminology of anthropogenic pathogen spillover. *The British Journal of Criminology*, 61(3), 607–626. https://doi.org/10.1093/bjc/azaa084

Bíl, M., Andrášik, R., Cícha, V., Arnon, A., Kruuse, M., Langbein, J., Náhlik, A., Niemi, M., Pokorny, B., Colino-Rabanal, V. J., Rolandsen, C. M., & Seiler, A. (2021). COVID-19 related travel restrictions prevented numerous wildlife deaths on roads: A comparative analysis of results from 11 countries. *Biological Conservation*, 256, 109076. https://doi.org/10.1016/j.biocon.2021.109076

Brancalion, P. H., Broadbent, E. N., De-Miguel, S., Cardil, A., Rosa, M. R., Almeida, C. T., Almeida, D. R. A., Chakravarty, S., Zhou, M., Gamarra, J. G., Liang, J., Crouzeilles, R., Hérault, B., Aragão, L. E. O. C., Silva, C. A., & Almeyda-Zambrano, A. M. (2020). Emerging threats linking tropical deforestation and the COVID-19 pandemic. *Perspectives in Ecology and Conservation*, 18(4), 243-246. https://doi.org/10.1016/j.pecon.2020.09.006

Brooks, M. E., Kristensen, K., Benthem, K. J. van, Magnusson, A., Berg, C. W., Nielsen, A., Skaug, H. J., Machler, M., & Bolker, B. M. (2017). Modeling Zero-Inflated count data with glmmTMB. *BioRxiv*, 132753. https://doi.org/10.1101/132753

Coba, G. (2021). Primicias. Las mafias de la balsa amenazan a la Amazonía ecuatoriana. Retrieved from: <https://www.primicias.ec/noticias/economia/tala-ilegal-madera-amazonia-balsa/>. Accessed on May 10, 2022.

Corlett, R. T., Primack, R. B., Devictor, V., Maas, B., Goswami, V. R., Bates, A. E., Koh, L. P., Regan, T. J., Loyola, R., Pakeman, R. J., Cumming, G. S., Pidgeon, A., Johns, D., & Roth, R. (2020). Impacts of the coronavirus pandemic on biodiversity conservation. *Biological Conservation*, 246, 108571. https://doi.org/10.1016%2Fj.biocon.2020.108571

Dantas, G., Siciliano, B., França, B. B., da Silva, C. M., & Arbilla, G. (2020). The impact of COVID-19 partial lockdown on the air quality of the city of Rio de Janeiro, Brazil. *Science of the Total Environment*, 729, 139085. https://doi.org/10.1016/j.scitotenv.2020.139085

Daszak, P., Cunningham, A. A., & Hyatt, A. D. (2000). Emerging infectious diseases of wildlife--threats to biodiversity and human health. *Science*, 287(5452), 443–449. doi/10.1126/science.287.5452.443

Dodson, C. H., & Gentry, A. H. (1991). Biological extinction in western Ecuador. *Annals of the Missouri Botanical Garden*, 78, 273–295. https://doi.org/10.2307/2399563

Duque, F. (2020). *Semana. La deforestación en Colombia no para.* Retrieved from: <https://www.semana.com/opinion/articulo/la-deforestacion-en-colombia-no-para/49828/>. Accessed on May 10, 2022.

Economic Commission for Latin America and the Caribbean. (2021). *Economic Survey of Latin America and the Caribbean. Ecuador.* Retrieved from: <https://repositorio.cepal.org/bitstream/handle/11362/47193/77/EI2021_Ecuador_en.pdf>. Accessed on December 13, 2021.

Ellwanger, J. H., Kulmann-Leal, B., Kaminski, V. L., Valverde-Villegas, J. M., Da Veiga, A. B. G., Spilki, F. R., Fearnside, F. M., Caesar, L., Giatti, L. L., Wallau, G. L., Almeida, S. E. M., Borba, M. R., Da Hora, V. P., & Chies, J. A. B. (2020). Beyond diversity loss and climate change: Impacts of Amazon deforestation on infectious diseases and public health. *Anais da Academia Brasileira de Ciências*, 92. https://doi.org/10.1590/0001-3765202020191375

Faridi, S., Yousefian, F., Janjani, H., Niazi, S., Azimi, F., Naddafi, K., & Hassanvand, M. S. (2021). The effect of COVID-19 pandemic on human mobility and ambient air quality around the world: a systematic review. *Urban Climate*, 38, 100888. https://doi.org/10.1016/j.uclim.2021.100888

Halabowski, D., & Rzymski, P. (2021). Taking a lesson from the COVID-19 pandemic: Preventing the future outbreaks of viral zoonoses through a multi-faceted approach. *Science of the Total Environment*, 757, 143723. https://doi.org/10.1016/j.scitotenv.2020.143723

Haro-Carrión, X., & Southworth, J. (2018). Understanding land cover change in a fragmented forest landscape in a biodiversity hotspot of coastal Ecuador. *Remote Sensing*, 10, 1–21. <https://doi.org/10.3390/rs10121980>

Heritage Foundation. (2022). 2022 Index of Economic Freedom. Ecuador. Retrieved from: <https://www.heritage.org/index/country/ecuador#:~:text=The%20world's%20largest%20banana%20exporter,percent%20of%20public%2Dsector%20revenues>. Accessed on June 20, 2022.

Iglesias, S. P. (2020). *Bloomberg News. Brazil to Boost Amazon Forest Oversight as Deforestation Jumps.* Retrieved from: <https://www.bloomberg.com/news/articles/2020-04-14/brazil-to-boost-amazon-forest-oversight-as-deforestation-jumps>. Accessed on February 15, 2022.

Kadykalo, A. N., Beaudoin, C., Hackenburg, D. M., Young, N., & Cooke, S. J. (2022). Social–ecological systems approaches are essential for understanding and responding to the complex impacts of COVID-19 on people and the environment. *PLOS Sustainability and Transformation*, 1(4), e0000006. https://doi.org/10.1371/journal.pstr.0000006

Keesing, F., Belden, L. K., Daszak, P., Dobson, A., Harvell, C. D., Holt, R. D., Hudson, P., Jolles, A., Jones, K. E., Mitchell, C. E., Myers, S.S., Bogich, T., & Ostfeld, R. S. (2010). Impacts of biodiversity on the emergence and transmission of infectious diseases. *Nature*, 468(7324), 647–652. https://doi.org/10.1038/nature09575

Kerimray, A., Baimatova, N., Ibragimova, O. P., Bukenov, B., Kenessov, B., Plotitsyn, P., & Karaca, F. (2020). Assessing air quality changes in large cities during COVID-19 lockdowns: The impacts of traffic-free urban conditions in Almaty, Kazakhstan. *Science of the Total Environment*, 730, 139179. https://doi.org/10.1016/j.scitotenv.2020.139179

Kline, L. R., DeAngelis, A. I., McBride, C., Rodgers, G. G., Rowell, T. J., Smith, J., Stanley, J. A., Read, A. D., & Van Parijs, S. M. (2020). Sleuthing with sound: Understanding vessel activity in marine protected areas using passive acoustic monitoring. *Marine Policy*, 120, 104138. https://doi.org/10.1016/j.marpol.2020.104138

Koju, N. P., Kandel, R. C., Acharya, H. B., Dhakal, B. K., & Bhuju, D. R. (2021). COVID‐19 lockdown frees wildlife to roam but increases poaching threats in Nepal. *Ecology and Evolution*, 11(14), 9198–9205. <https://doi.org/10.1002/ece3.7778>

Lara, M. G. (2022) *IFC. In Ecuador, plans for a tourism boom.* Retrieved from: <https://www.ifc.org/wps/wcm/connect/news_ext_content/ifc_external_corporate_site/news+and+events/news/insights/plans-for-a-tourism-boom-in-ecuador>. Accessed on June 20, 2022

LeClair, G., Chatfield, M. W., Wood, Z., Parmelee, J., & Frederick, C. A. (2021). Influence of the COVID‐19 pandemic on amphibian road mortality. *Conservation Science and Practice*, 3(11), e535. <https://doi.org/10.1111/csp2.535>

Lindahl, J. F., & Grace, D. (2015). The consequences of human actions on risks for infectious diseases: a review. *Infection Ecology & Epidemiology*, 5(1), 30048. https://doi.org/10.3402/iee.v5.30048

Liu, P., & Barlow, C. Y. (2016). The environmental impact of wind turbine blades. *IOP Conference Series: Materials Science and Engineering*, 139(1), 012032. https://doi.org/10.1088/1757-899X/139/1/012032

Manenti, R., & Hymas, O. (2021). Joint letter inspired by Hymas et al. (2021) “There’s nothing new under the sun – lessons conservationists could learn from previous pandemics”. Parks, 27.2, 79–83. https://doi.org/10.2305/IUCN.CH.2021.PARKS-27-2RM.en

Matache, M. G., Munteanu, M., Dumitru, D. N., & Epure, M. (2020). Evaluation of hand transmitted chainsaw vibrations during wood cutting. *E3S Web of Conferences*, 180, 03013. https://doi.org/10.1051/e3sconf/202018003013

Mittermeier, R. A., Turner, W. R., Larsen, F. W., Brooks, T. M., & Gascon, C. (2011). Global biodiversity conservation: the critical role of hotspots. In F. E. Zachos, J. C. Habel (Eds.), *Biodiversity hotspots: distribution and protection of conservation priority areas*. Heidelberg: Springer. 3–22.

Morcatty, T. Q., Feddema, K., Nekaris, K. A. I., & Nijman, V. (2021). Online trade in wildlife and the lack of response to COVID-19. *Environmental Research*, 193, 110439. https://doi.org/10.1016/j.envres.2020.110439

Myers, S. S., & Patz, J. A. (2009). Emerging threats to human health from global environmental change. *Annual Review of Environment and Resources*, 34(1), 223–252. 10.1146/annurev.environ.033108.102650

Pongsiri, M. J., Roman, J., Ezenwa, V. O., Goldberg, T. L., Koren, H. S., Newbold, S. C., Ostfeld, R. S., Pattanayak, S. K., & Salkeld, D. J. (2009). Biodiversity loss affects global disease ecology. *Bioscience*, 59(11), 945–954. https://doi.org/10.1525/bio.2009.59.11.6

Price, K. (2020). *Conservation International. Poaching, deforestation reportedly on the rise since COVID-19 lockdowns.* Retrieved from: <https://www.conservation.org/blog/poaching-deforestation-reportedly-on-the-rise-since-covid-19-lockdowns>. Accessed on December 5, 2021.

R Core Team. (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Rowcliffe, J. M., Kays, R., Kranstauber, B., Carbone, C., & Jansen, P. A. (2014). Quantifying levels of animal activity using camera trap data. Methods in ecology and evolution, 5(11), 1170-1179. https://doi.org/10.1111/2041-210X.12278

Rutz, C., Loretto, M. C., Bates, A. E., Davidson, S. C., Duarte, C. M., Jetz, W., Johnson, M., Kato, A., Kays, R., Mueller, T., Primack, R. B., Ropert-Coudert, Y., Tucker, M. A., Wikelski, M., & Cagnacci, F. (2020). COVID-19 lockdown allows researchers to quantify the effects of human activity on wildlife. *Nature Ecology & Evolution*, 4(9), 1156–1159. https://doi.org/10.1038/s41559-020-1237-z

Rahman, M. S., Alam, M. A., Salekin, S., Belal, M. A. H., & Rahman, M. S. (2021). The COVID-19 pandemic: A threat to forest and wildlife conservation in Bangladesh?. *Trees, Forests and People*, 5, 100119. https://doi.org/10.1016/j.tfp.2021.100119

Saraswat, R., & Saraswat, D. A. (2020). Research opportunities in pandemic lockdown. *Science*, 368(6491), 594-595. doi/10.1126/science.abc3372

Scanlon AO, J. E. (2021). Wildlife must be protected from crime and trade for the sake of public and planetary health. *PLoS Biology*, 19(10), e3001422. https://doi.org/10.1371/journal.pbio.3001422

Schofield, G., Dickson, L. C., Westover, L., Dujon, A. M., & Katselidis, K. A. (2021). COVID‐19 disruption reveals mass‐tourism pressure on nearshore sea turtle distributions and access to optimal breeding habitat. *Evolutionary Applications*, 14(10), 2516–2526. https://doi.org/10.1111/eva.13277

Shilling, F., Nguyen, T., Saleh, M., Kyaw, M. K., Tapia, K., Trujillo, G., Bejarano, M., Waetjen, D., Peterson, J., Kalisz, G., Sejour, R. A., Croston, S., & Ham, E. (2021). A reprieve from US wildlife mortality on roads during the COVID-19 pandemic. *Biological Conservation*, 256, 109013. https://doi.org/10.1016/j.biocon.2021.109013

Silva-Rodríguez, E. A., Gálvez, N., Swan, G. J., Cusack, J. J., & Moreira-Arce, D. (2021). Urban wildlife in times of COVID-19: What can we infer from novel carnivore records in urban areas?. *Science of The Total Environment*, 765, 142713. https://doi.org/10.1016/j.scitotenv.2020.142713

Tomaselli, I. (2019). Country Report: Ecuador. Retrieved from: <https://www.rinya.maff.go.jp/j/riyou/goho/jouhou/pdf/h30/H30report_nettaib_9.pdf>. Accessed on April 30, 2022

Wilmers, C. C., Nisi, A. C., & Ranc, N. (2021). COVID-19 suppression of human mobility releases mountain lions from a landscape of fear. *Current Biology*, 31(17), 3952–3955. https://doi.org/10.1016/j.cub.2021.06.050

Zahawi, R. A., Reid, J. L., & Fagan, M. E. (2020). Potential impacts of COVID‐19 on tropical forest recovery. *Biotropica*, 52(5), 803–807. https://doi.org/10.1111/btp.12851

Zinsstag, J., Schelling, E., Wyss, K., Mahamat, M. B. (2005) Potential of cooperation between human and animal health to strengthen health systems. *Lancet*, 366, 2142–2145. https://doi.org/10.1016/S0140-6736(05)67731-8

Zinsstag, J., & Tanner, M. (2008). One health’: the potential of closer cooperation between human and animal health in Africa. *Ethiopian Journal of Health Developmen*t, 22, 105–109. https://doi.org/10.4314/ejhd.v22i2.10078

Zohdy, S., Schwartz, T. S., & Oaks, J. R. (2019). The coevolution effect as a driver of spillover. *Trends in Parasitology*, 35(6), 399–408. https://doi.org/10.1016/j.pt.2019.03.010

**Figure 1:** Change in frequency of chainsaw detections in the Hacienda Camarones Key Biodiversity Area (HCKBA) after COVID-19 lockdowns (calculated by dividing total chainsaw detections per treatment by operating days and subtracting Post-Covid from Pre-Covid). Blue circles indicate a decrease in frequency, white indicates no change, and red indicates different degrees of increase. Inset is a map of South America, provided by DataBasin, with the red circle indicating the location of the HCKBA along the northeastern coast of Ecuador.

**Figure 2:** Predicted chainsaw frequency within the Hacienda Camarones Key Biodiversity Area in response to average rainfall (mm) by COVID-19 lockdown period with 95% confidence intervals.

**Figure 3:** Hourly chainsaw activity before and after the start of COVID-19 lockdowns in the Hacienda Camarones Key Biodiversity Area based on a 24 hr day. Peak of activity occurred around 10:00, and between the two time periods there was no significant shift in time of activity.

**Figure 4:** Map of known illegal activity throughout the Hacienda Camarones Key Biodiversity Area 2020 - 2021. Orange circles indicate evidence of timber extraction and blue circles indicate evidence of poaching. Yellow house icons indicate the location of communities.