THE LANCET
Planetary Health

Supplementary appendix

This appendix formed part of the original submission and has been peer reviewed. We post it as supplied by the authors.

Supplement to: Lawler OK, Allan HL, Baxter PWJ, et al. The COVID-19 pandemic is intricately linked to biodiversity loss and ecosystem health. *Lancet Planet Health* 2021; **5:** e840–50.

Appendix - Supplementary Material

Supplementary Box 1: Bat conservation and spillover risk reduction have common ground

Bats (*Chiroptera)* are a large order of flying mammals that include over 1,400 species around the globe.[1] Bats play key roles in ecological interaction networks and provide major ecosystem services, including pollination, seed dispersal, nutrient distribution and pest arthropod suppression.[2,3] Deforestation and fragmentation of bat habitats, and direct manipulation of bat populations, for example culling in response to disease outbreaks,[4,5] can have unfavourable consequences for a wide range of ecosystem services. These include reduced pollination of many bat-dependant crops,[3] reduced population suppression of mosquitoes (which are major disease vectors)[3,6] and other insects[7] and trophic cascade effects on the food web that can dramatically alter ecosystem structure and nutrient cycling.[3,8,9] Bat species are widely distributed, present globally except in Antarctica, the Arctic and a few oceanic islands[2] and are hunted throughout Africa, Asia, Oceania, Central and South America, primarily for consumption as food, but also for medicinal and cultural practices.[9-11] They provide an important source of tourism in some areas (e.g. up to 1500 tourists per evening visit a colony of Mexican free-tailed bats, *Tadarida brasiliensis*, in Texas, USA, contributing $3 million per year to the economy).[3] It is estimated that between 16 and 20% of bat species are highly vulnerable, threatened, endangered or at risk of extinction.[5] Pressures on bat populations include loss and fragmentation of their habitat and direct exploitation for food, medicine and other human use.[4,5]

Despite the vast importance of bats and the clear need to conserve bat species across ecosystems, direct or indirect contact between bats and humans can lead to pathogens originating in bats transmitting to humans, in some cases resulting in human disease outbreaks. Bats harbour significantly more zoonotic viruses per species than all other mammalian orders.[12] Bat-to-human pathogen transmission can result when people closely interact with bats, for example by capturing, hunting, trading and eating them[2,13,14], as has historically occurred in the cases of Lyssaviruses, Nipah virus, rabies and Ebola virus.[2,15] Spillover from bat to human populations can also occur with the involvement of an intermediate or amplifier host. This pathway has led to human outbreaks of Hendra, Nipah, Ebola, SARS-CoV and Lyssaviruses[2,15] (Supplementary Table 1) and possibly, COVID-19.[9,16-18]

Minimising risks of zoonotic disease emergence associated with bats is complex, as worldwide, bat habitat and human environments increasingly overlap.[2] It is critical not to foster an attitude of fear toward bats, which may reduce support for protection of bats or even prompt calls for bat-control programs.[4,5] These outcomes not only further threaten bat conservation, but may undermine efforts to control zoonotic pathogen spillover, making spillover events more, rather than less, likely.[4] In fact, bat conservation and spillover risk reduction both have significant crossover in their approaches – progress toward both goals require prevention of further encroachment into bat habitat and reduction in human exploitation of bats.

Many people, including some Indigenous communities around the world, rely on bats for a source of livelihood and cultural identity, despite the threats of zoonotic or potentially zoonotic pathogens within the bat populations they interact with. For example, in Papua New Guinea, over 80% of all rural dwellers heavily rely on wildlife, including native bats, for sources of protein.[19] A 2008 serology study of a sample of 66 bats from 3 locations across Papua New Guinea found that the genus *Henipavirus* (contains zoonotic Hendra and Nipah viruses) was present in 55% of the population, and the genus *Rubulavirus* (contains zoonotic Menangle virus) was present in 56% of the population.[20] In Nepal, some populations who traditionally hunt bats have limited alternative protein sources[21,22] due to a combination of growing human population, rapid land conversion and rural population poverty.[23] However, bat populations in Nepal carry rabies and other novel pathogens with zoonotic potential.[24] Addressing the consumption of bushmeat in both of these situations would minimise risks of zoonotic disease emergence and create better conservation outcomes for bats. However, doing so without ensuring alternatives to bat resources that are nutritionally, culturally and financially appropriate could have substantially negative outcomes for the people who rely on bats. In contexts where bats live in close proximity to humans and livestock,[25] opportunities are provided for pathogens to transmit from bat hosts to humans directly, when coming in contact with bats' saliva, urine or faeces, or indirectly via livestock as intermediate or amplifier hosts.[2,3,6,26] Conserving bat habitat by minimising both large and small-scale land conversion to agriculture, along with additional interventions that reduce the risk of spillover, such as pathogen surveillance in bats and other species[26] would minimise zoonotic spillover risks, but may have ramifications for food systems, livelihoods and economies.

In the context of the COVID-19 pandemic, responsible economic recovery strategies at multiple scales must consider how bats, their habitat and the people who rely on bats are impacted (Figure 1b), and the ramifications of these strategies for drivers of zoonotic disease emergence. Without these considerations, humans may increasingly experience outbreaks of disease caused by zoonotic pathogens of bat origin – possibly, this zoonotic disease pandemic will feed back into increased risk of future zoonotic spillover events (Figure 1b). Living safely alongside bats, while protecting bats, requires tactical and well-informed bat conservation and reduction of human contact with bats in its many forms. There is a need for raising awareness worldwide, including in remote areas, on the value of bats for both humans and natural ecosystems, and also their potential to be reservoirs of zoonotic pathogens. The complexity of environmental and socio-economic factors needs to be incorporated into any measures that aim to minimise zoonosis emergence risks worldwide.[27] Efficient and inclusive actions will take into account different drivers and risk factors associated with disease spillover from bats,[26] raise widespread awareness, and provide alternative resources and income sources for local communities.

Figure 1: Bats play essential ecological roles, such as that of the Greater short nosed fruit bat (*Cynopterus sphinx, left image*) being an important pollinator of the kapok tree (*Ceiba pentandra*), a significant fibre and oil crop in southern India (centre).[28] Protection of bat habitat helps maintain and support the benefits bats provide for both ecosystems and humans who depend on their services, and may also limit risks of future zoonotic spillover events between bat and human populations.[2]

Images: (left) Greater Short-nosed Fruit Bat by Mike Prince, CC BY 2.0; (centre) Pokok Kekabu - *Ceiba pentandra*, by musimpanas, CC BY-ND 2.0 (image cropped); (right) Protected Habitat Sign – Horseshoe Mesa – Grand Canyon, USA by Al_HikesAZ, CC BY-NC 2.0 (image cropped).

References – Supplementary Box 1

1. Burgin CJ, Colella JP, Kahn PL, Upham NS. How many species of mammals are there? *Journal of Mammalogy* 2018; **99**(1): 1-14.
2. Allocati N, Petrucci A, Di Giovanni P, Masulli M, Di Ilio C, De Laurenzi V. Bat–man disease transmission: zoonotic pathogens from wildlife reservoirs to human populations. *Cell death discovery* 2016; **2**(1): 1-8.
3. Kasso M, Balakrishnan M. Ecological and economic importance of bats (Order Chiroptera). *International Scholarly Research Notices* 2013; **2013**.
4. Olival KJ. To cull, or not to cull, bat is the question. *Ecohealth* 2016; **13**(1): 6-8.
5. Durán TG. Bats: Resistant to viruses, but not to humans. *Mongabay*, 13 May 2020. https://news.mongabay.com/2020/05/bats-resistant-to-viruses-but-not-to-humans/ (accessed 11 August 2020).
6. Reiskind MH, Wund MA. Experimental assessment of the impacts of northern long-eared bats on ovipositing Culex (Diptera: Culicidae) mosquitoes. *Journal of medical entomology* 2009; **46**(5): 1037-44.
7. O'Bryan CJ, Braczkowski AR, Magalhães RJS, McDonald-Madden E. Conservation epidemiology of predators and scavengers to reduce zoonotic risk. *The Lancet Planetary Health* 2020; **4**(8): e304-e5.
8. Polis GA, Sears AL, Huxel GR, Strong DR, Maron J. When is a trophic cascade a trophic cascade? *Trends in ecology & evolution* 2000; **15**(11): 473-5.
9. Boni MF, Lemey P, Jiang X, et al. Evolutionary origins of the SARS-CoV-2 sarbecovirus lineage responsible for the COVID-19 pandemic. *Nature Microbiology* 2020; **5**(11): 1408-17.
10. Mildenstein T, Tanshi I, Racey PA. Exploitation of bats for bushmeat and medicine. Bats in the Anthropocene: conservation of bats in a changing world: Springer, Cham; 2016: 325-75.
11. Mickleburgh S, Waylen K, Racey P. Bats as bushmeat: a global review. *Oryx* 2009; **43**(2): 217-34.
12. Olival KJ, Hosseini PR, Zambrana-Torrelio C, Ross N, Bogich TL, Daszak P. Host and viral traits predict zoonotic spillover from mammals. *Nature* 2017; **546**(7660): 646-50.
13. Luis AD, Hayman DT, O'Shea TJ, et al. A comparison of bats and rodents as reservoirs of zoonotic viruses: are bats special? *Proceedings of the Royal Society B: Biological Sciences* 2013; **280**(1756): 20122753.
14. Han GZ. Pangolins Harbor SARS-CoV-2-Related Coronaviruses. *Trends Microbiol* 2020; **28**(7): 515-7.
15. Chan JF, To KK, Tse H, Jin DY, Yuen KY. Interspecies transmission and emergence of novel viruses: lessons from bats and birds. *Trends Microbiol* 2013; **21**(10): 544-55.
16. World Health Organization. WHO-convened global study of origins of SARS-CoV-2: China part, 2021.
17. Andersen KG, Rambaut A, Lipkin WI, Holmes EC, Garry RF. The proximal origin of SARS-CoV-2. *Nature Medicine* 2020; **26**(4): 450-2.
18. Zhou H, Ji J, Chen X, et al. Identification of novel bat coronaviruses sheds light on the evolutionary origins of SARS-CoV-2 and related viruses. *bioRxiv* 2021.
19. Mack AL, West P. Ten thousand tonnes of small animals: wildlife consumption in Papua New Guinea, a vital resource in need of management. 2018.
20. Breed AC, Yu M, Barr JA, Crameri G, Thalmann CM, Wang L-F. Prevalence of henipavirus and rubulavirus antibodies in pteropid bats, Papua New Guinea. *Emerging infectious diseases* 2010; **16**(12): 1997.
21. Sharma DP. Understanding the Chepangs and shifting cultivation: A case study from rural village of central Nepal. *Dhaulagiri Journal of Sociology and Anthropology* 2011; **5**: 247-62.
22. Accharya PR, Adhikari H, Dahal S, Thapa A, Thapa S. Bats of Nepal, A field guide. Small Mammals Conservation and Research Foundation; 2012.
23. Piya L, Maharjan KL, Joshi NP. Vulnerability of rural households to climate change and extremes: Analysis of Chepang households in the Mid-Hills of Nepal, 2012.
24. Shah Y, Pandey K, Pant DK, et al. Potential Threat of Rabies Virus from Bat Bite in Nepal. *The Open Microbiology Journal* 2018; **12**(1).
25. Wood JL, Leach M, Waldman L, et al. A framework for the study of zoonotic disease emergence and its drivers: spillover of bat pathogens as a case study. *Philosophical Transactions of the Royal Society B: Biological Sciences* 2012; **367**(1604): 2881-92.
26. Plowright RK, Eby P, Hudson PJ, et al. Ecological dynamics of emerging bat virus spillover. *Proceedings of the Royal Society B: Biological Sciences* 2015; **282**(1798): 20142124.
27. Cunningham AA, Daszak P, Wood JL. One Health, emerging infectious diseases and wildlife: two decades of progress? *Philosophical Transactions of the Royal Society B: Biological Sciences* 2017; **372**(1725): 20160167.
28. Nathan PT, Raghuram H, Elangovan V, Karuppudurai T, Marimuthu G. Bat pollination of kapok tree, *Ceiba pentandra*. *Current Science* 2005: 1679-81.

Supplementary Table 1: Characteristics of a selection of zoonotic diseases and the impacts of significant outbreaks, both past and ongoing. 'Disease' refers to the name of the disease caused by the corresponding pathogen; 'Pathogen(s)' refers to the commonly accepted nomenclature of the pathogen causing the corresponding disease; 'Significant outbreak(s)' refers to selected examples of outbreaks (non-exhaustive) of the respective disease, generally considered to have had substantial human and economic impacts; 'Zoonotic origins' refers to what is known of the circumstances in which the corresponding pathogen was transmitted from animals to humans, for example, the reservoir and intermediate hosts, and the direct context surrounding the initial cross-species transmission; 'Human health impact' refers specifically to the known direct impacts on human health of the corresponding outbreak – that is, the known number of cases of the disease and the known mortality (indirect human health impacts are not included); 'Economic impact' refers to the known economic effects associated with the corresponding outbreak, which is significant in itself, and can act loosely acts as a proxy for effects on conservation spending as a result of the outbreak* (note that the calculation methods for economic impacts of outbreaks may be vastly different and what is reported may only be a selection of the true net impacts); 'Biodiversity Health related drivers' refers to the known associations of the corresponding disease and/or outbreak with the key anthropogenic drivers of zoonotic disease (agricultural intensification, land use change, wildlife trade, climate change). This table illustrates the major role the identified drivers of zoonotic disease transmission have played in zoonotic disease outbreaks of the past.
*Pergams et al. [2004] determined that GDP and personal income predict conservation spending.

Disease	Pathogen(s)	Significant outbreak(s)	Zoonotic origins	Direct human health impact	Economic impact	Biodiversity Health related drivers
Influenza	Influenza A virus subtype H1N1	Spanish flu pandemic, 1917-1921.[1]	Evidence suggests that the virus emerged from avian reservoirs, which adapted to infect humans.[4] ** See further details below table.*	The Spanish flu pandemic saw 500 million cases and 20 to 100 million deaths.[2,3,12]	The Spanish flu pandemic resulted in a GDP loss of 3% in Australia, 15% in Canada, 17% in the United Kingdom, and 11% in the United States.[5]	** *See further details below table.*
Influenza	Influenza A virus subtype H2N2	Asian flu pandemic, 1957-1958.[2]	Originated from reassortment between H1N1 virus circulating in human populations and H2N2 virus in wild avian reservoirs.[7] ** See further details below table.*	Caused 1 to 2 million deaths globally.[6,12]	The Asian flu pandemic resulted in a GDP loss of 3% in Canada, Japan, the United Kingdom, and the United States.[5]	** *See further details below table.*
Influenza	Influenza A virus subtype H3N2	Hong Kong flu pandemic, 1968-1969.[2]	Originated from reassortment between H1N1 virus circulating in human populations and H3 virus in wild avian reservoirs.[7] ** See further details below table.*	The 1968-1969 pandemic caused around 1 million deaths worldwide.[15] H3N2 has also become the leading cause of seasonal influenza disease and mortality.[8]	The 2010 Hong Kong flu pandemic contributed to a loss of between 0.4% and 1.5% global GDP,[9] including direct and indirect costs of US$23 billion–US$26 billion in the United States.[10]	** *See further details below table.*
Influenza	Influenza A virus subtype H1N1 (Swine-origin H1N1)	Mexican swine flu pandemic, 2009.[11]	Originated from reassortment of virus lineages circulating in pig populations.[10] ** See further details below table.*	Caused 284,000 deaths.[12]	The Mexican swine flu pandemic is estimated to have caused a loss to Mexico's economy of >$3.2 billion (0.3% of GNP). Tourism losses were estimated at US$2.8 billion.[12]	** *See further details below table.*
Marburg virus disease (MVD)	Marburg virus (MARV)	Outbreak in Germany and former Yugoslavia, 1967.[24] Outbreak in Durban and Watsa, DRC, 1998-2000.[18]	Bat-to-human transmission has been involved in most outbreaks.[24] Evidence suggests a major natural reservoir is the Egyptian fruit bat (*Rousettus aegyptiacus*), which can transmit the virus to humans and nonhuman primates.[20,21] Other bat species are also considered potential reservoirs, as they have tested positive to the virus.[22,23] There are	The first recorded outbreak (1967) caused at least 29-31 cases and 7 deaths.[10,25] The 1998-2000 outbreak led to 156 cases with an 83% mortality rate.[18] The 2004-2005 Angolan outbreak caused 252 cases with a 90% mortality rate.[19] Until 2012, 452 cases and 368 deaths were reported.[24]	Considered as marginal nevertheless, outbreaks usually occur in small rural areas, with limited health care settings, and where local impacts of this disease can be devastating.[26]	**Land-use change:** Can facilitate the presence of humans in areas inhabited by reservoir species[24]. Mine workers and tourists have been infected when entering caves inhabited by, or experienced close contact with bats.[18,19,24] **Wildlife trade**: Contact with tissues of an infected African green monkeys legally imported from Uganda to Germany, and Belgrade and Yugoslavia (now Serbia), was the cause of the first reported outbreak in 1967.[25]

		Outbreak in Angola, 2004-2005.[19]	reports of infected African green monkeys (*Chlorocebus aethiops*) being involved in the transmission of the virus to humans.[25]			
Acquired immuno-deficiency syndrome (AIDS)	Human immuno-deficiency viruses (HIV-1, HIV-2)	1981-present.[76]	Chimpanzees (*Pan troglodytes*) have been identified as the natural reservoirs of the pandemic (group M), responsible for most human infections, and nonpandemic (group N) HIV-1.[78] HIV-2 presumably originated from immunodeficiency virus strains after multiple cross-species transmission events from sooty mangabeys (*Cercocebus atys*) to humans.[79]	To date, HIV viruses have caused 75.70 million cases and 32.7 million deaths.[77] In 2019, there were 1.7 million new cases, which is a 40% decrease compared to the peak of the epidemic in 1998.[77]	The HIV/AIDS pandemic reduced the growth rate of Africa's per capita income by 0.7% annually between 1990 and 1997.[82] A 2019 study showed that a 1% increase in the HIV/AIDS prevalence rate in Sub Saharan Africa retarded growth in per capita income by 0.47% between 2000 and 2015.[83] AIDS global response in 2020 is expected to cost around US$26.2 billion.[77]	**Wildlife trade:** Based on the biology of HIV-1 viruses, bushmeat hunting is thought to have provided the context for transmission, which must have occurred through exposure to infected blood and/or body fluids of apes.[76,80] These practices increase human exposure to simian lentiviruses with the potential of causing new epidemics.[80,81]
Severe Acute Respiratory Syndrome (SARS)	SARS Coronavirus (SARS-CoV)	Outbreak in Guangdong Province, China, 2002-2004.[27]	Early evidence pointed to Himalayan palm civets (*Paguma larvata*) and racoon dogs (*Nyctereutes procyonoides*) as the source of infections to humans that caused the outbreak.[28] Recent evidence points to such species as being intermediate amplifying hosts, with bats as main reservoir hosts.[29,30] There is also evidence of SARS-CoV infection in other mammal species.[28,31]	To date, SARS-CoV has caused 8098 cases and 774 deaths.[1]	GDP loss estimated at 2.63% in Hong Kong and 1.05% for mainland China. Global loss in 2003 estimated at US$40 billion.[23]	**Wildlife trade:** Wet markets are thought to have provided the context for the initial transmission that caused the 2002 outbreak.[28] Sporadic infections between 2003 and 2004 were linked to restaurants that served Himalayan palm civet meat.[32] **Land use change:** Deforestation can increase contact between bats, as natural reservoirs of coronaviruses, and humans.[27]
Ebola Virus Disease (EVD)	Ebolavirus species (EBOV, SUDV, BDBV, TAFV)[50]	The West Africa EBOV outbreak (2013-2016) is the most significant outbreak recorded to date. It began in Guinea and affected Liberia, Sierra Leone, Senegal and Nigeria [49,50,51]	Outbreaks have been recorded in Africa since 1976 and are caused by 4 known strains.[50] Although still unclear,[53] several bat species are the putative reservoirs of ebolaviruses.[50,54,55] Spillover to humans can result from direct close contact or indirectly, through fluids from infected animals.[50,54,55] Non-human primates (such as chimpanzees) can also be infected and consumption of infected animals can facilitate transmission to humans.[56] Previous outbreaks indicate that after an initial spillover event from natural reservoirs or infected wild hosts, human to human transmission of the virus becomes the main mechanism of spread.[57,58]	Over 28,600 suspected cases and 11,300 deaths.[52]	Direct economic costs of the West Africa outbreak are estimated at US$14 billion.[60] A more comprehensive assessment of the economic and social burden found the outbreak led to losses exceeding US$53 billion when accounting for the cost of human lives, health care workforce, non-Ebola deaths, long-term sequelae, prevention costs and other social costs.[60] Guinea, Liberia and Sierra Leone experienced significant reductions in GDP and economic growth during and after the outbreak.[60,61]	**Land use change:** Human encroachment and habitat fragmentation of natural reservoirs has been associated with EVD outbreaks, as it can facilitate contact and spillover of EBOV to humans.[50,59] **Wildlife trade:** Consumption of bushmeat from infected animals, such as fruit bats, has been linked to human outbreaks.[53] **Climate change:** Research suggests that climate change may increase the likelihood of ebolavirus spillover events through facilitating more interactions between humans and animal hosts, as the preferred ranges of potential hosts increases.

Middle East respiratory syndrome (MERS)	Middle East respiratory syndrome coronavirus (MERS-CoV)	Outbreak in Saudi Arabia, 2013-2015.[33] Outbreak in South Korea, 2015.[33]	Dromedary camels have been identified as reservoirs of the virus and play an important role in the zoonotic transmission of this disease.[35] Bats have been identified as the evolutionary source for the virus.[30,36]	By November 2019, there were 2,494 confirmed cases with 848 associated deaths (35% mortality rate).[34]	Direct costs associated with disease treatment in Saudi Arabia are estimated to be over US$26 million. Costs associated with prevention and control responses have not been reported.[85] An estimated US$2.6 billion loss due to reduced tourism in the Republic of Korea in 2015.[86]	**Agricultural Intensification:** Camels are widely farmed and used in the Saudi Arabia Region, where several transmission events to humans have been reported.[33,37,38] The movement of dromedary camels for trade can promote the spread of the virus,[39] with the potential of affecting other livestock, such as llamas and pigs.[40]
Zika virus disease	Zika virus (ZIKV)	Outbreak in French Polynesia, 2013-2014.[41] Outbreak in Bahia Brazil 2015-2016.[84]	Zika is a vector-borne disease transmitted by several species of *Aedes* mosquitoes,[42] primarily *Aedes aegypti*, *Aedes albopictus* and *Aedes africanus*.[43,48] Non-human primates are known to be involved in the sylvatic transmission cycle (e.g. the disease is maintained in a cycle of transmission between non-human primate hosts and mosquito vectors in Africa).[44,45,89]*Aedes spp.* vectors act as a bridge to transmit the virus from non-human primates to humans, and vice versa.	Between 2013 and 2014, 30,000-32,000 symptomatic cases were reported across French Polynesia.[41] It is estimated that 440,000 -1,300,000 Zika cases occurred in 2015 in Brazil.[84]	Estimated short term costs in Latin America and the Caribbean was US$7-18 billion (0.05- 0.12% GDP of region) between 2015 and 2017.[22]	**Wildlife trade:** Practices including the wildlife trade, which bring humans into closer proximity to ZIKV-carrying non-human primates, in the presence of *Aedes spp.* mosquitoes, can provide opportunity for the transmission of the virus from non-human primates to humans, and vice versa, via mosquito vectors.[89] **Land-use change:** Deforestation has been associated with an increase in mosquitoes that are vectors of several zoonotic infectious diseases, including Zika.[46] **Climate change:** It is expected that, with increasing temperatures, there will be an expansion of the range of the vector and longer seasons of environmental suitability for ZIKV.[47]
Rabies	Rabies virus (RABV)	Outbreak in Bali, Indonesia, 2008-2011.[88]	Historical records of rabies date back 4,000 years.[62] Bats[66,67,68,69] and mesocarnivores[69,70,71] are among the main wild reservoirs of RABV in the sylvatic cycle, causing sporadic cases of human infection.[66,71] Domestic dogs are the reservoirs responsible for the majority of human infections, particularly in Asia and Africa, where canine rabies is enzootic.[72]	Rabies causes around 59,000 deaths every year, primarily in Asia and Africa.[63] Approximately 80% of human deaths occur in rural areas,[64] where uncontrolled domestic dog populations are common and where education and access to health services is low.[65] It is estimated that globally, more than 29 million people receive a post-bite vaccination every year.[63] The 2008-2011 Bali outbreak killed at least 130 people. Postexposure prophylaxis was administered to >130000 people who were bitten by dogs.[88]	Globally, rabies causes an estimated cost of US$8.6 billion per year, which is an important economic burden for some of the poorest regions in the world, associated with premature deaths, cost of post-exposure prophylaxis and loss of income.[63]	**Land-use change**: Bat-related rabies in Brazil has been linked to deforestation of the Amazon, which has increased bat contact with humans and livestock.[73] Human encroachment into natural areas can also facilitate direct contact with bats, carnivores, or other wild reservoirs.[66,71] Furthermore, increased contact between wild reservoirs and domestic dogs could increase the risk of human infection and reduce effectiveness of control measures.[74,75]

* The following applies to 'Zoonotic origins' of Influenza A in general:
Wild waterbirds (including orders Anseriformes and Charadriiformes) are considered the ancestral hosts of most, if not all, influenza A viruses.[13]
** The following applies to 'Biodiversity Health related drivers' of Influenza A outbreaks in general:

Agricultural intensification: Intensive farming conditions promote intra- and inter-specific influenza transmission due to high densities, stress and reduced genetic diversity. Moreover, livestock trade can spread different influenza viruses across regions,[13] and pigs in particular are a significant reservoir for the mixing and potential emergence of novel influenza A viruses to which humans are susceptible.[87]

Land use change: Loss of wetlands can impact waterfowl, which are important wild reservoirs of influenza, causing an increase in bird density in remaining wetlands, stress and proximity to domestic animals.[13]

Wildlife trade: Wild bird trade presents the risk of spreading existing strains of influenza viruses, as well as facilitating the evolution of new strains via 'strain mixing'. Illegally-traded wild birds present particularly significant risks, as the often circumvent local requirements for pathogen testing and quarantine measures. Where wildlife trade occurs alongside trade in domestic animals, particularly poultry and swine, risks are heightened by further opportunities for transmission to animals that may act as intermediate hosts for animal-to-human transmission, and by the creation of conditions that may allow new strains of Influenza A to emerge[13].

Climate Change: Early onset of influenza outbreaks tend to follow warm winters, which are increasing in frequency due to climate change.[16] Furthermore, it can alter bird migrations (timing and patterns), which could promote influenza transport, transmission and reassortment in reservoir populations.

References – Supplementary Table 1

[1] Liu WJ, Bi Y, Wang D, Gao GF. On the centenary of the Spanish flu: Being prepared for the next pandemic. *Virol Sin* 2018; **33**: 463-66.
[2] Guan Y, Vijaykrishna D, Bahl J, Zhu H, Wang J, Smith GJ. The emergence of pandemic influenza viruses. *Protein Cell* 2010; **1**: 9–13.
[3] Patterson KD, Pyle GF. The geography and mortality of the 1918 influenza pandemic. *Bull Hist Med* 1991; **65**: 4–21.
[4] Taubenberger JK, Reid AH, Lourens RM, Wang R, Jin G, Fanning TG. Characterization of the 1918 influenza virus polymerase genes. *Nature* 2005; **437**: 889–93.
[5] McKibbin WJ, Sidorenko A. Global macroeconomic consequences of pandemic influenza. Sydney, Australia: Lowy Institute for International Policy, 2006.
[6] Viboud C, Simonsen L, Fuentes R, Flores J, Miller MA, Chowell G. Global mortality impact of the 1957–1959 influenza pandemic. *J Infect Dis* 2016; **213**: 738-45.
[7] Lindstrom SE, Cox NJ, Klimov A. Genetic analysis of human H2N2 and early H3N2 influenza viruses, 1957–1972: Evidence for genetic divergence and multiple reassortment events. *Virology* 2004; **328:** 101-19.
[8] Jester BJ, Uyeki TM, Jernigan DB. Fifty Years of Influenza A (H3N2) Following the Pandemic of 1968. *Am J Public Health* 2020 May; **110**: 669-76.
[9] WHO. Pandemic influenza preparedness and response: a WHO guidance document. Geneva, World Health Organization, 2009.
[10] Madhav N, Oppenheim B, Gallivan M, Mulembakani P, Rubin E, Wolfe N. Pandemics: Risks, impacts, and mitigation. In: Jamison DT, Gelband H, Horton S, et al., eds. Disease control priorities: Improving health and reducing poverty, 3rd edn. Washington, DC: The International Bank for Reconstruction and Development / The World Bank, 2017.
[11] Smith GJD, Vijaykrishna D, Bahl J, et al. Origins and evolutionary genomics of the 2009 swine-origin H1N1 influenza A epidemic. *Nature* 2009; **459**: 1122–25.
[12] Hall CM, Scott D, Gössling S. Pandemics, transformations and tourism: be careful what you wish for. *Tourism Geographies* 2020; 1-22.
[13] Vandegrift KJ, Sokolow SH, Daszak P, Kilpatrick AM. Ecology of avian influenza viruses in a changing world. *Ann N Y Acad Sci* 2010; **1195**: 113–28.
[14] Naffakh N, Van Der Werf S. April 2009: an outbreak of swine-origin influenza A (H1N1) virus with evidence for human-to-human transmission. *Microbes and infection*; **11**: 725-8.
[15] Centres for Disease Control and Prevention (CDC). 1968 pandemic (H3N2 virus). Jan 2, 2019. https://www.cdc.gov/flu/pandemic-resources/1968-pandemic.html (accessed Sept 29, 2020).
[16] Towers S, Chowell G, Hameed R, et al. Climate change and influenza: the likelihood of early and severe influenza seasons following warmer than average winters. *PLoS Curr* 2013; **5**.
[17] Morin CW, Stoner-Duncan B, Winker K, et al. Avian influenza virus ecology and evolution through a climatic lens. *Environ Int* 2018; **119**: 241-49.
[18] Bausch DG, Nichol ST, Muyembe-Tamfum JJ, et al. Marburg hemorrhagic fever associated with multiple genetic lineages of virus. *N Engl J Med* 2006; **355**: 909-19.
[19] Towner JS, Khristova ML, Sealy TK, et al. Marburgvirus genomics and association with a large hemorrhagic fever outbreak in Angola. *J Virol* 2006; **80**: 6497-516.
[20] Towner JS, Pourrut X, Albariño CG, et al. Marburg virus infection detected in a common African bat. *PLoS One* 2007; **2**: e764.
[21] Towner JS, Amman BR, Sealy TK, et al. Isolation of genetically diverse Marburg viruses from Egyptian fruit bats. *PLoS Pathog* 2009; **5**: e1000536.
[22] Swanepoel R, Smit SB, Rollin PE, et al. Studies of reservoir hosts for Marburg virus. *Emerg Infect Dis* 2007; **13**: 1847-51.
[23] Kuzmin IV, Niezgoda M, Franka R, et al. Marburg virus in fruit bat, Kenya. *Emerg Infect Dis* 2010; **16**: 352-54.
[24] Brauburger K, Hume AJ, Mühlberger E, Olejnik J. Forty-five years of Marburg virus research. *Viruses* 2012; **4**: 1878-927.
[25] Martini GA, Siegert R. Marburg virus disease. New York: Springer, 1971.
[26] MacNeil A, Rollin PE. Ebola and Marburg hemorrhagic fevers: Neglected tropical diseases?. *PLoS Negl Trop Dis* 2012; **6**: e1546.
[27] da Silva PG, Mesquita, JR., Nascimento MSJ, Ferreira VAM. Viral, host and environmental factors that favor anthropozoonotic spillover of coronaviruses: An opinionated review, focusing on SARS-CoV, MERS-CoV and SARS-CoV-2. *Sci Total Environ* 2021; **750**: 141483.
[28] Guan Y, Zheng BJ, He YQ, et al. Isolation and characterization of viruses related to the SARS coronavirus from animals in southern China. *Science* 2003; **302**: 276-78.
[29] Li W, Shi Z, Yu M, et al. Bats are natural reservoirs of SARS-like coronaviruses. *Science* 2005; **310**: 676-79.
[30] Cui J, Li F, Shi Z. Origin and evolution of pathogenic coronaviruses. *Nat Rev Microbiol* 2019; **17**: 181–92.
[31] Martina B, Haagmans B, Kuiken T, et al. SARS virus infection of cats and ferrets. *Nature* 2003; **425**: 915.

[32] Song H, Tu C, Zang G, et al. Cross-host evolution of severe acute respiratory syndrome coronavirus in palm civet and human. *Proc Natl Acad Sci U S A* 2005; **102**: 2430-35.
[33] Willman M, Kobasa D, Kindrachuk J. A comparative analysis of factors influencing two outbreaks of Middle Eastern Respiratory Syndrome (MERS) in Saudi Arabia and South Korea. *Viruses* 2019; **11**: 1119.
[34] WHO. Middle East respiratory syndrome coronavirus (Mers-Cov). March 11, 2019. https://www.who.int/news-room/fact-sheets/detail/middle-east-respiratory-syndrome-coronavirus-(mers-cov) (accessed Sept 21, 2020).
[35] Azhar EI, El-Kafrawy SA, Farraj SA, et al. (2014). Evidence for camel-to-human transmission of MERS coronavirus. *N Engl J Med* 2014; **370**: 2499-505.
[36] Anthony SJ, Gilardi K, Menachery VD, et al. Further evidence for bats as the evolutionary source of Middle East Respiratory Syndrome coronavirus. *mBio* 2017; **8**: e00373-17.
[37] Dudas G, Carvalho L, Rambaut A, Bedford T. MERS-CoV spillover at the camel-human interface. *eLife* 2018; **7**: e31257.
[38] Sikkema RS, Farag EABA, Islam M, et al. Global status of Middle East respiratory syndrome coronavirus in dromedary camels: A systematic review. *Epidemiol Infect* 2019; **147:** e84.
[39] Younan M, Bornstein S, Gluecks IV. MERS and the dromedary camel trade between Africa and the Middle East. *Trop Anim Health Prod* 2016; **48**: 1277–82.
[40] Vergara-Alert J, van den Brand JM, Widagdo W, et al. Livestock Susceptibility to Infection with Middle East Respiratory Syndrome Coronavirus. *Emerg Infect Dis* 2017; **23**: 232-40.
[41] Kucharski AJ, Funk S, Eggo RM, Mallet HP, Edmunds WJ, Nilles EJ. Transmission dynamics of Zika virus in island populations: A modelling analysis of the 2013-14 French Polynesia outbreak. *PLoS Negl Trop Dis* 2016; **10**: e0004726.
[42] Musso D, Bossin H, Mallet HP, Besnard M, Broult J, Baudouin L, Levi JE, Sabino EC, Ghawche F, Lanteri MC, Baud D. Zika virus in French Polynesia 2013–14: anatomy of a completed outbreak. The Lancet Infectious Diseases. 2018 May 1;18(5):e172-82.
[43] Chouin-Carneiro T, Vega-Rua A, Vazeille M, et al. Differential susceptibilities of *Aedes aegypti* and *Aedes albopictus* from the Americas to Zika virus. *PLoS Negl Trop Dis* 2016; **10**: e0004543.
[44] Vasilakis N, Weaver SC. Flavivirus transmission focusing on Zika. *Curr Opin Virol* 2017; **22**: 30-35.
[45] Terzian ACB, Zini N, Sacchetto L, et al. Evidence of natural Zika virus infection in neotropical non-human primates in Brazil. *Sci Rep* 2018; **8**: 1-15.
[46] Burkett-Cadena ND, Vittor,AY. Deforestation and vector-borne disease: Forest conversion favors important mosquito vectors of human pathogens. *Basic Appl Ecol* 2018; **26**: 101-10.
[47] Tesla B, Demakovsky LR, Mordecai EA, et al. Temperature drives Zika virus transmission: Evidence from empirical and mathematical models. *Proc R Soc B* 2018; **285**: 20180795.
[48] Carlson CJ, Dougherty ER, Getz W. An ecological assessment of the pandemic threat of Zika virus. *PLoS Negl Trop Dis* 2016; **10**: e0004968.
[49] Vetter P, Dayer J, Schibler M, et al. The 2014–2015 Ebola outbreak in West Africa: Hands on. *Antimicrob Resist Infect Control* 2016; **5**.
[50] Alexander KA, Sanderson CE, Marathe M, et al. What factors might have led to the emergence of Ebola in West Africa?. *PLoS Negl Trop Dis* 2015; **9**: e0003652.
[51] International Ebola Response Team, Agua-Agum J, Ariyarajah A, et al. Exposure patterns driving Ebola transmission in West Africa: A retrospective observational study. *PLoS Med* 2016; **13**: e1002170.
[52] WHO Ebola Response Team. After Ebola in West Africa — Unpredictable risks, preventable epidemics. *N Engl J Med* 2016; **375**: 587-96.
[53] Leendertz SAJ, Gogarten JF, Düx A, Calvignac-Spencer S, Leendertz FH. Assessing the evidence supporting fruit bats as the primary reservoirs for Ebola viruses. *Ecohealth* 2016; **13**: 18–25.
[54] Pourrut X, Souris M, Towner JS, et al. Large serological survey showing cocirculation of Ebola and Marburg viruses in Gabonese bat populations, and a high seroprevalence of both viruses in *Rousettus aegyptiacus*. *BMC Infect Dis* 2009; **9**: 159.
[55] Leroy EM, Epelboin A, Mondonge V, et al. Human Ebola outbreak resulting from direct exposure to fruit bats in Luebo, Democratic Republic of Congo, 2007. *Vector Borne Zoonotic Dis* 2009; **9**: 723-28.
[56] Formenty P, Boesch C, Wyers M, Steiner C, Donati F, Dind F. Ebola virus outbreak among wild chimpanzees living in a rain forest of Côte d'Ivoire. *J Infect Dis* 1999;

179: 120-26.
[57] Gire SK, Goba A, Andersen KG, et al. Genomic surveillance elucidates Ebola virus origin and transmission during the 2014 outbreak. *Science* 2014; **345**: 1369-72.
[58] Urbanowicz RA, McClure CP, Sakuntabhai A, et al. Human adaptation of Ebola virus during the West African outbreak. *Cell* 2016; **167**: 1079-87.
[59] Rulli M, Santini M, Hayman D, D'Odorico, P. The nexus between forest fragmentation in Africa and Ebola virus disease outbreaks. *Sci Rep* 2017; **7**: 41613.
[60] Huber C, Finelli L, Stevens W. The economic and social burden of the 2014 Ebola outbreak in West Africa. *J Infect Dis* 2018; **218**: S698–704.
[61] Thomas MR, Smith G, Ferreira FHG, et al. The economic impact of Ebola on sub-Saharan Africa: Updated estimates for 2015. Washington, DC: World Bank, 2015.
[62] Tarantola A. Four thousand years of concepts relating to rabies in animals and humans, its prevention and its cure. *Trop Med Infect Dis* 2017; **2**: 5-21.
[63] Hampson K, Coudeville L, Lembo T, et al. Estimating the global burden of endemic canine Rabies. *PLoS Negl Trop Dis* 2015; **9**: e0003709.
[64] WHO. Rabies. Apr 21, 2020. https://www.who.int/news-room/fact-sheets/detail/rabies (accessed Sept 29, 2020).
[65] Hampson K, Dobson A, Kaare M, et al. Rabies exposures, post-exposure prophylaxis and deaths in a region of endemic canine Rabies. *PLoS Negl Trop Dis* 2008; **2**: e339.
[66] Salmón-Mulanovich G, Vásquez A, Albújar C, et al. Human Rabies and Rabies in vampire and nonvampire bat species, Southeastern Peru, 2007. *Emerg Infect Dis* 2009; **15**: 1308-11.
[67] Escobar LE, Peterson AT, Favi M, Yung V, Medina-Vogel G. Bat-borne rabies in Latin America. *Rev Inst Med Trop São Paulo* 2015; **57**: 63-72.
[68] Patyk K, Turmelle A, Blanton JD, Rupprecht CE. Trends in national surveillance data for bat rabies in the United States: 2001-2009. *Vector Borne Zoonotic Dis* 2012; **12**: 666-73.
[69] Ma X, Monroe BP, Cleaton JM, Orciari LA, Yager P, Li Y, Kirby JD, Blanton JD, Petersen BW, Wallace RM. Rabies surveillance in the United States during 2016. *Journal of the American Veterinary Medical Association* 2018; **252(8)**:945-57.
[70] Singer A, Kauhala K, Holmala K, Smith GC. Rabies in northeastern Europe—the threat from invasive raccoon dogs. *J Wild Dis* 2009; **45**: 1121-37.
[71] Finnegan CJ, Brookes SM, Johnson N, et al. Rabies in North America and Europe. *J R Soc Med* 2002; **95**: 9-13.
[72] Knobel DL, Cleaveland S, Coleman PG, et al. Re-evaluating the burden of rabies in Africa and Asia. *Bull World Health Organ* 2005; **83**: 360–368.
[73] de Andrade FAG, Gomes MN, Uieda W, Begot AL, Ramos OdS, Fernandes MEB. Geographical analysis for detecting high-risk areas for bovine/human Rabies transmitted by the common hematophagous bat in the Amazon region, Brazil. *PLoS One* 2016; **11**: e0157332.
[74] Fitzpatrick MC, Hampson K, Cleaveland S, Meyers LA, Townsend JP, Galvani AP. Potential for Rabies control through dog vaccination in wildlife-abundant communities of Tanzania. *PLoS Negl Trop Dis* 2012; **6**: e1796.
[75] Zulu GC, Sabeta CT, Nel LH. Molecular epidemiology of Rabies: Focus on domestic dogs (*Canis familiaris*) and black-backed jackals (*Canis mesomelas*) from northern South Africa. *Virus Res* 2009; 140: 71-78.
[76] Sharp PM, Hahn BH. Origins of HIV and the AIDS pandemic. *Cold Spring Harb Perspect Med* 2011; **1**: a006841.
[77] UNAIDS. Global HIV & AIDS statistics — 2020 fact sheet. 2020. https://www.unaids.org/en/resources/fact-sheet (accessed Sept 29, 2020).
[78] Keele B, Van Heuverswyn F, Li Y, Bailes E, Takehisa J, Santiago M. Chimpanzee reservoirs of pandemic and nonpandemic HIV-1. *Science* 2016; **313**: 523-526.
[79] Chen Z, Luckay A, Sodora DL, et al. Human immunodeficiency virus type 2 (HIV-2) seroprevalence and characterization of a distinct HIV-2 genetic subtype from the natural range of simian immunodeficiency virus-infected sooty mangabeys. *J Virol* 1997; **71**: 3953–60.
[80] Peeters M, Courgnaud V, Abela B, Auzel P, Pourrut X, Bibollet-Ruche F. Risk to human health from a plethora of simian immunodeficiency viruses in primate bushmeat. *Emerg Infect Dis* 2002; **8**: 451-57.
[81] Hahn BH. AIDS as a zoonosis: Scientific and public health implications. *Science* 2000; **287**: 607–14.
[82] Bonnel R. HIV/AIDS and economic growth: A global perspective. *S Afr J Econ* 2000; **68**: 820-55.
[83] Nketiah-Amponsah E, Abubakari M, Baffour PT. Effect of HIV/AIDS on economic growth in sub-Saharan Africa: Recent evidence. *Int Adv Econ Res* 2019; **25**: 469-80.
[84] Heukelbach J, Alencar CH, Kelvin AA, et al. Zika virus outbreak in Brazil. The Journal of Infection in Developing Countries 2016;**10**(2):116-120.
[85] AlRuthia Y, Somily AM, Alkhamali AS, et al. Estimation of direct medical costs of Middle East Respiratory Syndrome coronavirus infection: A single-center retrospective chart review study. *Infect Drug Resist* 2019; **12**: 3463-3473.

[86] Joo H, Maskery BA, Berro AD, Rotz LD, Lee YK, Brown CM. Economic impact of the 2015 MERS outbreak on the Republic of Korea's tourism-related industries. *Health Secur* 2019; **17**: 100-08.
[87] Ma W, Kahn RE, Richt JA. The pig as a mixing vessel for influenza viruses: human and veterinary implications. *Journal of molecular and genetic medicine: an international journal of biomedical research*. 2009 Jan; 3(1):158.
[88] Putra AA, Hampson K, Girardi J, Hiby E, Knobel D, Mardiana W, Townsend S, Scott-Orr H. Response to a rabies epidemic, Bali, Indonesia, 2008–2011. *Emerging infectious diseases*. 2013; **19**(4): 648.
[89] Althouse BM, Vasilakis N, Sall AA, Diallo M, Weaver SC, Hanley KA. Potential for Zika virus to establish a sylvatic transmission cycle in the Americas. *PLoS neglected tropical diseases*. 2016; **10**(12): e0005055.
[90] Chan JF, To KK, Tse H, Jin DY, Yuen KY. Interspecies transmission and emergence of novel viruses: lessons from bats and birds. *Trends in microbiology*. 2013; **21**(10):544-55.

Supplementary Table 2: A non-exhaustive selection of the documented and hypothesised, positive and negative, direct and indirect impacts of the COVID-19 pandemic on biodiversity and ecosystem health. 'Impact Category(s)' and 'Impact Area(s)' correspond with the impact categorisation shown in Figure 1b, where 'Impact Area(s)' are sub-categories of 'Impact Category(s)'. 'Summary' gives an overview of the impact(s) discussed. 'Examples' provides one or more examples of the impact(s). Note that some direct or indirect impacts of COVID-19 on drivers of zoonotic disease will only be accurately measurable in years to come, as data is collected and analysed.

Impact Category(s)	Impact Area(s)	Summary	Examples	References
Human-Nature Interactions; Ecosystems	Emissions & Pollution; Climate Change; Abiotic Factors	The COVID-19 pandemic has (generally) resulted in decreased greenhouse gas emissions, and decreased noise and water pollution, due to disrupted economic activity. Concerningly, the pandemic has also (generally) resulted in increased organic and inorganic waste pollution, particularly disposable plastics, due to heightened demand for such products, and as focus shifts to personal health concerns rather than recycling efforts, sustainability practices, and overall environmental concern.	COVID-19-associated disrupted economic activity has resulted in improvements in water quality [1], and reduced NO2, PM2.5 [2,3] and CO2 [3] in several regions. Air quality in India improved dramatically due to marked decreases I CO2, NO2, PM10, PM2.5 and other pollutants [4]. Organic and inorganic volume has increased, and recycling and sustainable waste management programs have been suspended in some locations [2]. NASA and the ESA report that air pollution had decreased in the USA, Spain, Italy, and Wuhan by up to 30%, though not all air pollution events have been mitigated [5,6]. Severe air pollution events have occurred regardless of decreased emissions, indicating that decreased emissions alone will not prevent future events [3,5]. Reductions are unlikely to continue long-term post-pandemic [3,5]. People are less concerned about environmental pollutants due to increased concern about personal and public health [7]. The demand for personal protective equipment and disposable plastic products utilised in health services has increased significantly [8].	[1] Saadat S, Rawtani D, Hussain CM. Environmental perspective of COVID-19. Science of The Total Environment. 2020:138870. [2] Zambrano-Monserrate, M. A., Ruano, M. A., & Sanchez-Alcalde, L. (2020). Indirect effects of COVID-19 on the environment. Science of the Total Environment, 138813. [3] Wang, Q., & Su, M. (2020). A preliminary assessment of the impact of COVID-19 on environment–A case study of China. Science of the Total Environment, 728: 138915. [4] Mahato, S., Pal, S., & Ghosh, K. G. (2020). Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India. Science of the Total Environment, 139086. [5] Wang P, Chen K, Zhu S, Wang P, Zhang H. Severe air pollution events not avoided by reduced anthropogenic activities during COVID-19 outbreak. Resources, Conservation and Recycling. 2020;158:104814. [6] Muhammad S, Long X, Salman M. COVID-19 pandemic and environmental pollution: a blessing in disguise?. Science of The Total Environment. 2020:138820. [7] Grodzińska-Jurczak, M., Krawczyk, A., Jurczak, A., Strzelecka, M., Rechciński, M., & Boćkowski, M. (2020). Environmental Choices Vs. Covid-19 Pandemic Fear – Plastic Governance Re-Assessment. Society Register, 4(2), 49-66. https://doi.org/10.14746/sr.2020.4.2.04. [8] Klemeš, J. J., Van Fan, Y., Tan, R. R., & Jiang, P. (2020). Minimising the present and future plastic waste, energy and environmental footprints related to COVID-19. Renewable and Sustainable Energy Reviews, 127, 109883.
Human-Nature Interactions; Ecosystems	Land Management; Land-use Change; Climate Change; Abiotic Factors	The rate of deforestation has increased in many regions, including in the Amazon during COVID-19 pandemic.	Research suggests that pandemics such as COVID-19 "can become a new indirect driver of tropical deforestation", as deforestation has increased in the Americas, Asia-Pacific, and Africa, by 63%, 63%, and 136% respectively [1]. This deforestation appears to be driven by decreased enforcement resulting from personnel restrictions and confinement [1]. Deforestation may further be exacerbated by the promotion of environmental policy deregulation by politicians aiming to capitalise on media domination [2].	[1] Brancalion, P. H. S., Broadbent, E. N., de-Miguel, S., Cardil, A., Rosa, M. R., … Almeyda-Zambrano, A. M. (2020). Emerging threats linking tropical deforestation and the COVID-19 pandemic. Perspectives in Ecological Conservation, https://doi.org/10.1016/j.pecon.2020.09.006. [2] Phillips D. Studies add to alarm over deforestation in Brazil under Bolsonaro. The Guardian. 2020. https://www.theguardian.com/environment/2020/may/28/studies-add-to-alarm-over-deforestation-in-brazil-under-bolsonaro-covid-19 (accessed 10 June 2020)
Human-Nature Interactions Ecosystems	Human-Wildlife Contact Biotic Factors	Risk of reverse zoonotic disease transmission of SARS-CoV-2 from humans to other species (zooanthroponosis). Zooanthroponotic spillover may compromise species and ecosystem health, and may be transmit	History of human-to-primate transmissions is well documented, with implications for extinction risk of endangered primates [1,2,3]. There is concern that non-human primates, including endangered great apes like gorillas, chimpanzees, and bonobos, may contract SARS-CoV-2 from humans, threatening populations [4,5,6]. High-risk countries (Democratic Republic of Congo, Uganda, Rwanda) closed national parks and reserves as a preventative measure [5]. Reopening protected areas to tourism will magnify spillover risks.	[1] Wallis J, Lee DR. Primate conservation: the prevention of disease transmission. International Journal of Primatology. 1999 Dec 1;20(6):803-26. [2] Köndgen S, Kühl H, N'Goran PK, et al. Pandemic human viruses cause decline of endangered great apes. Current Biology. 2008 Feb 26;18(4):260-4.

		back to humans with or without mutations.	Transmission of SARS-CoV-2 to non-primate vertebrates, including felids [6,7,9] and domesticated cats and dogs [6,8,9] has occurred in a natural setting. In experimental settings, it has been shown that Rhesus Macaques (*Macaca mulatta*), Crab-eating Macaques (*Macaca fascicularis*) and Common Marmosets (*Callithrix jacchus*) are susceptible to SARS-CoV-2 infection and that the virus can be transmitted between individuals [9]. One study found that SARS-CoV-2 was transmissible to and symptomatic in a range of animals, including species of Old World and New World monkeys [10]. Another study found that "apes and African and Asian monkeys, as well as some lemurs are all likely to be highly susceptible to SARS-CoV-2" [11].	[3] Gillespie TR, Nunn CL, Leendertz FH. Integrative approaches to the study of primate infectious disease: implications for biodiversity conservation and global health. American Journal of Physical Anthropology: The Official Publication of the American Association of Physical Anthropologists. 2008;137(S47):53-69. [4] Gaworecki M. Audio: The links between COVID-19, wildlife trade, and destruction of nature with John Vidal [Internet]. Mongabay Environmental News. 2020. https://news.mongabay.com/2020/03/audio-the-links-between-covid-19-wildlife-trade-and-destruction-of-nature-with-john-vidal/ (accessed 20 September 2020). [5] Vyawahare M. National parks in Africa shutter over COVID-19 threat to great apes. Mongabay Environmental News. 2020. https://news.mongabay.com/2020/03/national-parks-in-africa- (accessed 7 April 2020). [6] UNEP. Virus which causes COVID-19 threatens great ape conservation. United Nations Environment Programme. 2020. https://www.unenvironment.org/news-and-stories/story/virus-which-causes-covid-19-threatens-great-ape-conservation (accessed 7 April 2020) [7] Gollakner R, Capua I. Is COVID-19 the first pandemic that evolves into a panzootic?. Veterinaria Italiana. 2020 Apr 24;56(1):11-2. [8] Shi J, Wen Z, Zhong G, et al. Susceptibility of ferrets, cats, dogs, and other domesticated animals to SARS–coronavirus 2. Science. 2020;368(6494):1016-20. [9] Munir K, Ashraf S, Munir I, et al. Zoonotic and reverse zoonotic events of SARS-CoV-2 and their impact on global health. Emerging microbes & infections. 2020;9(1):2222-35. [10] Lu S, Zhao Y, Yu W, et al. Comparison of nonhuman primates identified the suitable model for COVID-19. Signal transduction and targeted therapy. 2020;5(1):1-9. [11] Melin AD, Janiak MC, Marrone III F, Arora PS, Higham JP. Comparative ACE2 variation and primate COVID-19 risk. bioRxiv. 2020.
Human-Nature Interactions	Emissions and Pollution	To limit opportunity for SARS-CoV-2 transmission, some governments have encouraged the public to use cars as opposed to public transport [1]. This may have an ongoing impact on transport trends and undermine the transition towards sustainable public transport.	In May 2020, the UK Government encouraged the public to return to work, but advised avoidance of public transport [1]. With the substantial loss of public transport revenue and ongoing lack of government funding sustainable public transport options and/or transitions will be limited [2].	[1] Budd L, Ison S. Responsible Transport: A post-COVID agenda for transport policy and practice. Transportation Research Interdisciplinary Perspectives. 2020 Jul 1;6:100151. [2] McArthur J, Smeds E, Ray RS. Coronavirus showed the way cities fund public transport is broken – here's how it needs to change. The Conversation, 2020. https://theconversation.com/coronavirus-showed-the-way-cities-fund-public-transport-is-broken-heres-how-it-needs-to-change-145136.
Human-Nature Interactions Ecosystems	Emissions and pollution; Biotic Factors	Large-scale use of disinfectants to curb the spread of COVID-19 threatens urban wildlife and ecosystems.	Disinfectants used to kill the SARS-CoV-2 virus, particularly those used in outdoor environments at a large scale, pose a direct threat to urban wildlife and may remain in the ecosystem where organisms can be exposed [1]. Disinfectants used contain harmful compounds, including "chlorine-releasing agents, oxidizing agents, and quaternary ammonium cations" [1]. When such chemicals enter waterways, they pose a threat to aquatic organisms and ecosystems [2].	[1] Nabi G, Wang Y, Hao Y, Khan S, Wu Y, Li D. Massive use of disinfectants against COVID-19 poses potential risks to urban wildlife. Environmental Research. 2020 Sep;188:109916. [2] Zhang H, Tang W, Chen Y, Yin W. Disinfection threatens aquatic ecosystems. Science. 2020 Apr 10;368(6487):146-7.

Human-Nature Interactions Ecosystems	Emissions and Pollution; Human-Wildlife Contact; Biotic Factors	Reduced anthropogenic noise (due to decreased transportation and human disturbance) may positively impact terrestrial fauna.	COVID-19 has resulted in reduced noise pollution globally [1], particularly in marine environments, in part due to disrupted global economics and supply chains decreasing maritime transport [2]. Aquatic noise alters marine mammal behaviour and physiology [3,4], thus, reduce anthropogenic noise should benefit marine mammals. Decreased vessel noise has been found to result in decreased stress hormones in endangered North Atlantic Right whales [5]. Reduced motor vehicle traffic noise may reduce pressure on songbirds [6]. Similarly, fish and amphibians are likely to benefit from reduced anthropogenic noise [7]. Research from the Max Planck Institute for Ornithology indicates that noise pollution negatively effects growth and embryo mortality in some birds [8], thus noise reductions will be favourable for bird survival. Anecdotal and media reports indicate that cetaceans, ungulates, felines, and avifauna all appear to be benefitting from a "quiter world" [9].	[1] Zambrano-Monserrate, M. A., Ruano, M. A., & Sanchez-Alcalde, L. (2020). Indirect effects of COVID-19 on the environment. Science of the Total Environment, 138813. [2] Weilgart, L. (2007). A Brief Review of Known Effects of Noise on Marine Mammals. International Journal of Comparative Psychology, 20(2). Retrieved from https://escholarship.org/uc/item/11m5g19h [3] Matthews LP, Fournet MEH, Gabriele C, Klinck H, Parks SE. 2020 Acoustically advertising male harbour seals in southeast Alaska do not make biologically relevant acoustic adjustments in the presence of vessel noise. Biol. Lett. 16: 20190795. http://dx.doi.org/10.1098/rsbl.2019.0795 [4] Berti, A., 2020. The Impact Of Covid-19 On Global Shipping: Part 1, System Shock. [online] Ship Technology. Available at: <https://www.ship-technology.com/features/impact-of-covid-19-on-shipping/> [Accessed 13 April 2020]. [5] R. M. Rolland, S. E. Parks, K. E. Hunt, M. Castellote, P. J. Corkeron, D. P. Nowacek, S. K. Wasser, S. D. Kraus. Evidence that ship noise increases stress in right whales. Proceedings of the Royal Society B: Biological Sciences, 2012; DOI: 10.1098/rspb.2011.2429 [6] Derryberry EP, Phillips JN, Derryberry GE, Blum MJ, Luther D. Singing in a silent spring: Birds respond to a half-century soundscape reversion during the COVID-19 shutdown. Science. 2020 Oct 30;370(6516):575-9. [7] Brumm, H., & Horn, A. G. (2018). Noise Pollution and Conservation. Reference Module in Life Sciences. doi:10.1016/b978-0-12-809633-8.90030-x. [8] https://www.dw.com/en/coronavirus-lockdown-gives-animals-rare-break-from-noise-pollution/a-53106214. [9] https://www.bbc.com/news/world-52459487.
Human-Nature Interactions Ecosystems	Human-Wildlife Contact; Biotic Factors	Decreased global aviation positively impacts avifauna by reducing bird strikes.	Decreased aviation results in less bird strikes, particularly of migratory species. [1]. Decreased global flight demand (24% decrease in February 2020 compared to February 2019) [2] thus likely to positively impact avifauna.	[1] Greenspan, J., 2015. Everything You Need To Know About Birds And Planes. [online] Audubon. Available at: <https://www.audubon.org/news/everything-you-need-know-about-birds-and-planes> [Accessed 13 April 2020]. [2] Iata.org. 2020. Passenger Demand Plunges On COVID-19 Travel Restrictions. [online] Available at: <https://www.iata.org/en/pressroom/pr/2020-04-02-02/> [Accessed 13 April 2020].
Human-Nature Interactions Ecosystems	Human-Wildlife Contact; Biotic Factors	Reduced human movement in populated areas due to government-imposed lockdowns and reduced economic activity may have resulted in a momentary 'rewilding' of urban areas. Temporary rewilding may result in increased human-wildlife conflict and further zoonotic spillover.	Numerous anecdotal observations of wild animals in urban environments – e.g. pumas in the streets of Santiago, Chile, and jackals in parks in Tel Aviv, Israel – indicate that wildlife may be moving more freely due to reduced human presence [1,2]. Though wildlife have flourished in some urban settings, problematic human-wildlife interactions (collisions, proximity, safety, disease] may increase when lockdown restrictions ease [3].	[1] Rutz C, Loretto MC, Bates AE, Davidson SC, Duarte CM, Jetz W, Johnson M, Kato A, Kays R, Mueller T, Primack RB. COVID-19 lockdown allows researchers to quantify the effects of human activity on wildlife. Nature Ecology & Evolution. 2020 Sep;4(9):1156-9. [2] Manenti R, Mori E, Di Canio V, Mercurio S, Picone M, Caffi M, Brambilla M, Ficetola GF, Rubolini D. The good, the bad and the ugly of COVID-19 lockdown effects on wildlife conservation: Insights from the first European locked down country. Biological conservation. 2020 Sep 1;249:108728. [3] Chrobak U. The real reason we're seeing more wildlife during the pandemic. Popular Science, 2020. https://www.popsci.com/story/environment/wildlife-in-cities-covid-shutdown/.

Human-Nature Interactions	Wildlife Trade	Markedly increased focus on illegal and problematic wildlife trade, resulting in changes to laws, consumption, and trade.	China declared immediate 'comprehensive and permanent' ban on wildlife trade and consumption in February 2020, though sincerity and adherence are doubtful. Fears that wildlife trade and consumption restrictions will be ineffective and temporary, given reversal of restrictions implemented following SARS outbreak in the 2000s. Evidence that wet markets have already reopened despite restrictions and government declarations. China's Ministry of Agriculture and Rural Affairs is drafting a "white list" of animals to be allowed to be raised for meat. Farmers of various wildlife argue that if the animal is not associated with SARS-CoV-2 production should continue.	[1] https://www.dailyexaminer.com.au/news/chinese-wet-markets-still-selling-bats/3984833/ [2] https://www.rte.ie/news/2020/0331/1127645-was-the-pangolin-the-source-of-the-covid-19-outbreak/ [3] Michael Standaert and Jonathan Zhong, 2020. Bamboo rats left in limbo as breeders push back against China wildlife ban. The Guardian Published 09 April 2020. [4] https://www.theguardian.com/environment/2020/apr/09/bamboo-rats-left-in-limbo-as-breeders-push-back-against-china-wildlife-ban?CMP=share_btn_tw
Human-Nature Interactions Ecosystems	Wildlife Trade; Biotic Factors	Wildlife poaching has increased due to extensive lockdown protocols preventing adequate anti-poaching surveillance.	Forced closures of protected areas, decreased funding for protected areas workforces, and reduced patrols of protected areas has resulted in increased wildlife poaching. There have been reports of critically endangered giant ibis being killed for meat, and painted storks being killed in a protected area in Cambodia [1]. Conservation International has reported increased poaching related to bush meat and ivory trade due to economies damaged by loss of tourism not supporting rangers [2]. Rhinoceros poaching has increased markedly in South Africa [3]. A significant increase in poaching of adult sea turtle nests has been documented in Costa Rica [4].	[1] https://newsroom.wcs.org/News-Releases/articleType/ArticleView/articleId/14039/COVID-19-FUELING-AN-UPTICK-IN-POACHING-Three-Critically-Endangered-Giant-Ibis-Cambodias-National-Bird-killed-in-Protected-Area.aspx [2] https://www.conservation.org/blog/poaching-deforestation-reportedly-on-the-rise-since-covid-19-lockdowns [3] https://www.nytimes.com/2020/04/08/science/coronavirus-poaching-rhinos.html [4] https://conserveturtles.org/sea-turtle-conservation-work-in-tortuguero-threatened-due-to-covid-19/
Human-Nature Interactions Ecosystems	Wildlife Trade; Biotic Factors	Decreased fishing efforts and fish trade benefitting fisheries and marine ecosystems, whilst negatively impacting the livelihoods of dependents and economic trade.	Closure of inshore fisheries results in increased global fish stocks [1], and grounded fleets of fishing vessels will likely magnify the benefit [2]. Expected prolonged downturn in global fish trade [3] due to shifting demands, changed market access and logistical challenges due to restriction transportation and border access [4]. There has been a downturn in the consumption of seafood, as some incorrectly perceive the link of COVID-19 to 'wet markets' as seafood being unsafe to eat [4]. Income and job losses from decreased fishing efforts will jeopardise the health and wellbeing of communities [5,6], and will result in increases in unregulated and illegal fishing efforts for subsistence and welfare [7].	[1] Holm, Poul. "World War II and the 'Great Acceleration' of North Atlantic Fisheries." Global Environment 10 (2012): 66–91. Republished by the Environment & Society Portal, Multimedia Library. http://www.environmentandsociety.org/node/7577. [2] Korten, T., 2020. With Boats Stuck In Harbor Because Of COVID-19, Will Fish Bounce Back?. [online] Smithsonian Magazine. Available at: <https://www.smithsonianmag.com/science-nature/fish-stop-covid-19-180974623/> [Accessed 15 April 2020]. [3] http://www.fao.org/in-action/globefish/news-events/details-news/en/c/1268337/ [4] http://www.fao.org/3/ca8637en/CA8637EN.pdf [5] Burke, J., 2020. Are You Prepared: Coronavirus And The Alaska Economy. [online] Ktuu.com. Available at: <https://www.ktuu.com/content/news/Are-You-Prepared-Coronavirus-and-the-Alaska-Economy---568577991.html> [Accessed 15 April 2020]. [6] Nathan J. Bennett, Elena M. Finkbeiner, Natalie C. Ban, Dyhia Belhabib, StacyD. Jupiter, John N. Kittinger, Sangeeta Mangubhai, Joeri Scholtens, David Gill & Patrick Christie(2020): The COVID-19 Pandemic, Small-Scale Fisheries and Coastal Fishing Communities,Coastal Management, DOI: 10.1080/08920753.2020.1766937 [7] Bennett NJ, Finkbeiner EM, Ban NC, Belhabib D, Jupiter SD, Kittinger JN, Mangubhai S, Scholtens J, Gill D, Christie P. The COVID-19 Pandemic, Small-Scale Fisheries and Coastal Fishing Communities.

Human-Nature Interactions	Indigenous Peoples; Land Management; Protected Areas	Jeopardised health and wellbeing of Indigenous communities due to disease susceptibility, land invasion and cultural tensions, resulting not only in inherent harm to these peoples, but also in threats to the land and environments that they manage and protect.	Increased health risk of Australian Aboriginal people in remote communities puts elders at risk [1]. Indigenous Peoples, and especially elders, hold priceless traditional ecological knowledge valuable to conservation planning [2]. Documented land encroachment [3], killing of Indigenous leaders [4], and increasing COVID-19 infections inside of Indigenous areas in South America [4] has been detrimental to these communities and the lands they manage.	[1] Department of Health. Coronavirus (COVID-19) advice for Aboriginal and Torres Strait Islander peoples and remote communities [Internet]. Australian Government Department of Health [updated 2020 Sep 22; cited 2020 Sep 30]. Available from: https://www.health.gov.au/news/health-alerts/novel-coronavirus-2019-ncov-health-alert/advice-for-people-at-risk-of-coronavirus-covid-19/coronavirus-covid-19-advice-for-aboriginal-and-torres-strait-islander-peoples-and-remote-communities. [2] Sobrevila, C. (2008). The role of indigenous peoples in biodiversity conservation: The natural but often forgotten partners. Washington DC: The World Bank. [3] Cowie, S., In Brazil, COVID-19 outbreak paves way for invasion of indigenous lands. Mongabay. Published 10 April 2020. https://news.mongabay.com/2020/04/in-brazil-covid-19-outbreak-paves-way-for-invasion-of-indigenous-lands/ [4] https://news.mongabay.com/2020/04/in-brazil-covid-19-outbreak-paves-way-for-invasion-of-indigenous-lands/
Human-Nature Interactions; Ecosystems	Tourism; Biotic Factors	Decreased oceanic tourism will benefit localised cetacean populations and will reduce localised air pollution.	It is potentially the first time in decades that large quantities of cruise ships will not be in Alaskan waters during the whale migration. This may have a positive impact on whale populations as their behaviours are not undermined by noise pollution [1,2,3,4]. Other potential benefits to the environment may be reduced air pollution around Juneau, where cruise ships port [5].	[1] Ljungblad, D. K., Würsig, B., Swartz, S. L., & Keene, J. M. (1988). Observations on the behavioral responses of bowhead whales (Balaena mysticetus) to active geophysical vessels in the Alaskan Beaufort Sea. Arctic, 183-194. [2] Nowacek, D. P., Thorne, L. H., Johnston, D. W., & Tyack, P. L. (2007). Responses of cetaceans to anthropogenic noise. Mammal Review, 37(2), 81-115. https://doi.org/10.1111/j.1365-2907.2007.00104.x [2] Ljungblad, D. K., Würsig, B., Swartz, S. L., & Keene, J. M. (1988). Observations on the behavioral responses of bowhead whales (Balaena mysticetus) to active geophysical vessels in the Alaskan Beaufort Sea. Arctic, 183-194. [3] Richardson, W. John, et al. Marine mammals, and noise. Academic press, 2013. https://books.google.com.au/books?hl=en&lr=&id=j6bYBAAAQBAJ&oi=fnd&pg=PP1&ots=BaUwCncwWf&sig=Td2PwHRMtCLN-fIlX_63Qqj5AIE&redir_esc=y#v=onepage&q&f=false [5] Baxter, A., Cruise industry responds to community concerns about environmental impacts. Alaska Public Media. 23 April 2019. https://www.alaskapublic.org/2019/04/23/cruise-industry-responds-to-community-concerns-about-environmental-impacts/

Human-Nature Interactions Conservation Action	Tourism; Conservation Funding	Decreased tourism will jeopardise conservation efforts through impacts to funding streams.	Decreases to tourism-associated funding and income for conservation has resulted from COVID-19 and will jeopardise conservation work, as well as global and local economies. The World Tourism Organization reports that between January and August 2020, international tourist arrivals declined 70% compared to the same period in 2019, translating to a US$ 730 billion loss in export revenues from international tourism, exceeding the impact of the 2009 global economic crisis 8-fold [1]. Many conservation programs rely on income and funding generated by tourism. Numerous IUCN-red listed mammals' species are partially supported by tourism funds. Most species rely on tourism to support at least 5% of remaining populations, and within a few species, up to 66% of the remaining population is supported by tourism [2]. There are concerns that as tourism businesses recover, sustainability incentives and investments will not be prioritized or will be cut completely [3]. Zoos may have to euthanise animals they can no longer afford to care for and cut back on conservation programs [4,5]. Many conservation programs face a loss in funding, resulting in a loss of research and a reduced ability to conduct monitoring and/or anti-poaching efforts [5].	[1]. Unwto.org. 2020. Impact Assessment of The COVID-19 Outbreak On International Tourism | UNWTO. https://www.unwto.org/impact-assessment-of-the-covid-19-outbreak-on-international-tourism (accessed 16 June 2020) [2] Buckley RC, Castley JG, Pegas FdV, Mossaz AC, Steven R (2012) A Population Accounting Approach to Assess Tourism Contributions to Conservation of IUCN-Redlisted Mammal Species. PLoS ONE 7(9): e44134. https://doi.org/10.1371/journal.pone.0044134 [3] Bisby, A., Coronavirus-fuelled tourism meltdown yields pros and cons for conservation. The Globe and Mail. Published 17 March 2020. https://www.theglobeandmail.com/life/travel/article-coronavirus-fuelled-tourism-meltdown-yields-pros-and-cons-for/ [4] Załęska-Olszewska I. A non-human animal perspective on the coronavirus pandemic. In: Norbert K, Paweł S, editors. The Book of Articles National Scientific Conference "Science and Young Researchers" [Internet]. 4th ed. Lodz: Promovendi Foundation Publishing, 2020 [Cited 2020 Sep 22]. p. 101-11. Available from: http://promovendi.pl/wp-content/uploads/2020/06/Articles-NOMN-IV-v4.pdf [5] Marshall M. Conservation in crisis. NewScientist. 2020 May 30;264(3284):8-9.
Value of Nature	Energy & Resources	Disruptions to the production of trade and commodities resulting in lost revenue and decreased GDP. This may be a catalyst for movement towards the sustainable energy transition, or, instead, governments may invest to bolster these industries.	Industrial metal values have decreased; copper (20%), nickel (13%), and zinc (14%) [1]. Precious metal values have decreased; palladium (38%), platinum (35%), and silver (30%) [2]. Mining sector and energy commodities such as oil have been significantly disrupted; the price of Brent Crude oil was reduced by 53% in March, rendering one-tenth of global oil production uneconomic, forcing producers (e.g. shale) into hardship [2]. The Minerals Council of Australia predicted in April that countries whose economies are reliant upon energy and resource sectors will consequently experience reduced GDP; e.g. 90% of Alaska's income is generated from oil/gas extraction and production [3], and 6-15% of Australia's GDP is generated from mining [4].	[1] Sandbrook C, Gómez-Baggethun E, Adams WM. Biodiversity conservation in a post-COVID-19 economy. Oryx. 2020 Oct 29:1-7. [2] Rumbens, D. and Campbell-Sloan, J., 2020. The Impacts Of COVID-19 On The Mining Sector - COVID-19 Blog | Deloitte Australia. Deloitte. https://www2.deloitte.com/au/en/blog/covid19-blog/2020/impacts-covid-19-mining.html (accessed 15 April 2020). [3] Burke, J., 2020. Are You Prepared: Coronavirus And The Alaska Economy. [online] Ktuu.com. Available at: <https://www.ktuu.com/content/news/Are-You-Prepared-Coronavirus-and-the-Alaska-Economy---568577991.html> [Accessed 15 April 2020]. [4] Minerals Council of Australia. 2020. Driving Prosperity. https://minerals.org.au/driving-prosperity (accessed 15 April 2020)
Value of Nature Cross-Boundary Collaboration	Attitudes towards Nature Communication	The pandemic may lead to increased support for environmental conservation as the links between environmental degradation and pandemics become common knowledge.	The pandemic may lead to the 'outrage effect', where increased support for conservation actions and policies, and increased donations to wildlife charities, when the causes of pandemics are linked back to human-mediated depletion of nature [1].	[1] Shreedhar, G., & Mourato, S. 2020. Linking human destruction of nature to COVID-19 increases support for wildlife conservation policies. Environmental and Resource Economics, 76:963–999.
Value of Nature	Ecosystem Services	The pandemic's links to biodiversity and ecosystem health may drive action from governments to commodify ecosystem services and tax industries based on services they diminish. The value of ecosystem services may be included in disaster risk reduction.	Action in this space would build on an emerging trend of commodification of the services ecosystems provide to economies [1]. For example, Barbier and Burgess propose developing countries adopt a "tropical carbon tax", where levies collected from the fossil fuel industry are invested in "natural climate solutions" aimed at "conserving, restoring and improving land management to protect biodiversity and ecosystem services" [1].	[1] Belinda Reyers, Jeanne L. Nel, Patrick J. O'Farrell, Nadia Sitas, Deon C. Nel. Coproducing ecosystem service knowledge and action. Proceedings of the National Academy of Sciences Jun 2015, 112 (24) 7362-7368; DOI: 10.1073/pnas.1414374112 [2] Barbier EB, Burgess JC. Sustainability and development after COVID-19. World Development. 2020 Nov 1;135:105082.

Human-nature interactions Conservation Actions	Land management On-the-ground conservation	Management of protected or special interest areas (parks, sanctuaries, wilderness, oceanic) obstructed by government-imposed lockdowns and restrictions on movement, disrupting important *in situ* projects, actions, and activities.	Paused conservation infrastructure development (Australian Wildlife Conservancy Kangaroo Island bushfire emergency protective fence building ceased; endangered Kangaroo Island dunnart survival jeopardised) [1]. Australian Wildlife Conservancy and Bush Heritage Australia sanctuaries closed to all non-employees [2,3], disrupting guided tours and public-driven scientific endeavours. Inability to conduct essential control of invasive species within managed areas; e.g. three-quarters of protected area managers in Italy stated that their eradication programs were at serious risk of failing due to COVID-19 interruptions [4], inability to conduct invasive rodent control on locked down islands leading to population explosions, negatively impacting nesting seabirds [5], inability for organisations to conduct feral animal control in rural Queensland, Australia due to restrictions on purchasing supplies [6]. Long-term ecological research/monitoring (LTER) programs halted due to inability to maintain equipment; potentially jeopardising data used to predict ecological phenomena [7]. Habitat restoration programs temporarily ceased; Landcare habitat restoration programs all put on hold (negatively impacting local ecosystems [8]), and North American annual wetland restoration works ceased (likely to negatively impact Great Lakes/North Atlantic waterfowl [9]).	[1] https://www.theguardian.com/australia-news/2020/apr/05/fears-for-wildlife-recovery-after-bushfires-as-coronavirus-crisis-stymies-scientists-fieldwork [2] Australian Wildlife Conservancy. Responding to Covid-19 [Internet]. Australian Wildlife Concervancy; 2020 Mar 21 [cited 2020 Sep 30]. Available from: https://www.australianwildlife.org/responding-to-covid-19/ [3] Bush Heritage Australia. Working through the Covid-19 pandemic [Internet]. Melbourne: Bush Heritgae Australia; 2020 Apr 02 [cited 2020 Sep 30]. Available from: https://www.bushheritage.org.au/news/videos/covid-19 [4] Manenti, R., Emiliano, M., Di Canio, V., Mercurio, S., Picone, M., Caffi, M., Brambilla, M., Ficetola, G. F., Rubolini, D. (2020). The good, the bad and the ugly of COVID-19 lockdown effects on wildlife conservation: Insights from the first European locked down country. Biological Conservation 249: 108728. https://doi.org/10.1016/j.biocon.2020.108728 [5] https://www.wired.com/story/coronavirus-lockdown-conservation/ [6] https://www.abc.net.au/news/2020-03-30/coronavirus-closes-gun-shops-in-queensland/12101850 [7] https://www.nature.com/articles/d41586-020-00924-6 [8] https://landcarensw.org.au/a-message-from-the-ceo-landcare-nsws-response-to-the-coronavirus-covid-19/ [9] https://www.outdoornews.com/2020/04/06/conservation-in-the-midst-of-a-crisis/
Conservation Actions	On-the-ground conservation	People's interest in citizen science may have increased since the onset of COVID-19, however the pandemic's associated restrictions to mobility has led to some declines in citizen science participation.	The Southern African Bird Atlas Project experienced significant declines in citizen science submissions in April 2020 [1]. The city of Kenai in Alaska is utilising existing urban cameras to monitor beluga populations in the nearby river [2]. Bird-watching citizen science database activity has increased ten-fold during lockdown [3]. New citizen science project (oceans) investigating the impacts of human absence on coastal systems [4].	[1] Rose S, Suri J, Brooks M, Ryan PG. COVID-19 and citizen science: lessons learned from southern Africa. Ostrich. 2020 Apr 2;91(2):188-91. [2] Belugas Count. (2020, April 16) https://www.facebook.com/BelugasCount [3] https://theconversation.com/birdwatching-increased-tenfold-last-lockdown-dont-stop-its-a-huge-help-for-bushfire-recovery-141970 [4] https://www.eoceans.co/project-covid19
Conservation Actions	On-the-ground conservation	Disrupted wildlife monitoring (reduced ability to assess annual/cyclical population trends and species responses to climatic events)	In Australia, Kosciuszko National Park closure preventing monitoring recovery trajectory of at-risk freshwater ecosystems/species [1]. Jack Dumbacher (California Academy of Sciences) re: inability to conduct wildlife monitoring post-fire season in California [2]. ANU (Sarah Legge) and Deakin (Euan Ritchie) comments re: disruptions to time-sensitive field operations. John White (Deakin) re: inability to conduct annual monitoring of small mammals in the Grampians [3]. All butterfly conservation and annual monitoring events cancelled (Butterfly Conservation UK) [4]. All bat conservation field work ceased (Bat Conservation International) [5].	[1] https://www.theguardian.com/ustralia-news/2020/apr/05/fears-for-wildlife-recovery-after-bushfires-as-coronavirus-crisis-stymies-scientists-fieldwork [2] https://www.wired.com/story/coronavirus-lockdown-conservation/ [3] https://www.theguardian.com/australia-news/2020/apr/05/fears-for-wildlife-recovery-after-bushfires-as-coronavirus-crisis-stymies-scientists-fieldwork [4] https://butterfly-conservation.org/events [5] http://www.batcon.org/resources/media-education/news-room/gen-news/80-latest-news/1231-coronavirus-and-changes-to-bci-s-operations

Conservation Action	Conservation Funding	Direct and indirect impacts of the COVID-19 pandemic will result in reduced funding for conservation.	Reduced funding for conservation has been significant in many locations [1]. In a March Wildlife and Countryside Link survey, estimated losses due to COVID-19 for 23 responding organisations were already greater than USD$100 million, not inclusive of future losses from decreased grant opportunities [2].	[1] Hockings M, Dudley N, Elliott W, et al. Editorial essay: Covid-19 and protected and conserved areas. *Parks* 2020; **26**(1). [2] Wildlife and Countryside Link. Environment and Conservation Organisations Coronavirus Impact Survey Report, 2020.
Conservation Action	Conservation Education, Training & Jobs	Increased support in some countries for stimulus packages and reforms that favour conservation-related job creation and opportunity.	A coalition of conservation, farming, environmental, and Landcare groups proposed the creation of a post-pandemic stimulus package ($4 billion) that would create 24,000 jobs working in land rehabilitation i.e., tree planting, bushfire restoration, coastal restoration, marine plastics clean-up etc. [1]. The New Zealand Government proposed a COVID-19 recovery bill for US$32 billion, of which US$706 million are earmarked for “nature-based jobs” focused habitat protection and restoration [2].	[1] O'Malley, N., 2020. Farming And Conservation Groups Call For $4B Post-Pandemic Jobs Boost. [online] The Sydney Morning Herald. Available at: <https://www.smh.com.au/environment/conservation/farming-and-conservation-groups-call-for-4b-post-pandemic-jobs-boost-20200402-p54gjc.html> [Accessed 16 April 2020]. [2] Department of Conservation NZG. $1.1 billion investment to create 11,000 environment jobs in our regions. 2020.
Conservation Action	Conservation Education, Training & Jobs	The pandemic has resulted in disruptions to conservation employment, career development and volunteering in the conservation field, negatively impacting conservation actions and outcomes.	Employment of conservation area management staff threatened by reduce revenue, resulting in reduced enforcement and inability to conduct important tasks [1]. Reported details indicate: 50% decrease in career opportunities, 90% employers reporting recruitment reduction, inability to travel for volunteer projects, workforce unable to perform all duties leading to poorer conservation outcomes, Examples from early in the pandemic include: - Natucate conservation projects were cancelled (some permanently) - Conservation Careers reported that many collaborative employers had been negatively impacted [2]. - Wildlife rescue and rehabilitation volunteer training and development ceased in April, jeopardising urban and rural wildlife rescue and welfare [3]. - Conservation-related volunteer programs, positions, and training in developing countries were put on hold indefinitely [4]. Decreased physical attendance to science education programs (fieldwork, classrooms) will jeopardise education and conservation outcomes [5,6].	[1] Hockings et al. 2020. Editorial Essay: COVID-19 and protected and conserved areas. [2] Foster K. 80 percent of conservation careers negatively affected by COVID pandemic (commentary). 9 April 2020. Available online at: https://news.mongabay.com/2020/04/80-percent-of-conservation-careers-negatively-affected-by-covid-pandemic-commentary/ [3] Wildlifetraining.org.au. 2020. Rescue And Immediate Care Course. [online] Available at: <https://www.wildlifetraining.org.au/training/rescue-and-immediate-care-course> [Accessed 16 April 2020]. [4] Australianvolunteers.com. 2020. Home — The Australian Volunteers Program. [online] Available at: <https://www.australianvolunteers.com/> [Accessed 17 April 2020]. [5] Collins, M. A., Dorph, R., Foreman, J., Pande, A., Strang, C., & Young, A. (2020). A field at risk: The impact of COVID-19 on environmental and outdoor science education: Policy brief. Lawrence Hall of Science, University of California, Berkeley; California. [6] Corlett, R. T., Primack, R. B., Devictor, V., Maas, B., Goswami, V. R., Bates, A. E., ... & Cumming, G. S. (2020). Impacts of the coronavirus pandemic on biodiversity conservation. Biological Conservation, 246, 108571.
Conservation Action	Socioeconomic Context	Potential for increased divisions between economic, social, cultural, and environmental causes jeopardising collective outcomes.	There is the potential for politicians and vested interests to use the COVID-19 pandemic to create divisions between groups within the community to undermine the collective support for the provision of public goods and protections for labour, health, and environmental protections. These outcomes would impact long-term viability of public and environmental health goals [1].	[1] McKee, M., Stuckler, D. If the world fails to protect the economy, COVID-19 will damage health not just now but also in the future. Nat Med (2020).

Cross-Boundary Collaboration Policy	International Relations Communication Legislation and Policy	Postponed or cancelled international conservation policy collaborations have resulted from COVID-19 related lockdowns and travel restrictions, disrupting conservation planning and decision-making.	Disrupted momentum for conservation action due to inability to conduct important global collaborations, meetings, and negotiations e.g postponed IUCN World Conservation Congress 2020 [1,2,3,4].	[1] Dinneen, J., COVID-19 disrupts a major year for biodiversity policy and planning. Mongabay. 03 April 2020. https://news.mongabay.com/2020/04/covid-19-disrupts-a-major-year-for-biodiversity-policy-and-planning/ [2] https://www.iucncongress2020.org/newsroom/all-news/iucn-world-conservation-congress-2020-postponed [3] https://www.forbes.com/sites/nishandegnarain/2020/04/16/ten-areas-where-covid-19-responses-are-leading-to-environmental-setbacks/#560631f44252 [4] Corlett, R. T., Primack, R. B., Devictor, V., Maas, B., Goswami, V. R., Bates, A. E., ... & Cumming, G. S. (2020). Impacts of the coronavirus pandemic on biodiversity conservation. Biological Conservation, 246, 108571.
Policy Conservation Action Human-Nature Interactions Value of Nature	Fiscal Measures Legislation & Policy Regulation and Enforcement Protected Areas Emissions and Pollution Energy and Resources Environmental Protection Rollback	Policy interventions aimed at recuperating the economy may lead to longer-term easing of environmental standards, including those relating to emissions and other waste, and may stagnate pre-COVID-19 trajectories towards sustainable transitions in sectors such as transport, energy, and agriculture [1].	Following the COVID-19 outbreak, many governments and regulators have changed legislation and decreased environmental regulation for industries to protect economies. These may not be restored soon, and there may be a continued trajectory on a similar trajectory [2]. Sandbrook et al. proposed that similar actions, and investment in industries such as fossil fuels, aviation, mining & logging may characterise a policy response scenario that focuses on "removal of obstacles to economic growth" [2]. A report by Climate Action Tracker cautioned that if governments delay implementation of "low carbon development strategies and policies", or if they "roll back existing climate policies", the reductions in greenhouse gas emissions attributable to the COVID-19 economic fallout could be negated, and the emissions could "rebound and even overshoot previously projected levels by 2030, despite lower economic growth in the period to 2030" [3]. Examples of removal or weakening of existing climate and other environmental policies during or due to the COVID-19 pandemic include: - Australia's Victorian government lifted ban on conventional onshore gas drilling in March [4]. - A new Government in Alberta, Canada announced in March that the government would sell off 38% provincial parks. Legislation was changed to allow this [5]. - US President Donald Trump suspended the enforcement of some environmental laws in March due to COVID-19, allowing companies to break pollution laws during the pandemic without penalty [6]. - NSW Government's approval of coalmining extension under Woronora Reservoir [7].	[1] Diffenbaugh NS, Field CB, Appel EA, Azevedo IL, Baldocchi DD, Burke M, Burney JA, Ciais P, Davis SJ, Fiore AM, Fletcher SM. The COVID-19 lockdowns: a window into the Earth System. Nature Reviews Earth & Environment. 2020 Sep;1(9):470-81. [2] Sandbrook C, Gómez-Baggethun E, Adams WM. Biodiversity conservation in a post-COVID-19 economy. Oryx. 2020 Oct 29:1-7. [3] Tracker CA. A government roadmap for addressing the climate and post COVID-19 economic crises. [4] https://www.abc.net.au/news/2020-03-17/victoria-lifts-ban-on-onshore-gas-exploration-but-bans-fracking/12063196 [5] https://nationalpost.com/pmn/news-pmn/canada-news-pmn/alberta-releases-list-of-parks-to-be-closed-or-partially-closed [6] Milman O, Holden E. Trump administration allows companies to break pollution laws during coronavirus pandemic. 2020. The Guardian. https://www.theguardian.com/environment/2020/mar/27/trump-pollution-laws-epa-allows-companies-pollute-without-penalty-during-coronavirus [7] Farrelly, E., Beware what's happening under the cover of COVID-19. Sydney Morning Herald. 04 April 2020. https://www.smh.com.au/national/beware-what-s-happening-under-the-cover-of-covid-20200402-p54gi0.html

Policy	Legislation & Policy	COVID-19 has been the potential catalyst for policy changes to separate health and environmental decision making.	In the US, a proposed change in March 2020 to EPA policy would limit researchers' ability to discuss the health impacts of environmental pollution in the EPA's decision-making process. The proposal, known as the ""Strengthening Transparency in Regulatory Science" rule, would restrict the agency's use of studies that rely on confidential human health data, including some of the seminal studies linking air pollution to premature death." [1]. The proposed policy change has been challenged by the scientific community [2], as well as legally, for example in the U.S. district court [3], but as yet, the matter has not been resolved. International policy regarding sustainable and environmentally friendly economic growth must incorporate pandemic risk factors into plans for development [4].	[1] Lavelle, M., 2020. Trumps' EPA Fast-Tracks A Controversial Rule That Would Restrict The Use Of Health Science. [online] InsideClimate News. Available at: <https://insideclimatenews.org/news/23032020/trump-epa-health-secret-science-coronavirus> [Accessed 16 April 2020]. [2] http://clinics.law.harvard.edu/environment/files/2020/05/Emmett-Clinic-Transparency-Supplemental-Notice-Comments-FINAL.pdf [3] Lynn L. Bergeson and Carla N. Hutton, 2020. Judge Suggests New TSCA Section 21 Petition Be Filed Regarding Fluoride in Drinking Water. Bergeson & Campbell PC. August 11, 2020. http://www.tscablog.com/entry/judge-suggests-new-tsca-section-21-petition-be-filed-regarding-fluoride-in [4] Di Marco, M., Baker, M. L., Daszak, P., De Barro, P., Eskew, E. A., Godde, C. M., ... & Karesh, W. B. (2020). Opinion: Sustainable development must account for pandemic risk. Proceedings of the National Academy of Sciences, 117(8), 3888-3892.
Media Value of Nature	Media Reporting Attitudes Towards Nature	The potential links of the SARS-CoV-2 virus to animals including bats and other animals has aroused fear of implicated animals. Such fears are often based on inaccurate or incomplete knowledge of zoonotic origins and risks. Implicated animals may face stigma or action.	COVID-19 pandemic is driving new threat to bats in several parts of the world, as people associate them with the outbreak [1,2,3]. In China, people living near bat colonies in urban areas demanded the bats be moved [1]. In Peru, bats were burned in their cave roosts by people driven by fear of their association with COVID-19 [2].	[1] Zhao H. COVID-19 drives new threat to bats in China. Science. 2020 Mar 27;367(6485):1436. [2] Fenton MB, Mubareka S, Tsang SM, Simmons NB, Becker DJ. COVID-19 and threats to bats. [3] MacFarlane D, Rocha R. Guidelines for communicating about bats to prevent persecution in the time of COVID-19. Biological Conservation. 2020 Jun 3:108650.
Media	Media Reporting Attitudes Towards Nature Communication	The COVID-19 pandemic allows for the writing of a 'conservation narrative' that aligns conservation goals with global public health goals. As such, public support for conservation issues may increase.	Collaboration may be encouraged between the conservation and health communities, governments, and interested groups, as conservation and environmental protection goals align with plans to mitigate future zoonotic disease outbreaks [1,2]. In March, the Humane Society International, a major conservation organisation, linked the wildlife trade to the COVID-19 pandemic. "The wildlife trade is driving species to extinction, is unbelievably cruel and provides the perfect conditions for the spread of diseases" [3]. There have been calls for the banning of the wildlife trade following COVID-19, in the interest of preventing future zoonotic disease emergence [4].	[1] Rodriguez-Morales, A., et al. "COVID-19, an Emerging Coronavirus Infection: Current Scenario and Recent Developments-An Overview." Journal of Pure and Applied Microbiology 14 (2020): 6150. [2] Rodriguez-Morales, Alfonso J., et al. "History is repeating itself: probable zoonotic spillover as the cause of the 2019 novel Coronavirus Epidemic." Infez Med 28.1 (2020): 3-5. [3] Humane Society International. Newsletter: Volume 26, Issue 1, March 2020. https://hsi.org.au/uploads/publication_documents/HSI_Newsletter_March_2020_WEB.pdf [4] Aguirre AA, Catherina R, Frye H, Shelley L. Illicit wildlife trade, wet markets, and COVID-19: preventing future pandemics. World Medical & Health Policy. 2020 Sep;12(3):256-65.
Media	Media Reporting	Media reporting and social media celebrating the possibly short-term environmental benefits of the COVID-19 pandemic's reductions to movement and economic activity may undermine the public's sense of urgency about environmental issues.	Stories suggesting increased wildlife sightings mean biodiversity has made significant recovery may undermine future conservation efforts by reducing the urgency of the biodiversity crisis. "The idea that animals can bounce back when humans retreat also "overestimates the speed of the recovery," Dodd said in a telephone interview. "It's marginalizing the active conservation required to reverse the impacts we've had on the Earth."" [2] Likewise, the media sharing data on COVID-19-related emissions reductions	Daly, N., Fake animal news abounds on social media as coronavirus upends life. National Geographic. Published 20 March 2020. https://www.nationalgeographic.com/animals/2020/03/coronavirus-pandemic-fake-animal-viral-social-media-posts/ [2] Daly, N., This 'hand-washing' orangutan went viral—but the story isn't true. National Geographic. Published 20 March 2020. https://www.nationalgeographic.com/animals/2020/04/coronavirus-fake-animal-news-part-two/

Media	Media Reporting	New Zealand Green Party is using lockdown to spread 'green' messages on Facebook. Australia Green Party is using lockdown to propose new financial policies on Facebook. Cook Inlet Belugas Count is seeking Facebook volunteers to help with virtual beluga counting.	Examples from NZ campaign: Attend an online climate rally Investigate if your bank is climate friendly. Switch if not. Try out a new vegetarian recipe or two. Learn something new! Listen to some sustainability or science podcasts. [1] Examples from Australia campaign: 80% wages subsidies Support for the Arts Industry Mortgage-holders and renters' financial holiday [2] Post from Cook Inlet asking viewers to watch the river mouth for ice and belugas [3]	[1] Green Party of Aotearoa New Zealand. (2020, April 16) Greening your lockdown. https://www.facebook.com/nzgreenparty [2] The Australian Greens. (2020, March 21) https://www.facebook.com/Australian.Greens [3] Belugas Count. (2020, April 16) https://www.facebook.com/BelugasCount