Tropical peatlands and their conservation are important in the context of COVID-19 and potential future (zoonotic) disease pandemics

Mark E Harrison [Corresp., 1, 2, 3], **Lahiru S. Wijedasa** [4, 5], **Lydia E S Cole** [6], **Susan M Cheyne** [2, 7, 8], **Shofwan Al Banna Choiruzzad** [9, 10], **Liana Chua** [11], **Greta C Dargie** [12], **Corneille E N Ewango** [13], **Euridice N Honorio Coronado** [14], **Suspense A Ifo** [15], **Muhammad Ali Imron** [16], **Dianna Kopansky** [17], **Trilianty Lestarisa** [18, 19], **Patrick J O'Reilly** [3], **Julie Van Offelen** [20], **Johannes Refisch** [21], **Katherine Roucoux** [6], **Jito Sugardjito** [22, 23], **Sara A Thornton** [2, 3], **Caroline Upton** [3], **Susan Page** [2, 3]

1   Centre for Ecology and Conservation, College of Life and Environmental Sciences, University of Exeter, Penryn, United Kingdom

2   Borneo Nature Foundation International, Penryn, United Kingdom, United Kingdom

3   School of Geography, Geology and the Environment, University of Leicester, Leicester, United Kingdom

4   Integrated Tropical Peatland Research Program (INTPREP), Environmental Research Institute, National University of Singapore, Singapore, Singapore

5   ConservationLinks Pvt Ltd, Singapore, Singapore

6   School of Geography and Sustainable Development, University of St. Andrews, St. Andrews, United Kingdom

7   Humanities and Social Sciences, Oxford Brookes University, Oxford, United Kingdom

8   IUCN SSC PSG Section on Small Apes, Oxford, United Kingdom

9   Department of International Relations, Universitas Indonesia, Depok, Indonesia

10   ASEAN Studies Center, Universitas Indonesia, Depok, Indonesia

11   Department of Social and Political Sciences, Brunel University, London, United Kingdom

12   School of Geography, University of Leeds, Leeds, United Kingdom

13   Faculty of Renewable Natural Resources Management / Faculty of Sciences, University of Kisangani, Kisangani, DR Congo

14   Instituto de Investigaciones de la Amazonía Peruana, Iquitos, Perú

15   Laboratoire de Géomatique et d'Ecologie Tropicale Appliquée, Département des Sciences et Vie de la Terre, Ecole Normale Supérieure, Université Marien Ngouabi, Brazzaville, Republic of Congo

16   Faculty of Forestry, Universitas Gadjah Mada, Yogyakarta, Indonesia

17   Global Peatlands Initiative, Ecosystems Division, United Nations Environment Programme, Nairobi, Kenya

18   Faculty of Medicine, Palangka Raya University, Palangka Raya, Kalteng, Indonesia

19   Doctoral Program of Public Health, Airlangga University, Surabaya, Indonesia

20   Independent Consultant, Nairobi, Kenya

21   Great Apes Survival Partnership, United Nations Environment Programme, Nairobi, Kenya

22   Centre for Sustainable Energy and Resources Management, Universitas Nasional, Jakarta, Indonesia

23   Faculty of Biology, Universitas Nasional, Jakarta, Indonesia

Corresponding Author: Mark E Harrison
Email address: m.e.harrison@exeter.ac.uk

The COVID-19 pandemic has caused global disruption, with the emergence of this and other pandemics having been linked to habitat encroachment and/or wildlife exploitation. High impacts of COVID-19 are apparent in some countries with large tropical peatland areas, some of which are relatively poorly resourced to tackle disease pandemics. Despite this, no previous investigation has considered tropical peatlands in the context of

emerging infectious diseases (EIDs). Here, we review: (i) the potential for future EIDs arising from tropical peatlands; (ii) potential threats to tropical peatland conservation and local communities from COVID-19; and (iii) potential steps to help mitigate these risks. We find that high biodiversity in tropical peat-swamp forests, including presence of many potential vertebrate and invertebrate vectors, combined, in places, with high levels of habitat disruption and wildlife harvesting represent suitable conditions for potential zoonotic EID (re-)emergence. Although impossible to predict precisely, we identify numerous potential threats to tropical peatland conservation and local communities from the COVID-19 pandemic. This includes impacts on public health, with the potential for haze pollution from peatland fires to increase COVID-19 susceptibility a noted concern; and on local economies, livelihoods and food security, where impacts will likely be greater in remote communities with limited/no medical facilities that depend heavily on external trade. Research, training, education, conservation and restoration activities are also being affected, particularly those involving physical groupings and international travel, some of which may result in increased habitat encroachment, wildlife harvesting or fire, and may therefore precipitate longer-term negative impacts, including those relating to disease pandemics. We conclude that sustainable management of tropical peatlands and their wildlife is important for mitigating impacts of the COVID-19 pandemic, and reducing the potential for future zoonotic EID emergence and severity, thus strengthening arguments for their conservation and restoration. To support this, we list seven specific recommendations relating to sustainable management of tropical peatlands in the context of COVID-19/disease pandemics, plus mitigating the current impacts of COVID-19 and reducing potential future zoonotic EID risk in these localities. Our discussion and many of the issues raised should also be relevant for non-tropical peatland areas and in relation to other (pandemic-related) sudden socio-economic shocks that may occur in future.

Tropical peatlands and their conservation are important in the context of COVID-19 and potential future (zoonotic) disease pandemics

Mark E. Harrison[1,2,3], Lahiru S. Wijedasa[4,5], Lydia E. S. Cole[6], Susan M. Cheyne[2,7,8], Shofwan Al Banna Choiruzzad[9,10], Liana Chua[11], Greta C. Dargie[12], Corneille E.N. Ewango[13], Euridice N. Honorio Coronado[14], Suspense Averti Ifo[15], Muhammad Ali Imron[16], Dianna Kopansky[17], Trilianty Lestarisa[18,19], Patrick J. O'Reilly[3], Julie Van Offelen[20], Johannes Refisch[21], Katherine Roucoux[6], Jito Sugardjito[22,23], Sara A. Thornton[2,3], Caroline Upton[3], Susan Page[2,3]

[1]   Centre for Ecology and Conservation, College of Life and Environmental Sciences, University of Exeter, Penryn, UK
[2]   Borneo Nature Foundation International, Tremough Innovation Centre, Penryn, UK.
[3]   School of Geography, Geology and the Environment, University of Leicester, Leicester, UK.
[4]   Integrated Tropical Peatland Research Program (INTPREP), Environmental Research Institute, National University of Singapore, Singapore
[5]   ConservationLinks Pvt Ltd, Singapore
[6]   School of Geography and Sustainable Development, University of St Andrews, St Andrews, UK
[7]   Humanities and Social Sciences, Oxford Brookes University, Oxford, UK
[8]   IUCN SSC PSG Section on Small Apes, Oxford, UK
[9]   Department of International Relations, Universitas Indonesia, Depok, Indonesia
[10] ASEAN Studies Center, Universitas Indonesia, Depok, Indonesia
[11] Department of Social and Political Sciences, Brunel University, London, UK
[12] School of Geography, University of Leeds, Leeds, UK
[13] Faculty of Renewable Natural Resources Management / Faculty of Sciences, University of Kisangani, P.O. Box 2012, Kisangani, DR Congo
[14] Instituto de Investigaciones de la Amazonía Peruana, Av. Abelardo Quiñones km 2.5, Iquitos, Perú
[15] Laboratoire de Géomatique et d'Ecologie Tropicale Appliquée, Département des Sciences et Vie de la Terre, Ecole Normale Supérieure, Université Marien N'GOUABI BP 237, Brazzaville, Republic of Congo
[16] Faculty of Forestry, Universitas Gadjah Mada, Yogyakarta, Indonesia
[17] Global Peatlands Initiative, Ecosystems Division, United Nations Environment Programme, Nairobi, Kenya
[18] Faculty of Medicine, Palangka Raya University, Palangka Raya, Indonesia
[19] Doctoral Program of Public Health, Airlangga University, Surabaya, Indonesia

41   [20]   Independent Consultant, Nairobi, Kenya
42   [21]   Great Apes Survival Partnership, United Nations Environment Programme, Nairobi,
43   Kenya
44   [22]   Centre for Sustainable Energy and Resources Management, Universitas Nasional,
45   Jakarta, Indonesia
46   [23]   Faculty of Biology, Universitas Nasional, Jakarta, Indonesia
47
48   Corresponding Author:
49   Mark E. Harrison
50   Centre for Ecology and Conservation, College of Life and Environmental Sciences, University of
51   Exeter, Penryn Campus, TR10 9FE, UK.
52   Email address: m.e.harrison@exeter.ac.uk
53

Abstract

The COVID-19 pandemic has caused global disruption, with the emergence of this and other
pandemics having been linked to habitat encroachment and/or wildlife exploitation. High
impacts of COVID-19 are apparent in some countries with large tropical peatland areas, some of
which are relatively poorly resourced to tackle disease pandemics. Despite this, no previous
investigation has considered tropical peatlands in the context of emerging infectious diseases
(EIDs). Here, we review: (i) the potential for future EIDs arising from tropical peatlands; (ii)
potential threats to tropical peatland conservation and local communities from COVID-19; and
(iii) potential steps to help mitigate these risks. We find that high biodiversity in tropical peat-
swamp forests, including presence of many potential vertebrate and invertebrate vectors,
combined, in places, with high levels of habitat disruption and wildlife harvesting represent
suitable conditions for potential zoonotic EID (re-)emergence. Although impossible to predict
precisely, we identify numerous potential threats to tropical peatland conservation and local
communities from the COVID-19 pandemic. This includes impacts on public health, with the
potential for haze pollution from peatland fires to increase COVID-19 susceptibility a noted
concern; and on local economies, livelihoods and food security, where impacts will likely be
greater in remote communities with limited/no medical facilities that depend heavily on external
trade. Research, training, education, conservation and restoration activities are also being
affected, particularly those involving physical groupings and international travel, some of which
may result in increased habitat encroachment, wildlife harvesting or fire, and may therefore
precipitate longer-term negative impacts, including those relating to disease pandemics. We
conclude that sustainable management of tropical peatlands and their wildlife is important for
mitigating impacts of the COVID-19 pandemic, and reducing the potential for future zoonotic
EID emergence and severity, thus strengthening arguments for their conservation and restoration.
To support this, we list seven specific recommendations relating to sustainable management of
tropical peatlands in the context of COVID-19/disease pandemics, plus mitigating the current
impacts of COVID-19 and reducing potential future zoonotic EID risk in these localities. Our
discussion and many of the issues raised should also be relevant for non-tropical peatland areas
and in relation to other (pandemic-related) sudden socio-economic shocks that may occur in
future.

Introduction

The COVID-19 pandemic has caused unprecedented global disruption, at the time of writing
infecting millions and killing hundreds of thousands of people across the globe (Dong, Du &
Gardner, 2020). These health impacts, plus lockdowns and other measures to control the
pandemic, have resulted in reduced economic activity and job losses, leading to potentially the
worst global recession since the Great Depression (IMF, 2020). While these global economic and
social disruptions have had a positive, albeit likely temporary, impact on global carbon emissions
(Le Quéré et al., 2020), negative outcomes are widely expected for biodiversity conservation,
research (Corlett et al., 2020; Evans et al., 2020; Hockings et al., 2020; Lindsey et al., 2020), and
indigenous communities (IUCN, 2020; UN/DESA, 2020; UN/EMRIP, 2020).

98 COVID-19 cases and deaths have been recorded for most tropical countries, with high numbers
99 in some (Dong, Du & Gardner, 2020), and with testing shortfalls likely partially accounting for
100 low reported case numbers for some other tropical nations, particularly in Africa (Ditekemena,
101 2020; Nordling, 2020) . Many tropical nations are low- or middle-income countries, with weaker
102 health systems and fewer resources to tackle the pandemic, generating further concerns. Some of
103 the countries with high infection and mortality rates also have large remaining areas of tropical
104 peatland, including Brazil, Peru, Ecuador and Indonesia (Dong, Du & Gardner, 2020; Page,
105 Rieley & Banks, 2011). While currently reporting relatively few cases, the Congo Basin contains
106 the world's largest tropical peatland area (Dargie et al., 2017), is among the most poorly
107 resourced to tackle disease pandemics in general (Oppenheim et al., 2019) and COVID-19 in
108 particular (WB, 2020a), and the Democratic Republic of Congo (DRC) is projected to suffer a
109 substantial number of cases and deaths (Cabore et al., 2020).
110
111 The importance of healthy tropical peatlands for carbon storage and emission mitigation,
112 conserving biodiversity and providing ecosystem services for local communities is increasingly
113 recognised (Baker et al., 2020; Crump, 2017; Dargie et al., 2017; Dommain et al., 2016; Hooijer
114 et al., 2009; Husson et al., 2018; Page, Rieley & Banks, 2011; Posa, Wijedasa & Corlett, 2011),
115 but to our knowledge no published study has specifically considered tropical peatlands and their
116 inhabitants in the context of emerging infectious disease (EID), although some infectious disease
117 studies have been conducted in tropical peatland areas (e.g., Vittor et al., 2006). Addressing this
118 gap is important because ongoing land-use change is reducing tropical peat-swamp forest (TPSF)
119 coverage, while bringing an increasing number of human communities in close contact with
120 peatlands (Field, van der Werf & Shen, 2009; Parish et al., 2008) and thus their biodiversity,
121 although to date this has occurred far less in South American and African peatlands, compared to
122 South-east Asia (Dargie et al., 2019; Roucoux et al., 2017). Such an assessment is made more
123 urgent considering the ongoing COVID-19 pandemic and its potential impacts, and the global
124 trend for increased EID event incidence (Jones et al., 2008). It is also relevant for understanding
125 and reducing the potential for emergence of, and impacts arising from, any future EIDs in
126 tropical peatland nations.
127
128 Our goals in this paper are thus to present a preliminary synthesis of: (i) the potential for future
129 EID (re-)emergence from tropical peatlands; (ii) potential threats to tropical peatland
130 conservation and local communities from the current COVID-19 pandemic; and (iii) potential
131 steps to help mitigate these risks. These goals cover a very broad range of potential topic areas,
132 ranging from local livelihoods and food security, to habitat conservation efforts and scientific
133 research, among others. A summary illustrating some key features relating to (i) and (ii) is
134 provided in Fig. 1. Although focused on tropical peatlands, many of the issues discussed and
135 concerns raised will also be relevant to non-peatland areas in the tropics. This synthesis should
136 thus be of interest to researchers, conservation/restoration/community project proponents, land
137 managers and policy makers in the tropics, especially in but not restricted to peatland areas.
138 While framed in the context of COVID-19, it is also pertinent to note that our discussion and
139 many of the issues raised are in reality not uniquely linked to COVID-19, but rather relate more
140 generally to (pandemic-related) sudden socio-economic shocks (e.g., economic recessions,
141 border closures due to other causes, or extreme events related to climate change) that may occur
142 in future.
143

144   INSERT FIG. 1 AROUND HERE
145

Survey Methodology

147
148   We conducted a scoping review of relevant literature in relation to the above goals. First, we
149   conducted a structured search of scientific databases using search terms related to these topics
150   (Table S1). This approach reduces potential for bias in awareness among our author team, but
151   yielded very few potentially relevant studies (total n = 6, Table S2), owing to a lack of past
152   studies concerning EIDs, including COVID-19, in the context of tropical peatlands. These results
153   alone were insufficient to draw meaningful conclusions relating to any one of our goals, whereas
154   conducting similarly structured database searches around every potential topic of relevance to
155   EIDs/COVID-19 in the context of tropical peatlands would have been impractical, given the
156   huge variety of potentially relevant topics relating to our goals, large number of countries
157   containing tropical peatlands and the fact that these countries are not entirely covered in tropical
158   peatlands, thus limiting potential to use individual tropical peatland nation names as search
159   criteria. Consequently, we also conducted a less formally structured literature review, drawing on
160   the subject knowledge, awareness of formal and informal literature sources, personal experiences
161   and networks of our author team. In line with our scoping aims and very broad line of
162   questioning, this did not employ strict inclusion and exclusion criteria, asides from excluding
163   studies of no conceivable relevance to EIDs/COVID-19 and tropical peatlands. Such an approach
164   allows us to draw relevant information from the many studies and reports of potential relevance
165   that we were aware of that do not specifically concern EIDs/COVID-19 in the context of tropical
166   peatlands and that did not therefore appear in our structured searches. The remainder of this
167   manuscript is therefore focused on this much more informative less formally structured review,
168   though findings from the structured search are integrated in relevant sections of the text.
169
170   To help ensure comprehensive coverage of the literature, and minimise geographic and subject
171   bias in this review, our author team was developed to include natural and social scientists with
172   substantial direct experience of, and familiarity with the literature in relation to, tropical peatland
173   research in South-east Asia, Africa and South America (see, e.g., past reviews: Dargie et al.,
174   2019; Harrison et al., 2020; Page & Hooijer, 2016; Roucoux et al., 2017). While we attempt to
175   provide context across all four continents on which tropical peatlands are found, we
176   acknowledge some bias towards South-east Asia, for which a far greater volume of information
177   is available. Where possible we draw upon peer-reviewed and other highly reputable sources
178   (e.g., UN reports), but owing to the COVID-19 pandemic's recent emergence and consequent
179   paucity of such literature relating specifically to it in the context of the issues considered, we also
180   draw upon pre-prints and media reports where peer-reviewed sources are unavailable or just
181   provide general (rather than COVID-19 specific) support for a statement. We attempt to indicate
182   such cases clearly and verify these from multiple sources, while noting that this reflects the
183   uncertainty and rapid evolution of the pandemic and associated public debate.
184

185 # Are Tropical Peatlands a Potential Source Habitat for
186 # Disease Pandemics?

187
188 Most EID events are dominated by zoonoses (60.3%), with the majority of these (71.8%)
189 originating in wildlife, including Acquired Immunodeficiency Syndrome (AIDS), Severe Acute
190 Respiratory virus (SARS), Middle East Respiratory Syndrome (MERS) and Ebola virus (Jones et
191 al., 2008), plus the novel COVID-2019, an ongoing global pandemic as we write this paper (Li et
192 al., 2020). In Africa, for example, 25 types of parasites, nine main types of viruses and eight
193 types of bacteria have been reported as present in wild meat and communicable to humans (van
194 Vliet et al., 2017). The joint-first reported case of Ebola in 1976 is from a peatland area
195 (Yambuku, DRC: Muyembe-Tamfum et al., 2012), as is the most recent outbreak in May 2020
196 (Mbandaka, DRC: WHO, 2020c; Fig. 2), and the cradle of the HIV/AIDS pandemic is believed
197 to be around Kinshasa, DRC, another area with extensive peatlands (Sharp & Hahn, 2011;
198 Worobey et al., 2008). The risk of zoonotic EID emergence is positively correlated with high
199 human population density and wildlife host richness (Allen et al., 2017; Jones et al., 2008); wild
200 animal harvesting and/or movement of animals or body parts, leading to increased contact
201 between wildlife vectors and humans (Bengis et al., 2004; Johnson et al., 2020); biodiversity loss
202 (Keesing et al., 2010); spread of non-indigenous vectors and pathogens; plus habitat
203 encroachment, fragmentation and alteration (Allen et al., 2017; Johnson et al., 2020; Pongsiri et
204 al., 2009).

205
206 INSERT FIG. 2 AROUND HERE

207
208 The natural habitat of tropical peatlands, tropical peat-swamp forest (TPSF), possesses a rich
209 fauna and flora, including numerous vertebrate taxa known to represent zoonotic EID risk, such
210 as bats, rodents, pangolins and primates (Husson et al., 2018; Inogwabini et al., 2012; Posa,
211 Wijedasa & Corlett, 2011). Indeed, previous studies on primates and small mammals in South-
212 east Asian TPSF areas have recorded numerous parasite species found in humans and that are of
213 medical concern (Hilser, 2011; Hilser et al., 2014; Madinah et al., 2011; Madinah et al., 2011;
214 Nurcahyo, Konstanzová & Foitová, 2017), and surveys of bats from TPSF areas in Peru have
215 detected high rates of *Bartonella* bacteria infection (Bai et al., 2012), suggesting potential for
216 disease transmission from humans to wildlife and zoonotic transmission from wildlife to humans
217 in TPSF areas. Studies conducted in non-TPSF areas on species that are also found in TPSF
218 support this conclusion (e.g., chimpanzee *Pan troglodytes* deaths from human paramyxoviruses
219 in Ivory Coast: Köndgen et al., 2008).

220
221 TPSF conversion, plus fire and wildlife harvesting brings more people into closer contact with
222 peatland biodiversity. In South-east Asia, degradation, fragmentation and conversion of TPSF to
223 agriculture has been particularly widespread, with the area of peatland in Malaysia, Sumatra and
224 Kalimantan covered by TPSF declining from 76% (11.9 Mha) in 1990 to 29% (4.6 Mha) in
225 2015, with a concomitant increase from 11% (1.7Mha) to 50% (7.8Mha) of the area covered by
226 agriculture over the same time period (Miettinen, Shi & Liew, 2016). This near doubling of
227 agricultural extent has been driven by small-scale farmers (43-44%), plus industrial oil palm
228 (39%) and paper pulp (11-26%) (Miettinen, Shi & Liew, 2016; Wijedasa et al., 2018). Further
229 forest habitat fragmentation is expected if all planned road and rail infrastructure development

230 projects on Kalimantan proceed as proposed, with a projected reduction in landscape
231 connectivity from 89% to 55% (Alamgir et al., 2019).
232
233 Such threats are not limited to South-east Asia. For example, although there is currently limited
234 encroachment into the TPSFs of the Peruvian Amazon from industrial agriculture and
235 infrastructure development (Lilleskov et al., 2019), these threats are present and considerable
236 (Baker et al., 2020; Roucoux et al., 2017), and could increase the likelihood of EID emergence
237 from the Amazon in the near future (Ellwanger et al., 2020). Likewise, projected mining permits,
238 gas and oil exploration, timber and palm oil concessions, associated road construction and
239 changing rainfall patterns due to global warming pose potential risks to the relatively undisturbed
240 TPSF of the Congo Basin and its wildlife (Dargie et al., 2019; Haensler, Saeed & Jacob, 2013;
241 Miles et al., 2017; Wich et al., 2014). In the Republic of Congo (RoC), health authority reports
242 claim that several recent malaria infections appeared in swampy forests for the first time
243 following opening of logging trails (Rédaction, 2020), highlighting the potential for increased
244 EID risk should these peatlands experience greater future encroachment.
245
246 Patterns of human-wildlife contact and wild meat hunting in tropical peatlands provide further
247 potential for disease spill-over events (during which a pathogen from one species moves into
248 another) from wildlife to humans to occur. Human population density in tropical peatland areas
249 is typically not high (e.g., Peru: Lilleskov et al., 2019; Congo Basin: Dargie et al., 2019), but
250 some large population centres are found close to TPSF (e.g., Jambi and Palangka Raya,
251 Indonesia; North and South Selangor, Malaysia; Iquitos, Peru; Fig. 2), and certain human
252 activities increase contact between people and potential animal vectors in TPSF. Wildlife
253 harvesting for consumption and trade is common in tropical forest nations (Fa, Currie &
254 Meeuwig, 2003; Nielsen et al., 2018), including in TPSF areas. For example, in Central
255 Kalimantan, Indonesia, *Pteropus vampyrus* (Linn.) fruit bats are captured in TPSF areas and
256 transported to local markets for sale as wild meat (Harrison et al., 2011). High contact levels
257 between bats, hunters and vendors occur, with hunters and vendors frequently bitten and most
258 bites drawing blood, raising concerns regarding potential zoonotic disease transmission
259 (Harrison et al., 2011), though recent anecdotal observations suggest that local demand and trade
260 has decreased as a likely result of the pandemic (R. Dwi et al., 2020, pers. comm.). Other species
261 are commonly harvested for commercial trade in tropical peatland nations, often for sale in dense
262 population areas, including turtles (Schoppe, 2009) and primates (Nijman et al., 2015) in
263 Indonesia; plus pangolins and numerous other species from across South-east Asia (Nijman,
264 2010). Similar unsustainable hunting has been reported in the Congo Basin (Fa, Currie &
265 Meeuwig, 2003; Poulsen et al., 2009). In the Peruvian Amazon TPSF, tapirs (*Tapirus terrestris*,
266 Linn.), primates, rodents and other mammals are commonly hunted by local communities
267 (Schulz et al., 2019a). Although there is some wildlife export to local market centres (e.g.
268 Iquitos: Bodmer & Lozano, 2001; Mayor et al., 2019), most is consumed at a household level
269 and constitutes an important protein source (Schulz et al., 2019a), providing higher potential to
270 limit wildlife export from peatland areas than may be the case in South-east Asia and Africa.
271
272 High densities of domestic and semi-wild animals reared on peatlands could also serve as a
273 direct or indirect zoonotic EID vector to humans. For instance, in Indonesia, over 1.8 million
274 chickens are kept in the predominantly peatland municipality of Palangka Raya (BPS Palangka
275 Raya, 2018), while large numbers of naturally cave-roosting edible-nest swiftlets (mostly

276 *Aerodramus* spp.) are reared in special buildings in many peatland areas, with most nests
277 exported to China (Husson et al., 2018; Koon & Cranbrook, 2014; Thorburn, 2014).
278
279 In summary, the combination of high native faunal diversity, habitat encroachment and
280 fragmentation, plus trade in native and non-native fauna in many tropical peatland areas appears
281 to represent a suitable set of conditions under which zoonotic EIDs could potentially (re-)emerge
282 in future. Given that TPSFs represent the largest remaining blocks of lowland forest in some
283 areas (e.g., lowland Borneo: Wijedasa et al., 2018; Congo Basin: Dargie et al., 2017; parts of the
284 Amazon: Roucoux et al., 2017), attention should be paid to conserving and sustainably managing
285 these TPSFs and their wildlife to reduce the likelihood of potential future zoonotic EID
286 pandemics arising.
287

What are the Potential Immediate Impacts of the COVID-19 Pandemic in Tropical Peatland Areas?

290
291 The impacts of the COVID-19 pandemic will depend heavily on its length and severity, and
292 evolving government and societal responses, which will vary between and potentially even
293 within tropical peatland nations. This unpredictability notwithstanding, we nevertheless outline
294 some areas of potential concern relating to tropical peatlands specifically, while referring readers
295 to the more generic issues raised by Corlett et al. (2020), Evans et al. (2020) and Hockings et al.
296 (2020), many of which will apply to tropical peatlands as much as to other habitats, and to any
297 potential future pandemics causing similar levels of socio-economic disruptions to COVID-19. It
298 is also pertinent to note that these issues occur on top of pre-existing challenges for tropical
299 peatland conservation and sustainable management (see Dargie et al., 2019; Harrison et al.,
300 2020; Roucoux et al., 2017 for reviews).
301

Public Health and Potential Combined Impacts from Haze Pollution

303
304 Disadvantaged populations are expected to be disproportionately affected by pandemics, further
305 exacerbating existing social and economic inequalities (Lee, Rogers & Braunack-Mayer, 2008;
306 WHO, 2009). With the exception of Reunion, Brunei, Puerto Rico and Australia, which contain
307 only small peatland areas, all tropical peatland nations listed by Page, Rieley & Banks (2011) are
308 classified as low or middle income (OECD, 2020), with many also being considered relatively
309 under-prepared to cope with disease pandemics (Oppenheim et al., 2019). Tropical peatland
310 communities are often relatively remote and (agricultural) conditions marginal, with lower
311 access to public health and other services, no or poor medical insurance, fewer formal
312 employment opportunities and higher poverty rates than non-peatland areas (e.g., Kalimantan:
313 Medrilzam et al., 2014; Thornton, 2017; van Beukering et al., 2008; Wiseman et al., 2018; DRC:
314 C. Ewango & G. Dargie, pers. obs.; Peru: E. Honorio, pers. obs.; Fig. 3). The rural populations of
315 several tropical peatland nations have disproportionate numbers of people with underlying health
316 conditions and/or malnutrition (e.g., Kandala et al., 2011; Nair, Wares & Sahu, 2010), and many
317 do not have access to formal healthcare, or the running water, good sanitation and hygiene
318 systems required to implement the recommended WASH approach to COVID-19 (WHO &

319   UNICEF, 2020). For example, in Central Kalimantan, less than 40% of people have access to
320   improved sanitation (WHO, 2017) and the province tends to perform poorly in healthcare
321   provision evaluations (Suparmi et al., 2018; Wiseman et al., 2018). Disseminating COVID-19
322   health guidance information will likely also be more difficult in rural tropical peatland areas with
323   poor communications infrastructure, further reducing the probability that risk reduction
324   behaviours will be followed. It is therefore possible that the health impacts of the COVID-19
325   pandemic may be relatively severe and/or prolonged in tropical peatland nations.
326
327   INSERT FIG. 3 AROUND HERE
328
329   While their remoteness and low population densities may reduce the potential for COVID-19 to
330   reach and spread between some rural tropical peatland communities, evidence to support this
331   supposition is limited, since many of these communities—like many others on resource
332   frontiers—are deeply embedded in market relations (e.g., Li, 2014; Medrilzam et al., 2014) and
333   local to international value chains bring them into regular contact with outsiders (Dove, 2011;
334   Schreer, 2016). Even among those communities living relatively autonomously, there are still
335   levels of contact with non-community actors, including NGOs, researchers, public agencies and
336   commercial organisations. Indeed, media reports from the Americas and Africa indicate that
337   COVID-19 has already spread into remote indigenous communities (Brito, 2020; Wallace,
338   2020). In DRC, this comes on top of existing Ebola and measles epidemics (Blomfield, 2020),
339   and in Iquitos, Peru, on top of dengue fever and leptospirosis outbreaks (Collyns, 2020b). Once
340   introduced, the possibility of COVID-19 cases going undetected and unreported, owing to a lack
341   of testing, limited awareness plus an element of fatalism arising from the commonness of disease
342   in such communities (e.g., Borneo: L. Chua, pers. obs.), combined with the important role that
343   communal activities and high levels of social interaction play in many peatland communities,
344   raises the risk of infection spreading. The more limited public health resources in rural tropical
345   peatland areas means that the health impacts arising should an outbreak occur are potentially
346   more serious than in less remote and more affluent communities. Furthermore, development and
347   medical assistance in tropical peatland areas may be temporarily halted due to financial and
348   organisational challenges (e.g., mobile medical teams in Peruvian Amazon: (Vine Trust, 2020).
349   These considerations place an onus on businesses, governments, NGOs and researchers working
350   with such communities to take measures to reduce the chances of introducing and spreading the
351   disease between communities.
352
353   Given that elderly people are more vulnerable to COVID-19 (Zhou et al., 2020), one impact of
354   outbreaks in tropical peatland areas may be a loss of traditional local knowledge regarding these
355   ecosystems. Another important knock-on impact highlighted by the WHO is potential for
356   disrupted responses to other major public health issues that may risk reversing gains made
357   against these. This includes malaria and dengue fever, which are endemic in many tropical
358   peatland areas and exhibit several symptoms similar to COVID-19 (PAHO, 2020; WHO, 2020d);
359   and immunisations for diseases such as diphtheria, measles and polio (WHO, 2020a). In
360   addition, co-infection of COVID-19 with other diseases and increased COVID-19 mortality
361   rates in co-infected patients has been reported (Lansbury et al., 2020; Zhou et al., 2020), as has a
362   case of co-infection of COVID-19 and *Plasmodium vivax* malaria (Sardar et al., 2020; following
363   hospitalisation and discharge, the patient in this case tested negative for both diseases). Important
364   questions therefore exist regarding the potential for (increased impacts from) COVID-19 co-

365   infection in tropical peatland areas, especially for the most vulnerable members of these
366   communities. Measures to tackle these pre-existing diseases must therefore continue to remain a
367   priority in tropical peatland areas.
368
369   Tropical peatland degradation and drainage increase fire risk. In Indonesia, peatland fires and
370   their associated haze (smoke pollution) now occur almost annually (Gaveau et al., 2014; Page &
371   Hooijer, 2016; Fig. 4), leading to high carbon emissions, forest and biodiversity losses, and
372   major public health impacts from inhalation of the toxic haze (see Harrison et al., 2020; Page &
373   Hooijer, 2016; Uda, Hein & Atmoko, 2019 for reviews). The haze contains high small particulate
374   concentrations and several toxic compounds, including CO_2, CO, CH_4, NH_3, HCN, NO_X, OCS
375   and HCl (Stockwell et al., 2016). Haze exposure during the prenatal period has been linked to
376   decreased adult height attainment (Tan-Soo & Pattanayak, 2019), and short-term exposure
377   during the severe 2015 fires is estimated to have caused 100,300 or more premature mortalities
378   in Equatorial Asia (Koplitz et al., 2016; see also Crippa et al., 2016). This is important in light of
379   recent reports that increased air pollution may elevate COVID-19 case numbers, hospital
380   admissions and mortality (Cole et al., 2020; Conticini, Frediani & Caro, 2020; Ogen, 2020; Wu
381   et al., 2020), and has led to concerns being raised by both regional think tanks (Gan et al., 2020)
382   and relevant experts in media reports regarding peatland fires and COVID-19 (Jong, 2020b;
383   Listiyorini, 2020; Varkkey, 2020), though under COVID-19 lockdown conditions such impacts
384   may be at least partially mitigated by general shutdowns of anthropogenic activities (Kanniah et
385   al., 2020). In particular, in a pre-print article, Cole et al. (2020) and Wu et al. (2020) report that
386   an increase in PM2.5 (small particulate matter) of just 1 $\mu g/m^3$ is associated with a 8-16.6%
387   increase in COVID-19 death rate, whereas in Central Kalimantan, PM2.5 levels have been
388   reported to exceed 1,500 $\mu g/m^3$ during severe fire periods (Atwood et al., 2016) and average
389   mean exposures between 2011-2015 have been estimated at 26 $\mu g/m^3$, over double the
390   recommended WHO exposure limit (Uda, Hein & Atmoko, 2019). Similar findings were
391   reported in relation to the impacts of air pollution on fatalities from the earlier SARS epidemic in
392   China (Cui et al., 2003), suggesting that high levels of air pollution may increase vulnerability of
393   populations exposed to haze from peatland fires to future pandemics. Observations that SARS-
394   CoV-2 RNA can be present on particulate matter (Setti et al., 2020), and suggestions that the
395   ability of fine particulates, such as PM2.5, to penetrate deep inside the lungs and remain in the
396   air for long periods of time (Frontera et al., 2020) lead to further concern that haze pollution
397   from peat fires may increase COVID-19 transmission. Finally, some symptoms of haze exposure
398   are also similar to those of COVID-19 (e.g., dry cough, weakness), which may lead to
399   complications with regards to COVID-19 testing and case identification. While extensive
400   tropical peatland fires are currently mainly limited to Indonesia (Dargie et al., 2019; Lilleskov et
401   al., 2019), increasing pressure to develop African and South American peatlands could elevate
402   their fire risks if preventative measures are not implemented (Roucoux et al., 2017), with
403   consequent potential impacts on the susceptibility of their populations to future respiratory EID
404   pandemics. Continuing and amplifying measures to avoid and control fires in tropical peatlands
405   (Page & Hooijer, 2016; Dohong et al., 2018; Wijedasa et al., 2018; Harrison et al., 2020) is
406   therefore of heightened importance.
407
408   INSERT FIG. 4 AROUND HERE
409

Economy and Livelihoods

The COVID-19 pandemic and associated response measures are likely to have deep and long-lasting adverse global and local economic impacts, with the worst case scenario being that poverty alleviation achieved in recent decades might be reversed, earnings reduced and our ability to meet the UN Sustainable Development Goal of ending poverty by 2030 compromised (ASEAN, 2020; Lucas, 2020; Sumner, Hoy & Ortiz-Juarez, 2020; WB, 2020b). Although tropical peatland communities are less likely to face the types of direct interruptions to livelihood resulting from strict lockdowns, adverse economic impacts linked to the pandemic may nevertheless have important consequences for them. Indeed, low incomes in many tropical peatland households, and weak social and food security safety nets in many tropical peatland countries (FAO et al., 2019), may make them particularly vulnerable. Anticipating the nature and the severity of these effects is complicated by the diversity of peatland communities and their livelihood heterogeneity (Jelsma et al., 2017). In Indonesia, for example, economic activities include self-employment in commodity tree crop, short-term vegetable crop and livestock production (especially chicken), swiftlet nest farming, hunting, fishing, gathering non-timber forest products, logging, artisanal mining, employment in construction and other industries, trading, remittances from family members employed elsewhere, and employment by government services and NGOs (Schreer, 2016; Thornton, 2017). The intensity of direct economic impacts arising from the COVID-19 pandemic are likely to be linked to the way communities are integrated into wider trade and resource allocation networks. Here we consider some of these potential impacts.

The anticipated global recession is expected to have a generally negative impact on agricultural prices, with prevalent low incomes in peatland areas likely to amplify the impact of price falls. Indeed, the UN and IUCN have flagged the expected negative impact of the COVID-19 pandemic on the livelihoods of remote indigenous groups and called for special measures to restore and support traditional indigenous economies (IUCN, 2020; UN/DESA, 2020; UN/EMRIP, 2020). Tropical peatland communities are commonly not food self-sufficient and tend to be close to poverty at the best of times (Wildayana & Armanto, 2018). Global food shortages due to COVID-19 may have implications for the price of imported food, increasing pressure on these communities and potentially forcing some into poverty (as feared more generally by key international institutions: (Sánchez-Páramo, 2020; WFP, 2020). Small-scale settler communities cultivating short-lifecycle food crops and staples serving local markets are likely to be less adversely affected, because demand for their output is relatively inelastic and close market proximity means they are better placed to respond to changes in local demand by rapidly switching production. To date, prices of such crops are indeed remaining relatively stable (Lucas, 2020), although some increases are anticipated (e.g., Amanta & Aprilianti, 2020). For such producers, the greater problem may be changes in the price of agricultural inputs (e.g., fertilisers) and other imported goods.

Producers of commodities such as palm oil, rubber and beef on tropical peatlands are likely to experience more severe adverse impacts due to falling prices resulting from changes in international demand. For example, the value of palm oil fell by over 20% from December 2019 to April 2020 (Index Mundi, 2020), and declining palm oil export volumes and domestic consumption have already been noted in Indonesia (Sarkar, 2020), leading to reported concerns

456 regarding lower demand and falling prices (Gan et al., 2020). Any sustained fall in palm oil price
457 is likely to more severely impact peatland-based production, which is less productive than
458 cultivation on mineral soil, and small-scale producers, for whom yields are typically lower and
459 who will have less resources to sustain them through difficult periods (Euler et al., 2016;
460 Sumarga et al., 2016). These problems are exacerbated by the long-term commitment and
461 substantial investments that these crops require, which restrict the capacity of farmers to rapidly
462 change to other crops, thus limiting their resilience. Prolonged low prices, combined with long-
463 standing issues such as land titling, are thus likely to lead to increased hardship among these
464 small-scale commodity producers, with previous commodity price falls being linked to increased
465 poverty, mental health issues and suicide among small scale producers (Tyson, Varkkey &
466 Choiruzzad, 2018). Conversely, decisions of better resourced, larger plantation companies
467 regarding expansion or contraction of operations will be more heavily influenced by predictions
468 of the longer-term impact of the COVID-19 pandemic, rather than immediate price changes.
469 Current thinking in the palm oil industry appears to be that, while the short-term impact may be
470 significant, longer-term effects are uncertain, given the nature of the product and its market
471 (Sarkar, 2020), reducing the likelihood of substantial longer-term reductions in oil palm
472 expansion by large operators. These price changes may nevertheless mean that alternative
473 economic and livelihood options may compete more favourably economically with palm oil in
474 tropical peatland areas (cf. Wich et al., 2011), possibly encouraging their uptake. However,
475 evidence of land holding in tropical peatlands strongly suggests that financial problems linked to
476 poor revenues and limited capital may contribute to plot abandonment (Yusoff, Muharam &
477 Khairunniza-Bejo, 2017).
478
479 It is likely that many employed and casual workers in tropical peatland cities will lose their
480 immediate income sources owing to lockdowns and other disruptions, leading to migration of
481 people from cities to home communities, with media reports suggesting this may already be
482 happening in Indonesia (Listori, 2020), Malaysia (Radhi, 2020) and Peru (Collyns, 2020a; E. N.
483 Honorio Coronado, pers. obs.). There is concern that this 'returning home' may bring sources of
484 infection to vulnerable communities, leading to media reports of the strict closure of some
485 indigenous territories (Sierra Praeli, 2020). This situation may impose a triple strain on tropical
486 peatland communities by increasing the risk of infection via returning community members,
487 imposing additional burdens on household resources and depriving households of external
488 income sources. Furthermore, during previous periods of economic instability in Indonesia, such
489 as following the 1998 financial crash, illegal land uses increased, including illegal logging (EIA-
490 TELAPAK, 1999), as people sought alternative economic means. Economic disruptions are also
491 expected in communities dependent upon eco-tourism (Evans et al., 2020; Hockings et al., 2020;
492 Lindsey et al., 2020). There is thus a risk that the financial burden caused by the COVID-19
493 pandemic could increase unlawful exploitation of natural resources (timber, wild animals), as
494 well as increasing other marginal livelihood practices (e.g. artisanal mining).
495

496 **Food Security**
497
498 The UN World Food Programme has predicted that the COVID-19 pandemic will lead to over a
499 quarter of a billion people suffering acute hunger by the end of 2020, owing to increased conflict,
500 reduced aid and trade, price fluctuations and lost incomes (Anthem, 2020). Concerns have been

501 raised that the pandemic is affecting all four pillars of food security (food availability,
502 utilisation/nutrient intake, stability and particularly food access) and is leading to forced cut-
503 backs in nutrient-rich non-staple foods towards starchy staples, with consequent long-term
504 adverse health impacts (Laborde et al., 2020). We have already suggested that, given existing
505 relatively high poverty levels and frequent lack of food self sufficiency, plus positions at the end
506 of long supply chains for many external commodities, tropical peatland communities may be
507 particularly vulnerable to food supply problems and price rises. Furthermore, while statutory and
508 NGO food assistance programmes are operating and good transport links exist in some tropical
509 peatland areas, these are designed to deal with relatively small numbers of clients and could be
510 quickly overwhelmed if demand increases dramatically, whilst other areas have poor assistance
511 infrastructure and poor, or often no, road access (e.g., Fig. 3). For indigenous communities, such
512 issues may be exacerbated by a common lack of visibility in public policy (UN, 2009). Ensuring
513 food security and the provision of food assistance to tropical peatland areas thus presents
514 logistical, organisational and political challenges, and development of more localised food
515 supply chains may therefore be favourable in post-pandemic responses (as recommended in a
516 general context by Pearson et al., 2020).
517
518 As previously mentioned, tropical peatland community livelihood strategies are often based on a
519 range of economic activities, whose relative importance varies temporally. For example, rural
520 communities in Borneo have for centuries been fairly entrepreneurial and responsive to changing
521 global/regional trade patterns (Arenz et al., 2017; Dove, 2011). From their perspective, the
522 COVID-19 pandemic may therefore not be viewed exceptionally, but rather as yet another
523 development to which they must respond. Consequently, any potential loss of economic
524 opportunities and reduced external demand for, or price of, locally produced commodities in
525 such communities may lead to individuals reconsidering their livelihood strategies, resulting in
526 changes in natural resource exploitation. For example, any price declines in swiftlet nests
527 produced in Indonesian peatland areas following potential economic slowdowns in China (the
528 main market), may lead swiftlet keepers to search for alternative incomes from harvesting forest
529 resources. While such shifts may not necessarily result in increased pressure on natural
530 resources, concern nevertheless appears warranted, as recent reviews suggest that increased
531 overall local environmental resource pressures may be expected under conditions of rural
532 economic hardship (Robinson, 2016) and that, where poverty exists, households are more likely
533 to pursue economic activities that improve their family's short-term livelihoods, regardless of
534 environmental impacts (South-east Asia: Douglas, 2006; Peru: Schulz et al., 2019b). From a
535 positive perspective, any such changes may present an opportunity to work productively with
536 affected communities to innovate and find more sustainable, locally rooted ways of responding
537 to their needs.
538
539 Nevertheless, research suggests that experience of adverse shocks leads to increased risk
540 aversion (Gloede, Menkhoff & Waibel, 2015) and that communities may be less willing to
541 engage in alternative "sustainable" livelihood activities if these are perceived to carry increased
542 risks (Rodriguez et al., 2009). Perceived threats to health, income and food security related to
543 COVID-19 may therefore reduce uptake or outcomes of revitalisation and community
544 development activities in tropical peatland areas. Indeed, work in Indonesia has demonstrated
545 that ecosystem restoration activities are unlikely to be adopted unless accompanied by assurances
546 concerning food and income security (Carmenta & Vira, 2018).

547
548 The post-(peak) pandemic pressures governments face to "rescue the economy", may lead
549 governments and companies in tropical peatland areas to reduce (or at least withhold attempting
550 to improve) social and environmental standards (e.g., media reports: Carrington, 2020; Hurowitz,
551 2020), in an effort to reduce commodity prices and thus increase sales to rescue or expand
552 industries such as palm oil. While evidence is currently limited, some media reports indicate that
553 the pandemic may be employed to chip away at existing environmental measures, such as the
554 EU's palm oil ban (Kobo, 2020). Such trends could be exacerbated if economic restrictions and
555 priority shifts lead to reduced enforcement of environmental and social regulations concerning
556 extractive industries, or reduced emphasis on conservation and restoration, in tropical peatland
557 areas.
558
559 **Land Conflicts**
560
561 Land conflicts are one of the most important and complicated problems in land-use management
562 in many countries with large peatland areas (Colchester, 2010; Colchester et al., 2007;
563 Nesadurai, 2013; Scullion et al., 2014). In Peru, 24% of the estimated peatlands of the Pastaza-
564 Marañon overlap with oil-extraction or exploration concessions, national reserves and territories
565 of indigenous communities (Roucoux et al., 2017). In Indonesia, 807,178 ha are in land tenure
566 conflict, with 73% of this contested land in the plantation sector (KPA, 2019). Increasing
567 economic pressures and food insecurity associated with the COVID-19 pandemic may
568 potentially aggravate this situation, with any increases in land tenure conflict likely to lead to
569 increased peat fire incidence, given previously reported links (Medrilzam et al., 2014; Suyanto,
570 2007), and potentially therefore to further disenfranchisement and displacement of the poorest
571 households and communities. This, in turn, may trigger further habitat encroachment and
572 increased human-wildlife contact, whilst both food insecurity and haze pollution in degraded
573 tropical peatland areas may increase COVID-19 impacts and susceptibility, as we have
574 previously outlined. A glimpse of the complex and uneven effects that can result from such
575 large-scale disruptions is found in Schreer's (2016) ethnography of a Central Kalimantan
576 village's experiences and aspirations in the early- to mid-2010s. Here, the end of the logging
577 boom—precipitated in by rapid governmental decentralisation—in the mid-2000s had highly
578 variable effects in her fieldsite, with migrants and non-migrants reacting differently, and other
579 industries and initiatives bringing in new opportunities, risks and land conflicts, as well as
580 widespread disillusionment and resentment at various external parties (Schreer, 2016).
581
582 The return migration of casual and temporary workers from cities in to rural tropical peatland
583 communities and the continued presence of migrant labour (working in industries disrupted by
584 COVID-19), as noted above, constitutes a further factor that may exacerbate pressure on land
585 resources and thus increase conflicts, as well as acting as a direct vector for disease transmission.
586 Supporting local communities in and around tropical peatland areas to resolve land tenure
587 conflicts and promote inclusive, sustainable community-led management will likely prove
588 important in mitigating these risks surrounding land conflict issues.
589
590 **Unequal Community and Gender Impacts**
591

592 Importantly, any negative economic, social, and health impacts for communities will not occur in
593 a vacuum, and the social and ecological impacts of COVID-19 will affect different communities
594 and community members unequally. Regional inequalities, and differences in access to health
595 facilities between rural and urban areas, are likely to impact (efforts to curb) COVID-19 impacts.
596 For example, in Indonesia, COVID-19 testing rates in Java have only surpassed WHO minimum
597 recommendations in the capital, Jakarta (WHO, 2020d), and other provinces with large peatland
598 areas generally lag behind in terms of health facility availability and access (MoH RoI, 2019).
599 Furthermore, there is evidence that legal and policy frameworks support development patterns
600 that marginalise peatland communities, resulting in the neglect of their interests by policy makers
601 (McCarthy & Robinson, 2016). The COVID-19 crisis may exacerbate these trends, contributing
602 to increased levels of economic (Payne & Bradley, 2020) and intersectional inequality (Bowleg,
603 2020). It is being increasingly recognised that tropical peatland communities are not
604 homogenous in relation to economic status, ethnicity, access to facilities, etc., (e.g., Thornton,
605 2017) and the interaction of these factors means that the impact of COVID-19 is therefore highly
606 unlikely to affect all members of tropical peatland communities equally, with impacts likely
607 varying between households.
608
609 In addition, studies have highlighted how economic, food and health crises often put women in a
610 more vulnerable position compared to men, despite shrinking options available for both genders
611 (Pitkin & Bedoya, 1997; Pollock & Lin Aung, 2010). For example, previous studies on other
612 diseases such as tuberculosis have demonstrated context-specific gender-related differences in
613 the barriers to access diagnostic and treatment services, especially in developing countries
614 (Krishnan et al., 2014), while the greater role of women as primary care givers may increase
615 their probability of infection (Davies & Bennet, 2016; Wenham et al., 2020). In line with
616 this,international organisations have already highlighted the key role that women play in food
617 provision in indigenous rural communities and the likely heightening of this and other burdens
618 on women, including the loss of childcare and other supports services, plus surges in domestic
619 violence, during the COVID-19 pandemic (FAO, 2020; UN, 2020; UN/DESA, 2020). For
620 example, the closure of schools is likely to disproportionately increase the childcare burden on
621 mothers and older daughters within families (de Paz et al., 2020). Recognising and accounting
622 for such gender differences will be important for mitigating the impact of COVID-19 in tropical
623 peatland areas. Related to this, care should also be taken in pursuing novel economic
624 developments, such as the expansion of independent oil palm smallholdings, which may risk
625 exacerbating or even producing new gender inequalities (Elmhirst et al. 2017; Julia & White
626 2012) that may in turn compound gender inequalities relating to COVID-19.
627

628 **Research, Training and Education**
629
630 The COVID-19 pandemic is significantly impacting field research globally, with travel
631 restrictions and social distancing, plus (potential) reductions in research funding, leading to the
632 adjustment, postponement or cancellation of many ongoing and planned field activities (Corlett
633 et al., 2020; Evans et al., 2020; Lindsey et al., 2020). Among other impacts, research disruptions
634 could potentially delay or prevent key output production (with possible knock-on effects on
635 policy development), cause data gaps (particularly for long-term ecological data collection) and
636 equipment supply issues. Social research, especially that involving bringing people together

637 physically, will be particularly impacted (Corlett et al., 2020). For example, at the time of
638 writing, the Indonesian Ministry of Research and Technology has prohibited new foreign
639 researchers from entering and conducting research activities until the pandemic has ended
640 (RISTEK-BRIN, 2020). In DRC, the UKRI-funded CongoPeat project is continuing to operate
641 virtually but field activities and face-to-face initiatives and meetings have been paused, with field
642 researchers required to depart suddenly and leave collected samples behind, thus delaying or
643 potentially even risking completion of their analysis (C. E. N. Ewango, G. Dargie & D.
644 Kopansky, pers. obs.). Media reports indicate that some indigenous communities have
645 effectively closed off to visitors to protect themselves from the potentially devastating impacts of
646 COVID-19 on their communities (Peruvian Amazon, including the peatland region of Loreto:
647 Sierra Praeli, 2020; Papua: Milko, 2020). Similar observations have also been made for remote
648 villages in Central and West Kalimantan, Sabah and Sarawak (L. Chua & M. A. Imron, pers.
649 obs.), with such measures representing a traditional mechanism among rural Borneo
650 communities for protecting themselves from the spiritual and other effects of dangerous events
651 like deaths or disease outbreaks (Chua, 2012). Even after the COVID-19 pandemic (peak), such
652 communities may retain their wariness, remaining less welcoming or even hostile to outside
653 researchers, who have an ethical obligation to ensure that they do not inadvertently transmit the
654 disease to these communities. Research on great apes and other primates is also at high risk of
655 disruption, as measures are put in place to prevent reverse zoonotic transmission of SARS-CoV-
656 2, given the perceived vulnerability of these species (Damas et al., 2020; Gillespie et al., 2020;
657 IUCN SSC WHSG & PSG SGA, 2020; Melin et al., 2020). This has led some to question
658 whether all primate field research should be cancelled for 2020 (Reid, 2020), with others
659 highlighting the potential negative impacts of such a move and the potential primate
660 conservation and research opportunities that may arise from the pandemic (Lappan et al., 2020;
661 Trivedy, 2020). Ultimately, the risks of any research in relation to the COVID-19 threat will
662 need to be carefully balanced against the counter-risks of not conducting or restricting research
663 in terms of addressing other important conservation and community wellbeing issues. From a
664 positive perspective, some of these developments may facilitate the empowerment of local
665 scientists and thus help strengthen in-country scientific research in tropical peatland areas.
666
667 Research and training meetings are being cancelled or postponed around the globe, including
668 rescheduling of the International Peatland Congress from June 2020 to May 2021, which will
669 negatively impact both networking opportunities for peat scientists and short-term income for the
670 International Peatland Society. Disruptions to teaching, research and networking activities, and
671 related publications, will potentially have reverberating impacts on the careers and (short-term)
672 incomes of students and junior researchers, with possible overall negative impacts on future
673 scientific expertise (Corlett et al., 2020). For example, Borneo Nature Foundation (BNF) and
674 Universitas Gadjah Mada (UGM) had been developing plans for BNF to support selected UGM
675 students to conduct research dissertations on tropical peatlands in 2020. These have now been
676 converted to desk-based projects, which cannot provide students with vital first-hand
677 perspectives of the tropical peatland environment. More widely, impacts are likely to be
678 especially severe and potentially irreversible for students and researchers already facing
679 (economic) disadvantages, acting to further entrench existing biases and low representation of
680 black, Asian and minority ethnic (BAME) groups in environmental organisations (Taylor, 2015),
681 and women in tropical peatland research (Thornton et al., 2019). Parents, and particularly
682 mothers, are also likely to be disproportionately affected (Staniscuaski et al., 2020). Some

683 positive responses are, however, already evident in tropical peatland nations, with for example
684 UGM instituting a series of online expert talks, BNF conducting live children's education
685 sessions through Facebook Live (BNF, 2020a) and some schools in remote areas of Kalimantan
686 without internet using radio broadcasts to deliver teaching during the pandemic (Jakarta Post,
687 2020).
688
689 There is also the risk that research and development funds will be redirected towards COVID-19-
690 related projects, increasing the difficulty of accessing funding for other research and
691 conservation priorities (Evans et al., 2020). Funding shortfalls for tropical peatland research may
692 lead to local research and other staff temporarily losing income tied to specific projects, or even
693 redundancies of permanent staff. While some international NGOs may be able to furlough some
694 staff to receive government funding support, this is unlikely to be an option in most tropical
695 peatland countries. In addition to negatively impacting local economies (tropical peatland
696 research is often conducted in remote rural areas with limited economic opportunities),
697 redundancies of permanent research staff would also represent a consequent loss in local
698 research project capacity if staff move to work in other sectors, which may be difficult and
699 require a long time to replace. On the plus side, prolonged international travel restrictions may
700 help promote the role of local researchers in multi-national research projects, while also reducing
701 the carbon footprint of research involving international flights. Whilst it may be possible to
702 maintain communications and coordination of many ongoing projects using online
703 communication tools, this may be limited by lack of or slow internet connections in more remote
704 tropical peatland areas. Equipping remote communities with such communication infrastructure
705 would help minimise this and other wider impacts resulting from reduced potential for outsider
706 travel to these areas. While researchers may be able to help contribute some individual-based
707 assistance (e.g., laptop provision, booster aerials), provided sufficient flexibility exists in
708 research grant provisions, larger-scale upgrades in communications infrastructure would require
709 in-country government support. Potential may also exist for international travel funds to be re-
710 allocated to support online learning or other training for local students and researchers, helping
711 to build local capacity in the long term, although in the shorter-term international travel to
712 undertake studentships and receive training may be curtailed.
713

714 **Conservation and Restoration**
715
716 In addition to potential funding impacts discussed in the previous section, field activity
717 disruptions, delays and cancelations will likely detrimentally impact many tropical peatland
718 conservation, restoration, community development and outreach projects (e.g., Indonesia: Gan et
719 al., 2020). This is particularly so when activities are time sensitive (e.g., planting seedlings
720 during periods of optimal peat water level), require continued maintenance (e.g., tending
721 seedlings in nurseries that may otherwise die, requiring much time and funds to replace), or
722 typically involve large teams or in-person gatherings. For example, BNF temporarily halted all
723 its in-person childrens' education and other activities involving groups of people, including
724 community development, sustainable livelihood and fire-fighting training (BNF, 2020b). Some
725 organisations have initiated self-isolation protocols before and after field visits as a COVID-19
726 precaution (e.g., Frankfurt Zoological Society in Jambi, Sumatra: Lestari, 2020, pers. comm.),

727   which although potentially effective in relation to reducing transmission risk, may place
728   additional demands and stresses upon staff.
729
730   Halting dialogue with tropical peatland communities, who are frequently remote and have
731   limited or no internet access, may lead to reduced uptake or failure of alternative livelihood
732   development activities, if critical implementation periods are missed (e.g. a planting season),
733   enthusiasm wanes, community members seek alternative opportunities and become tied to these,
734   or if initiatives are incorrectly implemented and so fail because of reduced training provision,
735   thus potentially decreasing local enthusiasm for such initiatives in future. Even activities that can
736   be postponed may still suffer from negative impacts, if this means that calendar-based targets are
737   not met, community engagement drops, or consequent additional damage occurs (e.g., dams to
738   restore peatland hydrology are damaged owing to lack of project presence in the area). As noted
739   in the previous section, equipping rural communities with improved communications
740   infrastructure would help minimise such impacts.
741
742   As is the case more generally (Corlett et al., 2020; Evans et al., 2020; Hockings et al., 2020;
743   Lindsey et al., 2020), TPSF encroachment, timber and wildlife harvesting is likely to increase if
744   conservation agencies are less active or visible, or enforcement reduced, particularly if rural
745   communities do increasingly fall back on exploiting natural resources owing to economic shock
746   or food insecurity (see above). For example, media reports quoting conservation organisations
747   have already indicated increased poaching in the Leuser Ecosystem, Sumatra, which includes
748   TPSF areas (Hanafiah, 2020). Importantly, if work restrictions or funding shortfalls lead to
749   reduced fire-fighting capabilities in degraded tropical peatland areas, this may result in increased
750   fire incidence and severity, as highlighted by reputed researchers and institutions in media
751   reports (Cannon, 2020; Taylor, 2020). Fire-fighting in South-east Asian peatlands is often
752   undertaken by local community members or, in plantations, by company teams. In these
753   situations, Moore et al. (2020) identify COVID-19 infection risks either from a home setting to
754   fire teams and, given the difficulties in social distancing during fire-fighting, from the fire team
755   back to the home and community. This could impact on the effectiveness of fire-fighting, as well
756   as on individuals and their families. As noted above, any resulting increases in TPSF
757   degradation, fragmentation, wildlife harvesting, or haze pollution will be expected to increase the
758   immediate impacts of the COVID-19 pandemic and/or future potential for zoonotic EID
759   emergence in tropical peatland areas.
760
761   As a result of the above, plus the potential for SARS-CoV-2 transmission to susceptible wildlife
762   species, there is a risk of significant negative impacts on tropical peatland biodiversity. This is
763   likely to be particularly important for peatland specialists and already threatened species. This
764   includes, for example, the orangutan (*Pongo* spp.): the two species occurring on tropical peatland
765   are Critically Endangered, with low and rapidly declining populations, have limited distribution
766   on only one island each (Sumatra: *P. abelii,* Lesson; Borneo: *P. pygmaeus*, Linn.), have
767   significant proportions of their populations in tropical peatland, are unable to persist in
768   completely deforested landscapes and are at high risk from hunting owing to their slow
769   reproductive rates (Utami-Atmoko et al., 2017). Orangutans and other non-human primates
770   (Damas et al., 2020; Melin et al., 2020) are also potentially at risk of spill-over of the virus,
771   including from asymptomatic human carriers, leading to recommendations for ape-based eco-
772   tourism, field research and non-essential habitat conservation activities to be reduced, and

773 impacting the activities of rescue, rehabilitation and release organisations (BOSF, 2020;
774 Gillespie et al., 2020; IUCN SSC PSG SGA, 2020; IUCN SSC WHSG & PSG SGA, 2020; Reid,
775 2020). The crisis thus increases the urgency to fully implement the IUCN best practice
776 guidelines on ape tourism and health monitoring/disease control (Gillespie et al., 2020; IUCN
777 SSC WHSG & PSG SGA, 2020). While eco-tourism is not currently commonplace in tropical
778 peatlands, disruptions to ape-based eco-tourism may potentially threaten the viability of
779 ape/habitat conservation and livelihood initiatives in those tropical peatland areas relying heavily
780 on this source of income, and result in shifts back towards more destructive economic activities
781 (cf. Evans et al., 2020; Hockings et al., 2020).
782

How Might COVID-19 Impact Future Tropical Peatland Conservation, and What Repercussions Might This Have in Relation to Disease Pandemics?

786
787 Recent comprehensive reviews have highlighted the multiple, inter-linked threats and challenges
788 already facing tropical peatland conservation and restoration, and provided suggestions to help
789 tackle these (Dargie et al., 2019; Harrison et al., 2020; Roucoux et al., 2017). The additional
790 short- to medium-term considerations arising in the context of the COVID-19 pandemic that we
791 outline above may not all come to light, may create only short-term issues if the pandemic
792 proves to be relatively short lived and recovery is relatively rapid, or may create longer-term
793 changes if the pandemic is long-lasting or creates irreversible shifts. The severity and duration of
794 impacts experienced will inevitably also vary between and within tropical peatland nations. We
795 cannot therefore provide firm predictions regarding longer-term impacts of the pandemic on
796 tropical peatlands and their communities, and consequently on changes in the potential of
797 tropical peatlands to act as a source of future zoonotic EID pandemics. This caveat
798 notwithstanding, we highlight some potential longer-term changes that may be important for
799 policy makers, scientists and other tropical peatland stakeholders to consider going forward.
800
801 Some tropical peatland nations have already indicated that development projects will be paused
802 or cancelled, and that economic growth may be prioritised above sustainability concerns in post-
803 pandemic recovery phases, which could have long-term repercussions. For example, media
804 reports indicate that Indonesia's planned capital city relocation may be postponed owing to the
805 pandemic (Demetriadi, 2020; Gokkon, 2020), whereas *Padat Karya* (Labour Intensive)
806 government projects involving large numbers of local community members are still proceeding
807 and being prioritised as an attempt to mitigate the economic impacts of the crisis (Iskandar,
808 2020; Widodo, 2020), as are 89 major infrastructure development projects, including potential
809 development of large peatland areas for food production in Central Kalimantan with the goal to
810 improve food security (Jong, 2020a). A history of prioritising economic growth over public
811 health in the context of haze from peatland fires has been suggested in Malaysia (Varkkey &
812 Copeland, 2020), while some recent media reports indicate that Indonesia will prioritise
813 economic growth following the pandemic, with the consequence that emission reduction targets
814 will not be increased (Jong, 2020c) and environmental protections potentially rolled back (Jong,
815 2020d). In Peru, the largest threat is the (re-)activation of regional economies to promote

816 agricultural development (El Peruano, 2020), which with the current lack of any documents to
817 guide land use planning, may increase deforestation and access to remote forests (e.g. potential
818 road construction that will affect peatlands in Loreto: Baker et al., 2020).
819
820 The race to return to economic growth and stability could also drive increased fossil fuel
821 extraction. This is a risk in the Congo Basin (Dargie et al., 2019; Miles et al., 2017) and Peruvian
822 Amazon (Lilleskov et al., 2019), where many oil concessions coincide with peatland areas. In
823 Peru, oil extraction and transportation has led to many spills from poorly maintained pipes that
824 have often been slow to be remediated (e.g., Rodríguez Mega, 2016). Expanding oil exploration
825 and bringing new concessions into production involves infrastructure creation, clearing seismic
826 survey lines, and building access roads and pipelines (Roucoux et al., 2017), typically causing
827 habitat loss and degradation (Laurance, Goosem & Laurance, 2009; Mäki, Kalliola & Vuorinen,
828 2001). We note, however, that conversely and at least in the short-term, an alternative outcome
829 of the pandemic could be lower global oil demand and production through at least 2020 (OGJ
830 Editors, 2020), which may result in oil exploration becoming a lower immediate priority. Indeed,
831 it has been indicated by the Ministry of Environment and Tourism that oil exploration in RoC
832 peatland areas will not proceed in accordance with the country's international climate
833 commitments (Arlette Soudan-Nonault, 2020, pers. comm.; see also Weston, 2020).
834
835 Concerns have been raised regarding the intersection of the COVID-19 outbreak and public
836 health responses with the ongoing increase in climate hazards associated with climate change
837 (Phillips et al., 2020). Tropical peatlands are vulnerable to climate change, which will likely
838 result in increased drought frequency, duration and/or severity, with consequent peat water table
839 lowering, and increased peat oxidation and fire incidence, as already seen extensively in South-
840 east Asia (Turetsky et al., 2015). There thus exists a risk of a positive-feedback loop
841 development (cf. Harrison et al., 2020), whereby any decisions or events related to the pandemic
842 that lead to increased peatland degradation and fire also then lead to further carbon emissions
843 and peatland degradation, thus increasing future fire prevalence and the various negative impacts
844 associated with this, including in relation to COVID-19 and potential future disease pandemics.
845
846 While peatland rewetting and revegetation may help mitigate some impacts of potential increases
847 in the areas of degraded and burned peatland, these processes are unavoidably slow in nature,
848 with peat burned in a single fire event taking potentially hundreds of years to re-form, generating
849 concerns regarding the political tractability of some tropical peatland restoration goals (Harrison
850 et al., 2020). Coupled with the existing large areas of degraded peatland already requiring
851 restoration, particularly in South-east Asia, any potential increase in the extent of degraded and
852 burned peatland as an indirect consequence of the COVID-19 pandemic would be expected to
853 have long-term negative repercussions for tropical peatland management, community
854 livelihoods, public health, carbon emissions and biodiversity. Reversing such changes, and
855 enhancing the sustainability of tropical peatland management in general, may also become more
856 challenging in the foreseeable future if, as discussed above, the current pandemic leads to loss of
857 skilled, in-country peatland scientists and conservationists who would take time to replace. Any
858 future pandemics may obviously exacerbate this.
859

Conclusions and Recommendations

Our review indicates that sustainable management and conservation of tropical peatlands is important for mitigating the impacts of the current COVID-19 pandemic, while avoiding further encroachment into these ecosystems and intensive harvesting of their wildlife could reduce the potential for future zoonotic EID emergence and severity (summarised in Fig 1.). Importantly, because many of the potential impacts identified in relation to COVID-19 arise through socio-economic disruptions relating to our response to the pandemic, rather than unique characteristics of the SARS-CoV-2 virus itself, this conclusion should be applicable more widely to pandemic situations and similar sudden socio-economic shocks. To our knowledge, this link between tropical peatland ecosystems and zoonotic EIDs has not been specifically noted previously and this therefore represents an important finding in terms of our understanding of the benefits that these ecosystems provide, thus strengthening the argument for their conservation and sustainable use. In addition, and recognising that our assessment is both preliminary and likely incomplete owing to the recent emergence and rapid evolution of the COVID-19 pandemic, we highlight the potential additional threats and challenges towards sustainable management of tropical peatlands and their wildlife posed by this pandemic, and the potential knock-on effects of these for tropical peatland conservation and local communities going forward.

These conclusions support and strengthen previous recommendations regarding the sustainable management of tropical peatlands, including regarding hydrological functions, fire prevention, avoiding encroachment and habitat fragmentation, plus maintaining and where necessary restoring healthy peatland ecosystems that support diverse biological communities, sequester carbon and provide socio-economic benefits to local communities (see, e.g., Dargie et al., 2019; Dohong, Abdul Aziz & Dargusch, 2018; Graham, Giesen & Page, 2017; Harrison et al., 2020; Mizuno, Fujita & Kawai, 2016; Roucoux et al., 2017; Schulz et al., 2019a; Schulz et al., 2019b; Wijedasa & *al.*, 2018 and references therein for detailed recommendations). They also support previous recommendations to carefully manage terrestrial wildlife harvesting in and trade from tropical peatland areas (Bodmer & Lozano, 2001; Harrison et al., 2011) and more generally (e.g., Corlett, 2007; Harrison et al., 2016). Further to these generic recommendations, we offer the following specific suggestions for researchers and practitioners relating to tropical peatland sustainable management, COVID-19 and potential future zoonotic EIDs:

1. Field projects should support frontline team members to reduce their COVID-19 exposure risk and, thus, the risk of them infecting other community members and of work being impacted through worker infection. In addition to ensuring and facilitating adherence to current government and WHO guidelines, specific recommendations have been proposed for fire-fighters (Moore et al., 2020), and work with great apes (IUCN SSC WHSG & PSG SGA, 2020) and in their habitats (IUCN PSG SGA, 2020). Development of similar specific guidelines for other sectors relating to tropical peatland management could be beneficial.
2. All actors should support local communities in and around tropical peatland areas to resolve land tenure conflicts and promote sustainable community-led management (Blackman et al., 2017; Santika et al., 2017), facilitate locally-derived sustainable economy development (Pearson et al., 2020), and prevent external users from unsustainably exploiting these ecosystems. This includes encouraging, and where necessary opening up new, discussions regarding the relationships between use of and encroachment into tropical peatlands,

906   commercial vs. subsistence wildlife harvesting, and zoonotic EID risk, and considering these
907   holistically in the context of community wellbeing and aspirations (cf. Kavousi et al., 2020).
908   It should also include re-orientating discussions, from conservation and development
909   organisations approaching with a perspective of "how can we help them" to an approach of
910   "we're all in this together, so what can we each bring to the table to help?". Such re-
911   orientations should ideally be informed by fresh social research on how communities' lives,
912   relations and experiences have been impacted by COVID-19, as these are unlikely to simply
913   revert to a pre-pandemic "normal".
914 3. The peatland research community should rethink approaches to research in at-risk
915   communities, to potentially incorporate more remote and online working, plus enhanced
916   roles for local research teams. This may require re-appraising how likely increasingly limited
917   research resources are distributed, and particularly supporting local research capacity
918   development and local researcher empowerment within international collaborations.
919   Incorporating and centering local knowledge and priorities from the outset has the additional
920   benefit of increasing the success of conservation and development interventions (Mistry &
921   Berardi, 2016). COVID-19 has forced increased use of online communications tools and we
922   hope this can help foster new patterns of international collaboration that further empower
923   local researchers. See Lupton (2020) for an extensive list of potential approaches to reducing
924   COVID-19 risk during social science fieldwork.
925 4. Wherever possible and working within all relevant government and sector COVID-19
926   guidelines, research, conservation and community projects should continue collection of
927   long-term monitoring data and initiate repeat data collection to provide before-and-after
928   comparisons, in order to help assess the impacts of the COVID-19 pandemic in relation to the
929   issues discussed in this paper. This may include, for example, patrol team or satellite data
930   monitoring to assess if forest incursions or fire incidence have increased, or community
931   livelihood data to assess if livelihood choices have changed and if/how this has impacted
932   local wellbeing. It should also include collecting baseline human and wildlife community
933   health information to better understand, monitor and thus mitigate zoonotic EID risk in
934   tropical peatland areas.
935 5. Policy makers in tropical peatland areas should ensure that their policy decisions do not
936   amplify the risks of the COVID-19 or potential future pandemics. In particular, any
937   weakening of environmental and social standards and regulations relating to tropical
938   peatlands should be avoided (see also Evers et al., 2017; Wijedasa et al., 2017). Instead, we
939   recommend development and implementation of a "One Health / Ecohealth" approach in
940   tropical peatland nations, that recognises and supports the complex, mutually-beneficial
941   interconnections among the health of people, animals, plants and our shared environment (El
942   Zowalaty & Järhult, 2020; Hockings et al., 2020; Roger et al., 2016; UNEP & ILRI, 2020).
943   We further recommend strengthening communications infrastructure in (remote) tropical
944   peatland areas, to help minimise any impacts of reduced travel or on-the-ground activities in
945   these areas.
946 6. Funders should exercise maximum possible flexibility to tropical peatland research,
947   conservation and community projects impacted by the COVID-19 pandemic, including
948   regarding achieving deliverable targets and deadlines, where possible offering additional
949   support to maintain local staff employment during periods of enforced down time instead of
950   offering zero-cost funding extensions, and not penalising unavoidable "failures" by current
951   projects in future funding application rounds. This will be important in minimising potential

952   project closures, plus staff redundancies or lost income, and associated risk of loss of
953   expertise. Opportunities to diversify revenue sources to increase the resilience of
954   conservation efforts should also be explored (Lindsey et al., 2020).
955   7. All actors should recognise the role that tropical peatlands, their conservation, sustainable
956   management and restoration will play in both the current COVID-19 pandemic and in the
957   potential for future zoonotic EID emergence; and actively promote this message in fund-
958   raising, education, outreach, community and government engagement, while taking care to
959   tailor messages and associated recommendations appropriately to local audiences (Chua,
960   2020; Kavousi et al., 2020; MacFarlane & Rocha, 2020; see also Charania & Tsuji, 2012;
961   Chua et al., 2020).
962
963   As is the case more generally (e.g., Corlett et al., 2020; Evans et al., 2020; Hockings et al., 2020;
964   UN/DESA, 2020; UN/EMRIP, 2020; UNEP & ILRI, 2020), our review indicates that the
965   relationships and reciprocal impacts between tropical peatland ecosystems and communities,
966   COVID-19 and disease pandemics are inter-linked, multi-faceted, and likely to vary over both
967   space and time. This adds an extra pandemic-related dimension to the increasingly complex
968   picture that is emerging regarding the challenges and opportunities for conservation and
969   sustainable management of tropical peatlands (Dargie et al., 2019; Harrison et al., 2020;
970   Roucoux et al., 2017). At the same time, this also suggests that potential for win-win solutions
971   exists to simultaneously address the challenges identified herein relating to COVID-19 and
972   disease pandemics in tropical peatland areas, alongside the previously identified challenges
973   facing these ecosystems and their resident human communities. This is particularly pertinent in
974   light of recent analyses estimating that global pandemic prevention costs associated with
975   reducing deforestation, wildlife trade and farmed animal spill-over, and early zoonotic disease
976   detection and control over the course of ten years is equivalent to only about 2% of the costs of
977   the COVID-19 pandemic (Dobson et al., 2020). Moving beyond these conclusions linked to our
978   review, and while we hope that the COVID-19 pandemic is rapidly mitigated and thus many of
979   the potential issues discussed in this paper fail to (fully) materialise, we nevertheless trust that
980   our consideration of these issues and recommendations provided helps improve our ability to
981   anticipate and prevent potential negative impacts that may arise from the pandemic. In addition,
982   and regardless of the pandemic, we contend that it helps to foster the inter-connected thinking
983   that will be required to ensure the future health and wellbeing of tropical peatlands and their
984   human communities alike.
985

Acknowledgements

987
988   We thank our respective institutions for their support, Stuart Smith and Nur Estya Binte Rahman
989   for discussions regarding literature reviews, and the many colleagues and tropical peatland
990   communities that have engaged in fruitful discussions over the years and thus contributed
991   towards our thinking in relation to the topics discussed in this paper. We are grateful to the
992   Editor, Valéria Kaminski and one anonymous reviewer for constructive comments that helped
993   improve the manuscript.
994

References

Alamgir M, Campbell MJ, Sloan S, Suhardiman A, Supriatna J, Laurance WF. 2019. High-risk infrastructure projects pose imminent threats to forests in Indonesian Borneo. *Scientific Reports* 9:140. DOI: 10.1038/s41598-018-36594-8

Allen T, Murray KA, Zambrana-Torrelio C, Morse SS, Rondinini C, Di Marco M, Breit N, Olival KJ, Daszak P. 2017. Global hotspots and correlates of emerging zoonotic diseases. *Nature Communications* 8:1124. DOI: 10.1038/s41467-017-00923-8

Amanta F, Aprilianti I. 2020. *Policy Briefing no. 1. Indonesian Food Trade Policy During Covid-19*. Jakarta, Indonesia: Centre for Indonesian Policy Studies. https://repository.cips-indonesia.org/media/309123-indonesian-food-trade-policy-during-covi-7dd48951.pdf

Anthem P. 2020. Risk of hunger pandemic as coronavirus set to almost double acute hunger by end of 2020 *World Food Programme Insight*. 16 April 2020. https://insight.wfp.org/covid-19-will-almost-double-people-in-acute-hunger-by-end-of-2020-59df0c4a8072

Arenz C, Haug M, Seitz S, Venz O. 2017. Continuity Under Change in Dayak Societies. Springer VS.

ASEAN. 2020. *Economic Impact of COVID-19 Outbreak on ASEAN.* Analysis and Monitoring on Finance and Socio-Economic Issues Division, ASEAN Integration Monitoring Directorate, ASEAN Secretariat. https://asean.org/storage/2020/04/ASEAN-Policy-Brief-April-2020_FINAL.pdf

Atwood EC, Englhart S, Lorenz E, Halle W, Wiedemann W, Siegert F. 2016. Detection and characterization of low temperature peat fires during the 2015 fire catastrophe in Indonesia using a new high-sensitivity fire monitoring satellite sensor (FireBird). *PLoS One* 11:e0159410. DOI: 10.1371/journal.pone.0159410

Bai Y, Recuenco S, Gilbert AT, Osikowicz LM, Gómez J, Rupprecht C, Kosoy MY. 2012. Prevalence and diversity of *Bartonella* spp. in bats in Peru. *The American Journal of Tropical Medicine and Hygiene* 87:518-523. DOI: 10.4269/ajtmh.2012.12-0097

Baker T, Del Castillo Torres D, Honorio Coronado E, Lawson I, Martín Brañas M, Montoya M, Roucoux K. 2020. The challenges for achieving conservation and sustainable development within the wetlands of the Pastaza - Marañon basin, Peru. In: Chirif Tirado A, ed. *Peru: Deforestation in Times of Climate Change*. Lima, Peru: IWGIA, 155-174.

Bengis RG, Leighton FA, Fischer JR, Artois M, Mörner T, Tate CM. 2004. The role of wildlife in emerging and re-emerging zoonoses. *Revue Scientifique et Technique (International Office of Epizootics)* 23:497-511.

Blackman A, Corral L, Lima ES, Asner GP. 2017. Titling indigenous communities protects forests in the Peruvian Amazon. *Proceedings of the National Academy of Sciences* 114:4123-4128. DOI: 10.1073/pnas.1603290114

Blomfield A. 2020. First Ebola, then measles, not Covid-19: Congo faces three simultaneous medical emergencies. 27 April 2020. https://www.telegraph.co.uk/global-health/science-and-disease/first-ebola-measles-now-covid-19-congo-faces-three-simultaneous/

BNF. 2020a. Jungle Explorers. *Borneo Nature Foundation*. 30 April 2020. https://www.facebook.com/watch/live/?v=1461107384091191&ref=watch_permalink

1040 BNF. 2020b. Statement by Borneo Nature Foundation concerning the CoVID-19 virus pandemic.
1041   *Borneo Nature Foundation*. 26 March 2020.
1042   http://www.borneonaturefoundation.org/en/news/statement-by-borneo-nature-foundation-
1043   concerning-the-covid-19-virus-pandemic/
1044 Bodmer RE, Lozano EP. 2001. Rural development and sustainable wildlife use in Peru.
1045   *Conservation Biology* 15:1163-1170. DOI: 10.1046/j.1523-1739.2001.0150041163.x
1046 BOSF. 2020. BOSF Official Statement - COVID-19. *Borneo Orangutan Survival Foundation*.
1047   (accessed 4 May 2020). http://orangutan.or.id/bosf-official-statement-covid-19/
1048 Bowleg L. 2020. We're not all in this together: On COVID-19, intersectionality, and structural
1049   inequality. *American Journal of Public Health* 110:917-917. DOI:
1050   10.2105/AJPH.2020.305766
1051 BPS Palangka Raya. 2018. *Palangka Raya Municipality in Figures: 2018.* Palangka Raya,
1052   Indonesia: BPS-Statistics of Palangka Raya Municipality.
1053 Brito C. 2020. 15-year-old boy from Amazon tribe dies of coronavirus. *CBS News*. 10 April
1054   2020. https://www.cbsnews.com/news/amazon-yanomami-tribe-15-year-old-boy-dies-
1055   coronavirus-covid-19/
1056 Cabore JW, Karamagi HC, Kipruto H, Asamani JA, Droti B, Seydi ABW, Titi-Ofei R, Impouma
1057   B, Yao M, Yoti Z, Zawaira F, Tumusiime P, Talisuna A, Kasolo FC, Moeti MR. 2020.
1058   The potential effects of widespread community transmission of SARS-CoV-2 infection in
1059   the World Health Organization African Region: a predictive model. *BMJ Global Health*
1060   5:e002647. DOI: 10.1136/bmjgh-2020-002647
1061 Cannon JC. 2020. COVID-19 and rainforest fires set up potential public health crisis. *Mongabay*.
1062   18 June 2020. https://news.mongabay.com/2020/06/covid-19-and-rainforest-fires-set-up-
1063   potential-public-health-crisis/
1064 Carmenta R, Vira B. 2018. Integration for restoration: Reflecting on lessons learned from the
1065   silos of the past. In: Mansourian S, Parrotta J, eds. *Forest Landscape Restoration:*
1066   *Integrated Approaches to Support Effective Implementation*. London: Routledge, 32–52.
1067 Carrington D. 2020. Polluter bailouts and lobbying during Covid-19 pandemic. *The Guardian*.
1068   17 April 2020. https://www.theguardian.com/environment/2020/apr/17/polluter-bailouts-
1069   and-lobbying-during-covid-19-pandemic
1070 Charania NA, Tsuji LJS. 2012. A community-based participatory approach and engagement
1071   process creates culturally appropriate and community informed pandemic plans after the
1072   2009 H1N1 influenza pandemic: remote and isolated First Nations communities of sub-
1073   arctic Ontario, Canada. *BMC Public Health* 12:268. DOI: 10.1186/1471-2458-12-268
1074 Chua L. 2012. *The Christianity of Culture: Conversion, Ethnic Citizenship, and the Matter of*
1075   *Religion in Malaysian Borneo.* New York: Palgrave Macmillan.
1076 Chua L. 2020. Message, medium, messenger: Communicating COVID-19 in rural Borneo.
1077   *POKOK*. 14 April 2020. https://pokokborneo.wordpress.com/2020/04/14/message-
1078   medium-messenger-communicating-covid-19-in-rural-borneo/
1079 Chua L, Harrison ME, Fair H, Milne S, Palmer A, Rubis J, Thung P, Wich S, Büscher B, Cheyne
1080   SM, Puri RK, Schreer V, Stępień A, Meijaard E. 2020. Conservation and the social
1081   sciences: Beyond critique and co-optation. A case study from orangutan conservation.
1082   *People and Nature* 2:42-60. DOI: 10.1002/pan3.10072
1083 Colchester M. 2010. *Palm Oil and Indigenous Peoples in Southeast Asia: Land Acquisition,*
1084   *Human Rights Violations and Indigenous Peoples on the Palm Oil Frontier*. Moreton-in-
1085   Marsh and Rome: Forest Peoples Programme and International Land Coalition.

1086 Colchester M, Wee AP, Wong MC, Jalong T. 2007. *Land is Life: Land Rights and Oil Palm*
1087   *Development in Sarawak.* . Moreton-in-Marsh, England and Bogor, Indonesia: Forest
1088   Peoples Programme and Perkumpulan Sawit Watch.
1089 Cole MA, Ozgen C, Strobl E. 2020. Air pollution exposure and Covid-19 in Dutch
1090   Municipalities. *Environmental and Resource Economics*. DOI: 10.1007/s10640-020-
1091   00491-4
1092 Collyns D. 2020a. Peru: riot police block highway as people attempt to flee amid lockdown. *The*
1093   *Guardian*. 20 April 2020. https://www.theguardian.com/world/2020/apr/20/peru-riot-
1094   police-highway-teargas-coronavirus-lockdown
1095 Collyns D. 2020b. 'We are living in a catastrophe': Peru's jungle capital choking for breath as
1096   Covid-19 hits. 7 May 2020. https://www.theguardian.com/global-
1097   development/2020/may/07/peru-jungle-iquitos-coronavirus-covid-19
1098 Conticini E, Frediani B, Caro D. 2020. Can atmospheric pollution be considered a co-factor in
1099   extremely high level of SARS-CoV-2 lethality in Northern Italy? *Environmental*
1100   *Pollution*:114465. DOI: 10.1016/j.envpol.2020.114465
1101 Corlett R, T. 2007. The impact of hunting on the mammalian fauna of tropical Asian forests.
1102   *Biotropica* 39:292-303.
1103 Corlett RT, Primack RB, Devictor V, Maas B, Goswami VR, Bates AE, Koh LP, Regan TJ,
1104   Loyola R, Pakeman RJ, Cumming GS, Pidgeon A, Johns D, Roth R. 2020. Impacts of the
1105   coronavirus pandemic on biodiversity conservation. *Biological Conservation*
1106   246:108571. DOI: 10.1016/j.biocon.2020.108571
1107 Crippa P, Castruccio S, Archer-Nicholls S, Lebron GB, Kuwata M, Thota A, Sumin S, Butt E,
1108   Wiedinmyer C, Spracklen DV. 2016. Population exposure to hazardous air quality due to
1109   the 2015 fires in Equatorial Asia. *Scientific Reports* 6:37074. doi: 10.1038/srep37074
1110 Crump J. 2017. *Smoke on Water – Countering Global Threats From Peatland Loss and*
1111   *Degradation. A UNEP Rapid Response Assessment.* Nairobi and Arendal: United Nations
1112   Environment Programme and GRID-Arendal. www.grida.no
1113 Cui Y, Zhang Z-F, Froines J, Zhao J, Wang H, Yu S-Z, Detels R. 2003. Air pollution and case
1114   fatality of SARS in the People's Republic of China: an ecologic study. *Environmental*
1115   *Health* 2:15. DOI: 10.1186/1476-069X-2-15
1116 Damas J, Hughes GM, Keough KC, Painter CA, Persky NS, Corbo M, Hiller M, Koepfli K-P,
1117   Pfenning AR, Zhao H, Genereux DP, Swofford R, Pollard KS, Ryder OA, Nweeia MT,
1118   Lindblad-Toh K, Teeling EC, Karlsson EK, Lewin HA. 2020. Broad host range of SARS-
1119   CoV-2 predicted by comparative and structural analysis of ACE2 in vertebrates.
1120   *Proceedings of the National Academy of Sciences*. DOI: 10.1073/pnas.2010146117
1121 Dargie GC, Lawson IT, Rayden TJ, Miles L, Mitchard ETA, Page SE, Bocko YE, Ifo SA, Lewis
1122   SL. 2019. Congo Basin peatlands: threats and conservation priorities. *Mitigation and*
1123   *Adaptation Strategies for Global Change* 24:669-686. DOI: 10.1007/s11027-017-9774-8
1124 Dargie GC, Lewis SL, Lawson IT, Mitchard ETA, Page SE, Bocko YE, Ifo SA. 2017. Age,
1125   extent and carbon storage of the central Congo Basin peatland complex. *Nature* 542:86-
1126   90. doi: 10.1038/nature21048
1127 Davies SE, Bennet B. 2016. A gendered human rights analysis of Ebola and Zika: locating
1128   gender in global health emergencies. *International Affairs* 92:1041-1060. DOI:
1129   10.1111/1468-2346.12704
1130 de Paz C, Muller M, Munoz Boudet A, Maria Gaddis I. 2020. *Gender Dimensions of the*
1131   *COVID-19 Pandemic.* World Bank Group. DOI: 10.1596/33622

1132 Demetriadi A. 2020. As the virus ravages Indonesia's economy, will the new capital be shelved?
1133   *Southeast Asia Globe*. 17 July 2020. https://southeastasiaglobe.com/indonesias-new-
1134   capital-covid19/
1135 Ditekemena J. 2020. COVID-19 amidst Ebola's retreat. *Science* 368:445-445. DOI:
1136   10.1126/science.abc4859
1137 Dobson AP, Pimm SL, Hannah L, Kaufman L, Ahumada JA, Ando AW, Bernstein A, Busch J,
1138   Daszak P, Engelmann J, Kinnaird MF, Li BV, Loch-Temzelides T, Lovejoy T, Nowak K,
1139   Roehrdanz PR, Vale MM. 2020. Ecology and economics for pandemic prevention.
1140   *Science* 369:379-381. DOI: 10.1126/science.abc3189
1141 Dohong A, Abdul Aziz A, Dargusch P. 2018. A review of techniques for effective tropical
1142   peatland restoration. *Wetlands* 38:275-292. DOI: 10.1007/s13157-018-1017-6
1143 Dommain R, Dittrich I, Giesen W, Joosten H, Rais D, Silvius M, Wibisono I. 2016. Ecosystem
1144   services, degradation and restoration of peat swamps in the Southeast Asian tropics. In:
1145   Bonn A, Allott T, Evans M, Stoneman R, Joosten H, eds. *Peatland Restoration and*
1146   *Ecosystem Services: Science, Policy and Practice*. Cambridge: Cambridge University
1147   Press, 255-290.
1148 Dong E, Du H, Gardner L. 2020. An interactive web-based dashboard to track COVID-19 in real
1149   time. *The Lancet Infectious Diseases* 20:533-534. DOI: 10.1016/S1473-3099(20)30120-1
1150 Douglas I. 2006. The local drivers of land degradation in South-East Asia. *Geographical*
1151   *Research* 44:123-134. DOI: 10.1111/j.1745-5871.2006.00373.x
1152 Dove M. 2011. *The Banana Tree at the Gate: A History of Marginal Peoples and Global*
1153   *Markets in Borneo*. New Haven: Yale University Press.
1154 EIA-TELAPAK. 1999. *The Final Cut, Illegal Logging in Indonesia's Orangutan Parks*.
1155   Environmental Investigation Agency and Telapak Indonesia.
1156 El Peruano. 2020. Normas Legales. Decreto Supremo No. 101-2020-PCM [Legal Norms.
1157   Supreme Decree No. 101-2020-PCM]. *El Peruano*. 4 June 2020. pp 17-20.
1158   https://cdn.www.gob.pe/uploads/document/file/818735/DS_101-2020-
1159   PCM.pdf (accessed via: https://diariooficial.elperuano.pe/normas).
1160 El Zowalaty ME, Järhult JD. 2020. From SARS to COVID-19: A previously unknown SARS-
1161   related coronavirus (SARS-CoV-2) of pandemic potential infecting humans – Call for a
1162   One Health approach. *One Health* 9:100124. DOI: 10.1016/j.onehlt.2020.100124
1163 Ellwanger JH, Kulmann-Leal B, Kaminski VL, Valverde-Villegas JM, Veiga A, Spilki FR,
1164   Fearnside PM, Caesar L, Giatti LL, Wallau GL, Almeida SEM, Borba MR, Hora VPD,
1165   Chies JAB. 2020. Beyond diversity loss and climate change: Impacts of Amazon
1166   deforestation on infectious diseases and public health. *An Acad Bras Cienc*
1167   92:e20191375. DOI: 10.1590/0001-3765202020191375
1168 Elmhirst R, Siscawati M, Basnett BS, Ekowati D. 2017. Gender and generation in engagements
1169   with oil palm in East Kalimantan, Indonesia: insights from feminist political ecology. *The*
1170   *Journal of Peasant Studies* 44:1135-1157. DOI: 10.1080/03066150.2017.1337002
1171 Euler M, Hoffmann MP, Fathoni Z, Schwarze S. 2016. Exploring yield gaps in smallholder oil
1172   palm production systems in eastern Sumatra, Indonesia. *Agricultural Systems* 146:111-
1173   119. DOI: 10.1016/j.agsy.2016.04.007
1174 Evans KL, Ewen JG, Guillera-Arroita G, Johnson JA, Penteriani V, Ryan SJ, Sollmann R,
1175   Gordon IJ. 2020. Conservation in the maelstrom of Covid-19 – a call to action to solve
1176   the challenges, exploit opportunities and prepare for the next pandemic. *Animal*
1177   *Conservation* 23:235-238. DOI: 10.1111/acv.12601

1178 Evers S, Yule CM, Padfield R, O'Reilly P, Varkkey H. 2017. Keep wetlands wet: the myth of
1179   sustainable development of tropical peatlands – implications for policies and
1180   management. *Global Change Biology* 23:534-549. DOI: 10.1111/gcb.13422
1181 Fa JE, Currie D, Meeuwig J. 2003. Bushmeat and food security in the Congo Basin: linkages
1182   between wildlife and people's future. *Environmental Conservation* 30:71-78. DOI:
1183   10.1017/S0376892903000067
1184 FAO. 2020. Forest and farm facility. *Food and Agriculture Organization of the United Nations*.
1185   20 June 2020. http://www.fao.org/forest-farm-facility/coviden/en/
1186 FAO, IFAD, UNICEF, WFP, WHO. 2019. *The State of Food Security and Nutrition in the World*
1187   *2019. Safeguarding against economic slowdowns and downturns* Rome: Food and
1188   Agriculture Organization.
1189 Field RD, van der Werf GR, Shen SSP. 2009. Human amplification of drought-induced biomass
1190   burning in Indonesia since 1960. *Nature Geoscience* 2:185-188. DOI: 10.1038/NGEO443
1191 Frontera A, Martin C, Vlachos K, Sgubin G. 2020. Regional air pollution persistence links to
1192   COVID-19 infection zoning. *The Journal of infection* 81:318-356. DOI:
1193   10.1016/j.jinf.2020.03.045
1194 Gan M, Choo A, Leng KY, Sharif N. 2020. *SIIA Haze Outlook.* Singapore: Singapore Institute of
1195   International Affairs. http://www.siiaonline.org/wp-content/uploads/2020/06/SIIA-Haze-
1196   Outlook-2020.pdf
1197 Gaughan AE, Stevens FR, Linard C, Jia P, Tatem AJ. 2013. High resolution population
1198   distribution maps for Southeast Asia in 2010 and 2015. *PLoS One* 8:e55882. DOI:
1199   10.1371/journal.pone.0055882
1200 Gaveau DLA, Salim MA, Hergoualc'h K, Locatelli B, Sloan S, Wooster M, Marlier ME,
1201   Molidena E, Yaen H, DeFries R, Verchot L, Murdiyarso D, Nasi R, Holmgren P, Sheil D.
1202   2014. Major atmospheric emissions from peat fires in Southeast Asia during non-drought
1203   years: evidence from the 2013 Sumatran fires. *Scientific Reports* 4:6112. DOI:
1204   10.1038/srep06112
1205 Gillespie TR, Ahouka S, Ancrenaz M, Bergl R, Calvignac-Spencer S, Couacy-Hymann E,
1206   Deschner T, Duex A, Fuh-Neba T, Gogarten JF, Herbinger I, Kalema-Zikusoka G, Kone
1207   I, Lonsdorf EV, Lumbu Banza C-P, Makoutoutou Nzassi P, Raphael J, Mpungu DC,
1208   Patrono LV, Refisch J, Robbins M, Rwego IB, Surbeck M, Wich S, Wittig R, Leendertz
1209   FH. 2020. COVID-19: protect great apes during human pandemics. *Nature* 579:497.
1210   DOI: 10.1038/d41586-020-00859-y
1211 Gloede O, Menkhoff L, Waibel H. 2015. Shocks, individual risk attitude, and vulnerability to
1212   poverty among rural households in Thailand and Vietnam. *World Development* 71:54-78.
1213   DOI: 10.1016/j.worlddev.2013.11.005
1214 Gokkon B. 2020. Indonesia's new capital in the Bornean jungle on hold amid COVID-19 crisis.
1215   *Mongabay*. 15 April 2020. https://news.mongabay.com/2020/04/indonesias-new-capital-
1216   in-the-bornean-jungle-on-hold-amid-covid-19-crisis/
1217 Graham LLB, Giesen W, Page SE. 2017. A common-sense approach to tropical peat swamp
1218   forest restoration in Southeast Asia. *Restoration Ecology* 25:312-321.
1219   DOI: 10.1111/rec.12465
1220 Haensler A, Saeed F, Jacob D. 2013. Assessing the robustness of projected precipitation changes
1221   over central Africa on the basis of a multitude of global and regional climate projections.
1222   *Climatic Change* 121:349-363. DOI: 10.1007/s10584-013-0863-8

1223 Hanafiah J. 2020. Poaching in Indonesia's biodiverse Leuser Ecosystem on the rise amid
1224   COVID-19. *Mongabay*. 28 May 2020. https://news.mongabay.com/2020/05/wildlife-
1225   poaching-indonesia-leuser-covid19-tiger-orangutan-rhino/
1226 Harrison ME, Cheyne SM, Darma F, Ribowo DA, Limin SH, Struebig MJ. 2011. Hunting of
1227   flying foxes and perception of disease risk in Indonesian Borneo. *Biological*
1228   *Conservation* 144:2441-2449. DOI: 10.1016/j.biocon.2011.06.021
1229 Harrison ME, Ottay JB, D'Arcy LJ, Cheyne SM, Anggodo, Belcher C, Cole L, Dohong A,
1230   Ermiasi Y, Feldpausch T, Gallego-Sala A, Gunawan A, Höing A, Husson SJ, Kulu IP,
1231   Soebagio SM, Mang S, Mercado L, Morrogh-Bernard HC, Page SE, Priyanto R, Ripoll
1232   Capilla B, Rowland L, Santos E, Schreer V, Sudyana IN, Bin Bakeri Taman S, Thornton
1233   SA, Upton C, Wich SA, van Veen F. 2020. Tropical forest and peatland conservation in
1234   Indonesia: Challenges and directions. *People and Nature* 2:4-28. DOI:
1235   10.1002/pan3.10060
1236 Harrison RD, Sreekar R, Brodie JF, Brook S, Luskin M, O'Kelly H, Rao M, Scheffers B, Velho
1237   N. 2016. Impacts of hunting on tropical forests in Southeast Asia. *Conservation Biology*
1238   30:972–981. DOI: 10.1111/cobi.12785
1239 Hilser H. 2011. An Assessment of Primate Health in the Sabangau Peat-Swamp Forest, Central
1240   Kalimantan, Indonesian Borneo. MSc thesis, Oxford Brookes University, UK.
1241 Hilser H, Ehlers Smith YC, Ehlers Smith DA. 2014. Apparent mortality as a result of an elevated
1242   parasite infection in Presbytis rubicunda. Folia Primatologica 85:265-276. DOI:
1243   10.1159/000363740
1244 Hockings M, Dudley N, Ellio W, Ferreira MN, MacKinnon K, Pasha M, Phillips A, Stolton S,
1245   Woodley S, Appleton M, Chassot O, Fitzsimons J, Galliers C, Kroner RG, Goodrich J,
1246   Hopkins J, Jackson W, Jonas H, Long B, Mumba M, Parrish J, Paxton M, Phua C,
1247   Plowright R, Rao M, Redford K, Robinson J, Rodríguez CM, Sandwith T, Spenceley A,
1248   Stevens C, Tabor G, Troëng S, Willmore S, Yang A. 2020. Editorial essay: COVID-19
1249   and Protected and Conserved Areas. *PARKS* 26:7-24. DOI:
1250   10.2305/IUCN.CH.2020.PARKS-26-1MH.en
1251 Hooijer A, Page S, Canadell JG, Silvius M, Kwadijk J, Wösten H, Jauhiainen J. 2009. Current
1252   and future CO_2 emissions from drained peatlands in Southeast Asia. *Biogeosciences*
1253   *Discussions* 6:7207-7230. DOI: 10.5194/bg-7-1505-2010
1254 Hurowitz G. 2020. The coronavirus climate profiteers ... and the climate heroes doing the right
1255   thing in a time of crisis. *Mighty Earth* (accessed 2 May 2020).
1256   https://stories.mightyearth.org/the-coronavirus-climate-profiteers/index.html
1257 Husson SJ, Limin SH, Adul, Boyd NS, Brousseau JJ, Collier S, Cheyne SM, D'Arcy LJ, Dow
1258   RA, Dowds NW, Dragiewicz ML, Smith DAE, Iwan, Harsanto FA, Hendri, Houlihan
1259   PR, Jeffers KA, Jarrett BJM, Kulu IP, Morrogh-Bernard HC, Page SE, Perlett ED,
1260   Purwanto A, Capilla BR, Salahuddin, Santiano, Schreven SJJ, Struebig MJ, Thornton SA,
1261   Tremlett C, Yeen Z, Harrison ME. 2018. Biodiversity of the Sabangau tropical peat-
1262   swamp forest, Indonesian Borneo. *Mires and Peat* 22:1-50. DOI:
1263   10.19189/MaP.2018.OMB.352
1264 IMF. 2020. *World Economic Outlook: April 2020.* International Monetary Fund.
1265 Index Mundi. 2020. Commodity Prices - Palm Oil. *Index Mundi* (accessed 20 June 2020).
1266   https://www.indexmundi.com/commodities/?commodity=palm-oil&months
1267 Inogwabini B-I, Abokome M, Kamenge T, Mbende L, Mboka L. 2012. Preliminary bonobo and
1268   chimpanzee nesting by habitat type in the northern Lac Tumba Landscape, Democratic

Republic of Congo. *African Journal of Ecology* 50:285-298. DOI: 10.1111/j.1365-2028.2012.01323.x

Iskandar AH. 2020. *Surat Edaran Menteri Desa, Pembangunan Daerah Tertinggal, dan Transmigrasi No. 8 Tahun 2020 tentang Desa Tanggap COVID-19 dan Penegasan Padat Karya Tunai Desa* [Circular Letter of the Minister of Villages, Development of Disadvantaged Regions, and Transmigration No. 8/2020 on COVID-19 Ready Village and the Affirmation of Cash Village Padat Karya]. Jakarta, Indonesia: Ministry of Villages, Development of Disadvantaged Regions, and Transmigration.

IUCN. 2020. *Amplifying Indigenous Voices: IUCN Indigenous Members' Solutions and Challenges Related to the COVID-19 Crisis.* International Union for Conservation of Nature. https://www.iucn.org/sites/dev/files/ipo-c19-brief.pdf

IUCN SSC PSG SGA. 2020. *COVID-19 and Great Apes: Advisory for Conservation Teams Operating in Great Ape Habitat During the COVID-19 Pandemic.* IUCN SSC Primate Specialist Group, Section on Great Apes. http://static1.1.sqspcdn.com/static/f/1200343/28319773/1593547413467/COVID-19_advisory_for_conservation_field_teams.pdf?token=VxfNtaYPReJa73UifZyT6AoHBQQ%3D

IUCN SSC WHSG, PSG SGA. 2020. *Great Apes, COVID-19 and the SARS CoV-2* Joint Statement of the IUCN SSC Wildlife Health Specialist Group and the Primate Specialist Group, Section on Great Apes. https://www.cms.int/sites/default/files/uploads/gorilla/pdf/Final%20-%20SARS%20CoV-2%20and%20Great%20Apes%20Joint%20Communique%2016-05-20.pdf

Jakarta Post. 2020. Life without internet: Bornean students learn by radio during pandemic. *Jakarta Post*. 2 May 2020. https://www.thejakartapost.com/news/2020/05/02/life-without-internet-bornean-students-learn-by-radio-during-pandemic.html?src=mostviewed&pg=news/2020/05/03/fight-against-illegal-logging-could-be-cut-back-by-mobility-restrictions-ngo.html

Jelsma I, Schoneveld GC, Zoomers A, van Westen ACM. 2017. Unpacking Indonesia's independent oil palm smallholders: An actor-disaggregated approach to identifying environmental and social performance challenges. *Land Use Policy* 69:281-297. DOI: 10.1016/j.landusepol.2017.08.012

Johnson CK, Hitchens PL, Pandit PS, Rushmore J, Evans TS, Young CCW, Doyle MM. 2020. Global shifts in mammalian population trends reveal key predictors of virus spillover risk. *Proceedings of the Royal Society B: Biological Sciences* 287:20192736. DOI: 10.1098/rspb.2019.2736

Jones KE, Patel NG, Levy MA, Storeygard A, Balk D, Gittleman JL, Daszak P. 2008. Global trends in emerging infectious diseases. *Nature* 451. DOI: 10.1038/nature0653

Jong HN. 2020a. Experts see environmental, social fallout in Indonesia's infrastructure push. *Mongabay*. 15 June 2020. https://news.mongabay.com/2020/06/indonesia-national-strategic-project-infrastructure-road-railway-dam-smelter-nickel-peatland/

Jong HN. 2020b. Forest fires in Indonesia set to add toxic haze to COVID-19 woes. 23 April 2020. https://news.mongabay.com/2020/04/forest-fires-in-indonesia-look-set-to-add-toxic-haze-to-covid-19-woes/

Jong HN. 2020c. Indonesia won't 'sacrifice economy' for more ambitious emissions cuts. *Mongabay*. 14 April 2020. https://news.mongabay.com/2020/04/indonesia-emissions-reduction-climate-carbon-economy-growth/

1315 Jong HN. 2020d. Indonesian lawmakers push to pass deregulation bills as COVID-19 grips
1316   country. *Mongabay*. 6 April 2020. https://news.mongabay.com/2020/04/indonesia-
1317   parliament-dpr-omnibus-bill-mining-covid19/
1318 Julia, White B. 2012. Gendered experiences of dispossession: oil palm expansion in a Dayak
1319   Hibun community in West Kalimantan. *The Journal of Peasant Studies* 39:995-1016.
1320   DOI: 10.1080/03066150.2012.676544
1321 Kandala N-B, Madungu TP, Emina JBO, Nzita KPD, Cappuccio FP. 2011. Malnutrition among
1322   children under the age of five in the Democratic Republic of Congo (DRC): does
1323   geographic location matter? *BMC Public Health* 11:261. DOI: 10.1186/1471-2458-11-
1324   261
1325 Kanniah KD, Kamarul Zaman NAF, Kaskaoutis DG, Latif MT. 2020. COVID-19's impact on the
1326   atmospheric environment in the Southeast Asia region. *Science of The Total Environment*
1327   736:139658. DO: 10.1016/j.scitotenv.2020.139658
1328 Kavousi J, Goudarzi F, Izadi M, Gardner CJ. 2020. Conservation needs to evolve to survive in
1329   the post-pandemic world. *Global Change Biology* 26:4651-4653. DOI:
1330   10.1111/gcb.15197
1331 Keesing F, Belden LK, Daszak P, Dobson A, Harvell CD, Holt RD, Hudson P, Jolles A, Jones
1332   KE, Mitchell CE, Myers SS, Bogich T, Ostfeld RS. 2010. Impacts of biodiversity on the
1333   emergence and transmission of infectious diseases. *Nature* 468:647-652. DOI:
1334   10.1038/nature09575
1335 Kobo Y. 2020. Why coronavirus means the EU must suspend its palm oil ban. *The Parliament*
1336   *Magazine*. 20 March 2020.
1337   https://www.theparliamentmagazine.eu/articles/partner_article/why-coronavirus-means-
1338   eu-must-suspend-its-palm-oil-ban
1339 Köndgen S, Kühl H, N'Goran PK, Walsh PD, Schenk S, Ernst N, Biek R, Formenty P, Mätz-
1340   Rensing K, Schweiger B, Junglen S, Ellerbrok H, Nitsche A, Briese T, Lipkin WI, Pauli
1341   G, Boesch C, Leendertz FH. 2008. Pandemic human viruses cause decline of endangered
1342   great apes. Current Biology 18:260-264. DOI: 10.1016/j.cub.2008.01.012
1343 Koon LC, Cranbrook Eo. 2014. *Swiftlets of Borneo: Builders of Edible Nests. Second Edition.*
1344   Kota Kinibalu: Natural History Publications (Borneo).
1345 Koplitz SN, Mickley LJ, Marlier ME, Buonocore JJ, Kim PS, Liu T, Sulprizio MP, DeFries RS,
1346   Jacob DJ, Schwartz J, Pongsiri M, Myers SS. 2016. Public health impacts of the severe
1347   haze in Equatorial Asia in September–October 2015: demonstration of a new framework
1348   for informing fire management strategies to reduce downwind smoke exposure.
1349   *Environmental Research Letters* 11:094023. DOI: 10.1088/1748-9326/11/9/094023
1350 KPA. 2019. *Catatan Akhir Tahun 2018 [Year End Notes 2018]*. Jakarta, Indonesia: Konsorsium
1351   Pembaruan Agraria.
1352 Krishnan L, Akande T, Shankar AV, McIntire KN, Gounder CR, Gupta A, Yang W-T. 2014.
1353   Gender-related barriers and delays in accessing tuberculosis diagnostic and treatment
1354   services: a systematic review of qualitative studies. *Tuberculosis Research and Treatment*
1355   2014:215059-215059. DOI: 10.1155/2014/215059
1356 Laborde D, Martin W, Swinnen J, Vos R. 2020. COVID-19 risks to global food security. *Science*
1357   369:500-502. DOI: 10.1126/science.abc4765
1358 Lansbury L, Lim B, Baskaran V, Lim WS. 2020. Co-infections in people with COVID-19: a
1359   systematic review and meta-analysis. *Journal of Infection* 81:266-275. DOI:
1360   10.1016/j.jinf.2020.05.046

1361 Lappan S, Malaivijitnond S, Radhakrishna S, Riley EP, Ruppert N. 2020. The human–primate
1362   interface in the New Normal: Challenges and opportunities for primatologists in the
1363   COVID-19 era and beyond. *American Journal of Primatology*:e23176. DOI:
1364   10.1002/ajp.23176
1365 Laurance WF, Goosem M, Laurance SGW. 2009. Impacts of roads and linear clearings on
1366   tropical forests. *Trends in Ecology & Evolution* 24:659-669. DOI:
1367   10.1016/j.tree.2009.06.009
1368 Le Quéré C, Jackson RB, Jones MW, Smith AJP, Abernethy S, Andrew RM, De-Gol AJ, Willis
1369   DR, Shan Y, Canadell JG, Friedlingstein P, Creutzig F, Peters GP. 2020. Temporary
1370   reduction in daily global CO2 emissions during the COVID-19 forced confinement.
1371   *Nature Climate Change*. DOI: 10.1038/s41558-020-0797-x
1372 Lee C, Rogers WA, Braunack-Mayer A. 2008. Social justice and pandemic influenza planning:
1373   the role of communication strategies. *Public Health Ethics* 1:223-234. DOI:
1374   10.1093/phe/phn031
1375 Leifeld J, Menichetti L. 2018. The underappreciated potential of peatlands in global climate
1376   change mitigation strategies. *Nature Communications* 9:1071. DOI: 10.1038/s41467-018-
1377   03406-6
1378 Li T. 2014. *Land's End: Capitalist Relations on an Indigenous Frontier*. Durham and London:
1379   Duke University Press.
1380 Li X, Giorgi EE, Marichannegowda MH, Foley B, Xiao C, Kong X-P, Chen Y, Gnanakaran S,
1381   Korber B, Gao F. 2020. Emergence of SARS-CoV-2 through recombination and strong
1382   purifying selection. *Science Advances* eabb9153. DOI: 10.1126/sciadv.abb9153
1383 Lilleskov E, McCullough K, Hergoualc'h K, del Castillo Torres D, Chimner R, Murdiyarso D,
1384   Kolka R, Bourgeau-Chavez L, Hribljan J, del Aguila Pasquel J, Wayson C. 2019. Is
1385   Indonesian peatland loss a cautionary tale for Peru? A two-country comparison of the
1386   magnitude and causes of tropical peatland degradation. *Mitigation and Adaptation*
1387   *Strategies for Global Change* 24:591-623. DOI: 10.1007/s11027-018-9790-3
1388 Linard C, Gilbert M, Snow RW, Noor AM, Tatem AJ. 2012. Population distribution, settlement
1389   patterns and accessibility across Africa in 2010. *PLoS One* 7:e31743. DOI:
1390   10.1371/journal.pone.0031743
1391 Lindsey P, Allan J, Brehony P, Dickman A, Robson A, Begg C, Bhammar H, Blanken L, Breuer
1392   T, Fitzgerald K, Flyman M, Gandiwa P, Giva N, Kaelo D, Nampindo S, Nyambe N,
1393   Steiner K, Parker A, Roe D, Thomson P, Trimble M, Caron A, Tyrrell P. 2020.
1394   Conserving Africa's wildlife and wildlands through the COVID-19 crisis and beyond.
1395   *Nature Ecology & Evolution*. DOI: 10.1038/s41559-020-1275-6
1396 Listiyorini E. 2020. Indonesia says looming haze can worsen health of virus patients. *Bloomberg*.
1397   8 May 2020. https://www.bloomberg.com/news/articles/2020-05-08/indonesia-says-
1398   looming-haze-can-worsen-health-of-virus-patients
1399 Listori E. 2020. Indonesia plans village squads to prevent spread of Coronavirus. *Bloomberg*. 31
1400   March 2020. https://www.bloomberg.com/news/articles/2020-03-31/indonesia-plans-
1401   village-squads-to-prevent-spread-of-coronavirus
1402 Lucas B. 2020. *Impacts of Covid-19 on Inclusive Economic Growth in Middle-Income Countries*.
1403   *K4D Helpdesk Report 811*. Brighton, UK: Institute of Development Studies.
1404   https://opendocs.ids.ac.uk/opendocs/handle/20.500.12413/15310

1405 Lupton D. 2020. Doing fieldwork in a pandemic (crowd-sourced document). Available at:
1406   https://docs.google.com/document/d/1clGjGABB2h2qbduTgfqribHmog9B6P0NvMgVui
1407   HZCl8/edit?ts=5e88ae0a#
1408 MacFarlane D, Rocha R. 2020. Guidelines for communicating about bats to prevent persecution
1409   in the time of COVID-19. *Biological Conservation* 248:108650. DOI:
1410   10.1016/j.biocon.2020.108650
1411 Madinah A, Abang F, Mariana A, Abdullah MT, Mohd-Azlan J. 2014. Interaction of
1412   ectoparasites-small mammals in tropical rainforest of Malaysia. *Community Ecology*
1413   15:113. DOI: 10.1556/comec.15.2014.1.12
1414 Madinah A, Fatimah A, Mariana A, Abdullah MT. 2011. Ectoparasites of small mammals in four
1415   localities of wildlife reserves in Peninsular Malaysia. *Southeast Asian Journal of Tropical*
1416   *Medicine and Public Health* 42:803-813
1417 Mäki S, Kalliola R, Vuorinen K. 2001. Road construction in the Peruvian Amazon: process,
1418   causes and consequences. *Environmental Conservation* 28:199-214. DOI:
1419   10.1017/S0376892901000212
1420 Mayor P, El Bizri HR, Morcatty TQ, Moya K, Solis S, Bodmer RE. 2019. Assessing the
1421   minimum sampling effort required to reliably monitor wild meat trade in urban markets.
1422   *Frontiers in Ecology and Evolution* 7:180. DOI: 10.3389/fevo.2019.00180
1423 McCarthy J, Robinson K. 2016. Land and Development in Indonesia: Searching for the People's
1424   Sovereignty. Singapore: ISEAS–Yusof Ishak Institute.
1425 Medrilzam M, Dargusch P, Herbohn J, Smith C. 2014. The socio-ecological drivers of forest
1426   degradation in part of the tropical peatlands of Central Kalimantan, Indonesia. *Forestry:*
1427   *An International Journal of Forest Research* 87:335-345. DOI: 10.1093/forestry/cpt033
1428 Melin AD, Janiak MC, Marrone F, Arora PS, Higham JP. 2020. Comparative ACE2 variation
1429   and primate COVID-19 risk. *bioRxiv*:2020.2004.2009.034967. DOI:
1430   10.1101/2020.04.09.034967
1431 Miettinen J, Shi C, Liew SC. 2016. Land cover distribution in the peatlands of Peninsular
1432   Malaysia, Sumatra and Borneo in 2015 with changes since 1990. *Global Ecology and*
1433   *Conservation* 6:67–78. DOI: 10.1016/j.gecco.2016.02.004
1434 Miles L, Ravilious C, García-Rangel S, de Lamo X, Dargie G, Lewis S. 2017. *Carbon,*
1435   *Biodiversity and Land-use in the Central Congo Basin Peatlands.* United Nations
1436   Environment Programme.
1437 Milko V. 2020. Pandemic poses special threat to indigenous health, culture. *AP News*. 7 May
1438   2020. https://apnews.com/fb15142c3d209c92ef2f502a4ba0d6fa
1439 Mistry J, Berardi A. 2016. Bridging indigenous and scientific knowledge. *Science* 352:1274-
1440   1275. DOI: 10.1126/science.aaf1160
1441 Mizuno K, Fujita MS, Kawai S. 2016. Catastrophe & Regeneration in Indonesia's Peatlands:
1442   Ecology, Economy & Society. Singapore: NUS Press.
1443 MoH RoI. 2019. *Indonesia Health Profile 2018.* Jakarta, Indonesia: Ministry of Health of the
1444   Republic of Indonesia. https://www.kemkes.go.id/resources/download/pusdatin/profil-
1445   kesehatan-indonesia/indonesia-health-profile-2018.pdf
1446 Moore P, Hannah B, de Vries J, Poortvliet M, Steffens R, Stoof CR. 2020. *Wildland Fire*
1447   *Management Under COVID-19. Brief 1, Review of Materials.* Wageningen: Wageningen
1448   University. DOI: 10.18174/521344

1449 Muyembe-Tamfum JJ, Mulangu S, Masumu J, Kayembe JM, Kemp A, Paweska JT. 2012. Ebola
1450   virus outbreaks in Africa: Past and present. *Onderstepoort Journal of Veterinary*
1451   *Research* 79:06-13.
1452 Nair N, Wares F, Sahu S. 2010. Tuberculosis in the WHO South-East Asia region. *Bulletin of the*
1453   *World Health Organisation* 88:164-165. doi: 10.2471/BLT.09.073874
1454 Nesadurai HES. 2013. Food security, the palm oil–land conflict nexus, and sustainability: a
1455   governance role for a private multi-stakeholder regime like the RSPO? *The Pacific*
1456   *Review* 26:505-529. DOI: 10.1080/09512748.2013.842311
1457 Nielsen MR, Meilby H, Smith-Hall C, Pouliot M, Treue T. 2018. The importance of wild meat in
1458   the global south. *Ecological Economics* 146:696-705. DOI:
1459   10.1016/j.ecolecon.2017.12.018
1460 Nijman V. 2010. An overview of international wildlife trade from Southeast Asia. *Biodiversity*
1461   *and Conservation* 19:1101-1114. DOI: 10.1007/s10531-009-9758-4
1462 Nijman V, Spaan D, Rode-Margono EJ, Wirdateti, Nekaris KAI. 2015. Changes in the primate
1463   trade in Indonesian wildlife markets over a 25-year period: Fewer apes and langurs, more
1464   Macaques, and slow Lorises. *American Journal of Primatology* 79:e22517. DOI:
1465   10.1002/ajp.22517
1466 Nordling L. 2020. Africa's pandemic puzzle: why so few cases and deaths? *Science* 369:756-757.
1467   DOI: 10.1126/science.369.6505.756
1468 Nurcahyo W, Konstanzová V, Foitová I. 2017. Parasites of orangutans (primates: ponginae): An
1469   overview. *American Journal of Primatology* 79:e22650. DOI: 10.1002/ajp.22650
1470 OECD. 2020. *DAC List of ODA Recipients Effective for Reporting on 2020 Flows*. Organisation
1471   for Economic Co-operation and Development. http://www.oecd.org/dac/financing-
1472   sustainable-development/development-finance-standards/DAC-List-of-ODA-Recipients-
1473   for-reporting-2020-flows.pdf
1474 Ogen Y. 2020. Assessing nitrogen dioxide (NO_2) levels as a contributing factor to coronavirus
1475   (COVID-19) fatality. *Science of The Total Environment* 726:138605. DOI:
1476   10.1016/j.scitotenv.2020.138605
1477 OGJ Editors. 2020. EIA lowers 2020 oil demand forecast amid high uncertainties. *Oil & Gas*
1478   *Journal*. 12 May 2020. https://www.ogj.com/general-interest/economics-
1479   markets/article/14175840/eia-lowers-2020-oil-demand-forecast-amid-high-uncertainties
1480 Oppenheim B, Gallivan M, Madhav NK, Brown N, Serhiyenko V, Wolfe ND, Ayscue P. 2019.
1481   Assessing global preparedness for the next pandemic: development and application of an
1482   Epidemic Preparedness Index. *BMJ Global Health* 4:e001157. DOI: 10.1136/bmjgh-
1483   2018-001157
1484 Page SE, Hooijer A. 2016. In the line of fire: the peatlands of Southeast Asia. *Philosophical*
1485   *Transactions of the Royal Society of London B* 371:20150176. DOI:
1486   10.1098/rstb.2015.0176
1487 Page SE, Rieley JO, Banks CJ. 2011. Global and regional importance of the tropical peatland
1488   carbon pool. *Global Change Biology* 17:798-818. DOI: 10.1111/j.1365-
1489   2486.2010.02279.x
1490 PAHO. 2020. *Dengue Prevention and Control During COVID-19 Pandemic*. Washington, DC:
1491   Pan American Health Organization. https://www.paho.org/en/documents/dengue-
1492   prevention-and-control-during-covid-19-pandemic

1493 Parish F, Sirin A, Charman D, Joosten H, Minayeva T, Silvius M, Stringer L. 2008. *Assessment*
1494   *on Peatlands, Biodiversity and Climate Change: Main Report.* Global Environment
1495   Centre, Kuala Lumpur and Wetlands International, Wageningen.
1496 Payne J, Bradley B. 2020. *The Consequences of Pandemic-driven Inequality.* Oxford: Oxford
1497   Economics.
1498 Pearson RM, Sievers M, McClure EC, Turschwell MP, Connolly RM. 2020. COVID-19
1499   recovery can benefit biodiversity. *Science* 368:838-839. DOI: 10.1126/science.abc1430
1500 Phillips CA, Caldas A, Cleetus R, Dahl KA, Declet-Barreto J, Licker R, Merner LD, Ortiz-
1501   Partida JP, Phelan AL, Spanger-Siegfried E, Talati S, Trisos CH, Carlson CJ. 2020.
1502   Compound climate risks in the COVID-19 pandemic. *Nature Climate Change* 10:586-
1503   588. DOI: 10.1038/s41558-020-0804-2
1504 Pitkin K, Bedoya R. 1997. Women's multiple roles in economic crisis: Constraints and
1505   adaptation. *Latin American Perspectives* 24:34-49. DOI: 10.1177/0094582x9702400403
1506 Pollock J, Lin Aung S. 2010. Critical times: gendered implications of the economic crisis for
1507   migrant workers from Burma/Myanmar in Thailand. *Gender & Development* 18:213-227.
1508   DOI: 10.1080/13552074.2010.491324
1509 Pongsiri MJ, Roman J, Ezenwa VO, Goldberg TL, Koren HS, Newbold SC, Ostfeld RS,
1510   Pattanayak SK, Salkeld DJ. 2009. Biodiversity loss affects global disease ecology.
1511   *BioScience* 59:945-954. DOI: 10.1525/bio.2009.59.11.6
1512 Posa MRC, Wijedasa LS, Corlett RT. 2011. Biodiversity and conservation of tropical peat
1513   swamp forests. *BioScience* 61:49-57. DOI: 10.1525/bio.2011.61.1.10
1514 Poulsen JR, Clark CJ, Mavah G, Elkan PW. 2009. Bushmeat supply and consumption in a
1515   tropical logging concession in northern Congo. *Conservation Biology* 23:1597-1608.
1516   DOI: 10.1111/j.1523-1739.2009.01251.x
1517 Radhi NSM. 2020. Malaysians scramble ahead of RMO. *Straits New Times*. 18 March 2020.
1518   https://www.nst.com.my/news/nation/2020/03/575684/malaysians-scramble-balik-
1519   kampung-ahead-rmo
1520 Rédaction. 2020. *Deux ong attaquent la CIB pour le décès de 57 enfants autochtones dams la*
1521   *Likouala* [Two NGOs attack the CIB for the deaths of 57 indigenous children in
1522   Likouala]. *Vox Médiaire*. 18 September 2017. https://www.vox.cg/2017/09/deux-ong-
1523   attaquent-cib-deces-de-57-enfants-autochtones-likouala/
1524 Reid MJC. 2020. Is 2020 the year when primatologists should cancel fieldwork? *American*
1525   *Journal of Primatology* 82:e23161. DOI: 10.1002/ajp.23161
1526 RISTEK-BRIN. 2020. Official Notice. *Ministry of Reserach and Technology / National Agency*
1527   *for Research and Innovation* (accessed 21 June 2020). https://frp.ristekbrin.go.id/
1528 Robinson EJZ. 2016. Resource-Dependent Livelihoods and the Natural Resource Base. *Annual*
1529   *Review of Resource Economics* 8:281-301. DOI: 10.1146/annurev-resource-100815-
1530   095521
1531 Rodriguez JM, Molnar JJ, Fazio RA, Sydnor E, Lowe MJ. 2009. Barriers to adoption of
1532   sustainable agriculture practices: Change agent perspectives. *Renewable Agriculture and*
1533   *Food Systems* 24:60-71. DOI: 10.1017/S1742170508002421
1534 Rodríguez Mega E. 2016. Oil spills stain Peruvian Amazon. *Scientific American*. 4 March 2016.
1535   https://www.scientificamerican.com/article/oil-spills-stain-peruvian-amazon/
1536 Roger F, Caron A, Morand S, Pedrono M, Garine-Wichatitsky Md, Chevalier V, Tran A, Gaidet
1537   N, Figuié M, de Visscher M-N, Binot A. 2016. One Health and EcoHealth: the same wine

in different bottles? *Infection Ecology & Epidemiology* 6:30978. DOI: 10.3402/iee.v6.30978

Roucoux KH, Lawson IT, Baker TR, Del Castillo Torres D, Draper FC, Lähteenoja O, Gilmore MP, Honorio Coronado EN, Kelly TJ, Mitchard ETA, Vriesendorp CF. 2017. Threats to intact tropical peatlands and opportunities for their conservation. *Conservation Biology* 31:1283-1292. DOI: 10.1111/cobi.12925

Sánchez-Páramo C. 2020. COVID-19 will hit the poor hardest. Here's what we can do about it. *World Bank Blogs*. 23 April 2020. https://blogs.worldbank.org/voices/covid-19-will-hit-poor-hardest-heres-what-we-can-do-about-it

Santika T, Meijaard E, Budihartab S, Law EA, Kusworo A, Hutabarat JA, Indrawan TP, Struebig M, Raharjo S, Huda I, Sulhani, Ekaputri AD, Trison S, Stigner M, Wilson KA. 2017. Community forest management in Indonesia: Avoided deforestation in the context of anthropogenic and climate complexities. *Global Environmental Change* 46:60-71. DOI: 10.1016/j.gloenvcha.2017.08.002

Sardar S, Sharma R, Alyamani TYM, Aboukamar M. 2020. COVID-19 and *Plasmodium vivax* malaria co-infection. *IDCases* 21:e00879. DOI: 10.1016/j.idcr.2020.e00879

Sarkar S. 2020. Coronavirus thumps palm oil demand. *China Dialogue*. 8 April 2020. https://www.chinadialogue.net/article/show/single/en/11945-Coronavirus-thumps-palm-oil-demand

Schoppe S. 2009. *Status, trade, dynamics and management of the Southeast Asian box turtle Cuora amboinensis in Indonesia.* Petaling Jaya, Selangor, Malaysia: TRAFFIC Southeast Asia.

Schreer V. 2016. Longing for Prosperity in Indonesian Borneo. PhD dissertation. University of Kent.

Schulz C, Martín Brañas M, Núñez Pérez C, Del Aguila Villacorta M, Laurie N, Lawson IT, Roucoux KH. 2019a. Peatland and wetland ecosystems in Peruvian Amazonia: indigenous classifications and perspectives. *Ecology and Society* 24:12. DOI: 10.5751/ES-10886-240212

Schulz C, Martín Brañas M, Núñez Pérez C, Del Aguila Villacorta M, Laurie N, Lawson IT, Roucoux KH. 2019b. Uses, cultural significance, and management of peatlands in the Peruvian Amazon: Implications for conservation. *Biological Conservation* 235:189-198. DOI: 10.1016/j.biocon.2019.04.005

Scullion JJ, Vogt KA, Sienkiewicz A, Gmur SJ, Trujillo C. 2014. Assessing the influence of land-cover change and conflicting land-use authorizations on ecosystem conversion on the forest frontier of Madre de Dios, Peru. *Biological Conservation* 171:247-258. DOI: 10.1016/j.biocon.2014.01.036

Setti L, Passarini F, De Gennaro G, Barbieri P, Perrone MG, Borelli M, Palmisani J, Di Gilio A, Torboli V, Fontana F, Clemente L, Pallavicini A, Ruscio M, Piscitelli P, Miani A. 2020. SARS-Cov-2RNA found on particulate matter of Bergamo in Northern Italy: First evidence. *Environmental Research* 188:109754. DOI: 10.1016/j.envres.2020.109754

Sharp PM, Hahn BH. 2011. Origins of HIV and the AIDS pandemic. *Cold Spring Harbor perspectives in medicine* 1:a006841-a006841. DOI: 10.1101/cshperspect.a006841

Sierra Praeli Y. 2020. Indigenous people are most vulnerable to the spread of coronavirus in Latin America. *Mongabay*. 30 March 2020. https://news.mongabay.com/2020/03/indigenous-people-are-most-vulnerable-to-the-spread-of-coronavirus-in-latin-america/

1584 Staniscuaski F, Reichert F, Werneck FP, de Oliveira L, Mello-Carpes PB, Soletti RC, Almeida
1585   CI, Zandona E, Ricachenevsky FK, Neumann A, Schwartz IVD, Tamajusuku ASK,
1586   Seixas A, Kmetzsch L. 2020. Impact of COVID-19 on academic mothers. *Science*
1587   368:724-724. DOI: 10.1126/science.abc2740
1588 Steinberg P. 2020. Free COVID-19 illustrations, SARS-CoV-2 virus and world. Accessed 21
1589   April 2020. *Innovative Genomics Institute*. https://innovativegenomics.org/free-covid-19-
1590   illustrations/
1591 Stockwell CE, Jayarathne T, Cochrane MA, Ryan KC, Putra EI, Saharjo BH, Nurhayati AD,
1592   Albar I, Blake DR, Simpson IJ, Stone EA, Yokelson RJ. 2016. Field measurements of
1593   trace gases and aerosols emitted by peat fires in Central Kalimantan, Indonesia, during
1594   the 2015 El Niño *Atmospheric Chemistry and Physics* 16:11711-11732. DOI:
1595   10.5194/acp-16-11711-2016
1596 Sumarga E, Hein L, Hooijer A, Vernimmen R. 2016. Hydrological and economic effects of oil
1597   palm cultivation in Indonesian peatlands. *Ecology and Society* 21:52. DOI: 10.5751/ES-
1598   08490-210252
1599 Sumner A, Hoy C, Ortiz-Juarez E. 2020. *Estimates of the impact of COVID-19 on global*
1600   *poverty. WIDER Working Paper 2020/43.* United Nations University World Instutute for
1601   Development Economics Research.
1602 Suparmi, Kusumawardani N, Nambiar D, Trihono, Hosseinpoor AR. 2018. Subnational regional
1603   inequality in the public health development index in Indonesia. *Global Health Action*
1604   11:41-53. DOI: 10.1080/16549716.2018.1500133
1605 Suyanto S. 2007. Underlying cause of fire: Different form of land tenure conflicts in Sumatra.
1606   *Mitigation and Adaptation Strategies to Global Change* 12:67-74. DOI: 10.1007/s11027-
1607   006-9039-4
1608 Tan-Soo J-S, Pattanayak SK. 2019. Seeking natural capital projects: Forest fires, haze, and early-
1609   life exposure in Indonesia. *Proceedings of the National Academy of Sciences* 116:5239-
1610   5245. DOI: 10.1073/pnas.1802876116
1611 Taylor DE. 2015. Gender and racial diversity in environmental organizations: uneven
1612   accomplishments and cause for concern. *Environmental Justice* 8:165-180. DOI:
1613   10.1089/env.2015.0018
1614 Taylor M. 2020. Will coronavirus fan the flames of Southeast Asia's haze problem? *Reuters*. 22
1615   April 2020. https://www.reuters.com/article/us-health-coronavirus-southeast-asia-haz-
1616   idUSKCN224021
1617 Thorburn C. 2014. The edible birds' nest boom in Indonesia and South-east Asia. *Food, Culture*
1618   *& Society* 17:535-553. DOI: 10.2752/175174414X14006746101439
1619 Thornton SA. 2017. (Un)tangling the Net, Tackling the Scales and Learning to Fish: An
1620   Interdisciplinary Study in Indonesian Borneo.PhD dissertation. University of Leicester.
1621 Thornton SA, Cook S, Astiani D, Hapsari KA, Varkkey H, Cole LES, Dargie GC, Sjogersten S,
1622   Zawawi NZ, Page SE. 2019. 'Pushing the limits': experiences of women in tropical
1623   peatland research. *Marine and Freshwater Research*. DOI: 10.1071/MF19132
1624 Trivedy C. 2020. Is 2020 the year when primatologists should cancel fieldwork? A reply.
1625   *American Journal of Primatology* 82:e23173. DOI: 10.1002/ajp.23173
1626 Turetsky MR, Benscoter B, Page S, Rein G, van der Werf GR, Watts A. 2015. Global
1627   vulnerability of peatlands to fire and carbon loss. *Nature Geoscience* 8:11-14. DOI:
1628   10.1038/ngeo2325

1629   Tyson A, Varkkey H, Choiruzzad SAB. 2018. Deconstructing the palm oil industry narrative in
1630   Indonesia: Evidence from Riau Province. *Contemporary Southeast Asia* 40:422-448.
1631   https://www.jstor.org/stable/26545302
1632   Uda SK, Hein L, Atmoko D. 2019. Assessing the health impacts of peatland fires: a case study
1633   for Central Kalimantan, Indonesia. *Environmental Science and Pollution Research*. DOI:
1634   10.1007/s11356-019-06264-x
1635   UN. 2009. *State of the World's Indigenous Peoples*. New York: UN Department of Economic
1636   and Social Affairs.
1637   https://www.un.org/esa/socdev/unpfii/documents/SOWIP/en/SOWIP_web.pdf
1638   UN. 2020. *Policy Brief: The Impact of COVID-19 on Women*. United Nations.
1639   https://www.un.org/sites/un2.un.org/files/policy_brief_on_covid_impact_on_women_9_a
1640   pril_2020.pdf
1641   UN/DESA. 2020. *The Impact of COVID-19 on Indigenous Peoples. Policy Brief No. 70*. Unitied
1642   Nations Department of Economic and Social Affairs.
1643   https://www.un.org/development/desa/dpad/wp-
1644   content/uploads/sites/45/publication/PB_70.pdf
1645   UN/EMRIP. 2020. *COVID-19 Yet Another Challenge for Indigenous Peoples*. UN Expert
1646   Mechanism on the Rights of Indigenous Peoples.
1647   https://www.un.org/development/desa/indigenouspeoples/wp-
1648   content/uploads/sites/19/2020/04/EMRIP-English.pdf
1649   UNEP, ILRI. 2020. *Preventing the Next Pandemic: Zoonotic Diseases and how to Break the
1650   Chain of Transmission*. Nairobi, Kenya: United Nations Environment Programme and
1651   International Livestock Research Institute.
1652   https://wedocs.unep.org/bitstream/handle/20.500.11822/32316/ZP.pdf?sequence=1&isAll
1653   owed=y
1654   Utami-Atmoko S, Traylor-Holzer K, Rifqi MA, Siregar PG, Achmad B, Priadjati A, Husson S,
1655   Wich S, Hadisiswoyo P, Saputra F, Campbell-Smith G, Kuncoro P, Russon A, Voigt M,
1656   Santika T, Nowak M, Singleton I, Sapari I, Meididit A, Chandradewi DS, Ripoll Capilla
1657   B, Ermayanti, Lees CM. 2017. *Orangutan Population and Habitat Viability Assessment:
1658   Final Report*. Apple Valley, MN: IUCN/SSC Conservation Breeding Specialist Group.
1659   van Beukering PJH, Schaafsma M, Davies O, Oskolokaite I. 2008. *The Economic Value of
1660   Peatland Resources within the Central Kalimantan Peatland Project in Indonesia:
1661   Perceptions of Local Communities*. Amsterdam, Netherlands: Institute for Environmental
1662   Studies.
1663   van Vliet N, Moreno J, Gomez J, Zhou W, Fa JE, Golden C, Romeu R, Alves N, Nasi R. 2017.
1664   Bushmeat and human health: Assessing the Evidence in tropical and sub-tropical forests.
1665   *Ethnobiology and Conservation* 6:1-45. DOI: 10.15451/ec2017-04-6.3-1-45
1666   Varkkey H. 2020. Air pollution and COVID-19 mortality: Considerations for Southeast Asia.
1667   *AsiaGlobal Online*. 23 April 2020. https://www.asiaglobalonline.hku.hk/air-pollution-
1668   and-covid-19-mortality-considerations-southeast-asia?
1669   Varkkey H, Copeland A. 2020. Exhanging health for economic growth?: Haze in the context of
1670   public health and political economy in Malaysia. *Journal of Social Health* 3.
1671   Vine Trust. 2020. An update from Vine Trust. *Vine Trust*. 9 April 2020.
1672   https://www.vinetrust.org/media/latest-news/an-update-from-vine-trust
1673   Vittor AY, Gilman RH, Tielsch J, Glass G, Shields T, Lozano WS, Pinedo-Cancino V, Patz JA.
1674   2006. The effect of deforestation on the human-biting rate of *Anopheles darlingi*, the

1675   primary vector of falciparum malaria in the Peruvian Amazon. *The American Journal of*
1676   *Tropical Medicine and Hygiene* 74:3-11. DOI: 10.4269/ajtmh.2006.74.3
1677 Wallace S. 2020. First coronavirus deaths reported in indegenous communities in the Amazon.
1678   *National Geogarphic*. 14 April 2020. https://www.nationalgeographic.co.uk/science-and-
1679   technology/2020/04/first-coronavirus-deaths-reported-indigenous-communities-amazon
1680 WB. 2020a. *Congo, Democratic Republic of - COVID-19 Strategic Preparedness and Response*
1681   *Project* Washington, D.C.: World Bank Group.
1682   http://documents.worldbank.org/curated/en/349641585951020231/Congo-Democratic-
1683   Republic-of-COVID-19-Strategic-Preparedness-and-Response-Project
1684 WB. 2020b. *East Asia and Pacific in the Time of COVID-19. East Asia and Pacific Economic*
1685   *Update (April)*. Washington, DC.: World Bank. DOI: 10.1596/978-1-4648-1565-2.
1686 Wenham C, Smith J, Morgan R. 2020. COVID-19: the gendered impacts of the outbreak. *The*
1687   *Lancet* 395:846-848. DOI: 10.1016/S0140-6736(20)30526-2
1688 Weston. 2020. Plan to drain Congo peat bog for oil could release vast amount of carbon. *The*
1689   *Guardian*. 28 February 2020.
1690   https://www.theguardian.com/environment/2020/feb/28/ridiculous-plan-to-drain-congo-
1691   peat-bog-could-release-vast-amount-of-carbon-aoe
1692 WFP. 2020. Coronavirus and the 5 major threats it poses to global food security. *World Food*
1693   *Programme Insight*. 30 March 2020. https://insight.wfp.org/covid-19-and-the-5-major-
1694   threats-it-poses-to-global-food-security-1c4da2ff6657
1695 WHO. 2009. *Pandemic Influenza Preparedness and Response. WHO Guidance Document.*
1696   Geneva, Switzerland: World Health Organization.
1697   https://www.who.int/influenza/resources/documents/pandemic_guidance_04_2009/en/
1698 WHO. 2017. *State of Health Inequality: Indonesia, Geneva*. Geneva: World Health Organisation.
1699   https://apps.who.int/iris/bitstream/handle/10665/259685/9789241513340-
1700   eng.pdf?sequence=1
1701 WHO. 2020a. At least 80 million children under one at risk of diseases such as diphtheria,
1702   measles and polio as COVID-19 disrupts routine vaccination efforts, warn Gavi, WHO
1703   and UNICEF. *World Health Organization*. 22 May 2020. https://www.who.int/news-
1704   room/detail/22-05-2020-at-least-80-million-children-under-one-at-risk-of-diseases-such-
1705   as-diphtheria-measles-and-polio-as-covid-19-disrupts-routine-vaccination-efforts-warn-
1706   gavi-who-and-unicef
1707 WHO. 2020b. *Coronavirus Disease Situation Report - 15: Indonesia 8 July 2020*. Indonesia:
1708   World Health Organisation. https://www.who.int/docs/default-
1709   source/searo/indonesia/covid19/external-situation-report-15-
1710   08july2020.pdf?sfvrsn=42d8ee3d_2
1711 WHO. 2020c. Ebola virus disease – Democratic Republic of the Congo. *World Health*
1712   *Organization*. 3 June 2020. https://www.who.int/csr/don/03-June-2020-ebola-drc/en/
1713 WHO. 2020d. WHO urges countries to ensure the continuity of malaria services in the context of
1714   the COVID-19 pandemic. *World Health Organization*. 25 March 2020.
1715   https://www.who.int/news-room/detail/25-03-2020-who-urges-countries-to-ensure-the-
1716   continuity-of-malaria-services-in-the-context-of-the-covid-19-pandemic
1717 WHO, UNICEF. 2020. *Water, Sanitation, Hygiene, and Waste Management for the COVID-19*
1718   *Virus: Interim Guidance: 23 April 2020*. World Health Organization and the United
1719   Nations Children's Fund. https://apps.who.int/iris/bitstream/handle/10665/331846/WHO-
1720   2019-nCoV-IPC_WASH-2020.3-eng.pdf?ua=1

1721 Wich S, Riswan, Jenson J, Refisch J, Nellemann C. 2011. *Orangutans and the economics of*
1722   *sustainable forest management in Sumatra.* Norway:
1723   UNEP/GRASP/PanEco/YEL/ICRAF/GRID-Arendal.
1724 Wich SA, Garcia-Ulloa J, Kühl HS, Humle T, Lee JSH, Koh LP. 2014. Will oil palm's
1725   homecoming spell doom for Africa's great apes? *Current Biology* 24:1659-1663. DOI:
1726   10.1016/j.cub.2014.05.077
1727 Widodo J. 2020. *Inpres no. 4/2020: Refocussing Kegiatan, Realokasi Anggaran, Serta*
1728   *Pengadaan Barang dan Jasa Dalam Rangka Percepatan Penanganan Corona Virus*
1729   *Disease 2019 (COVID-19) [Presidential Instruction no. 4/2020: Activity Refocussing,*
1730   *Budget Reallocation, and Procurement of Goods and Services in Order to Accelerate*
1731   *Handling of Corona Virus Disease 2019 (COVID-19)].* Jakarta, Indonesia: President of
1732   the Republic of Indonesia.
1733 Wijedasa LS, Jauhiainen J, Könönen M, Lampela M, Vasander H, Leblanc MC, Evers S, Smith
1734   TEL, Yule CM, Varkkey H, Lupascu M, Parish F, Singleton I, Clements GR, Aziz SA,
1735   Harrison ME, Cheyne S, Anshari GZ, Meijaard E, Goldstein JE, Waldron S, Hergoualc'h
1736   K, Dommain R, Frolking S, Evans CD, Posa MRC, Glaser PH, Suryadiputra N, Lubis R,
1737   Santika T, Padfield R, Kurnianto S, Hadisiswoyo P, Lim TW, Page SE, Gauci V, Van
1738   Der Meer PJ, Buckland H, Garnier F, Samuel MK, Choo LNLK, O'Reilly P, Warren M,
1739   Suksuwan S, Sumarga E, Jain A, Laurance WF, Couwenberg J, Joosten H, Vernimmen
1740   R, Hooijer A, Malins C, Cochrane MA, Perumal B, Siegert F, Peh KSH, Comeau LP,
1741   Verchot L, Harvey CF, Cobb A, Jaafar Z, Wösten H, Manuri S, Müller M, Giesen W,
1742   Phelps J, Yong DL, Silvius M, Wedeux BMM, Hoyt A, Osaki M, Hirano T, Takahashi H,
1743   Kohyama TS, Haraguchi A, Nugroho NP, Coomes DA, Quoi LP, Dohong A, Gunawan
1744   H, Gaveau DLA, Langner A, Lim FKS, Edwards DP, Giam X, van der Werf G, Carmenta
1745   R, Verwer CC, Gibson L, Gandois L, Graham LLB, Regalino J, Wich SA, Rieley J,
1746   Kettridge N, Brown C, Pirard R, Moore S, Capilla BR, Ballhorn U, Ho HC, Hoscilo A,
1747   Lohberger S, Evans TA, Yulianti N, Blackham G, Onrizal, Husson S, Murdiyarso D,
1748   Pangala S, Cole LES, Tacconi L, Segah H, Tonoto P, Lee JSH, Schmilewski G,
1749   Wulffraat S, Putra EI, Cattau ME, Clymo RS, Morrison R, Mujahid A, Miettinen J, Liew
1750   SC, Valpola S, Wilson D, D'Arcy L, Gerding M, Sundari S, Thornton SA, Kalisz B,
1751   Chapman SJ, Su ASM, Basuki I, Itoh M, Traeholt C, Sloan S, Sayok AK, Andersen R.
1752   2017. Denial of long-term issues with agriculture on tropical peatlands will have
1753   devastating consequences. *Global Change Biology* 23:977-982. DOI: 10.1111/gcb.13516.
1754 Wijedasa LS, Sloan S, Page SE, Clements GR, Lupascu M, Evans TA. 2018. Carbon emissions
1755   from Southeast Asian peatlands will increase despite emission-reduction schemes. *Global*
1756   *Change Biology*. DOI: 10.1111/gcb.14340
1757 Wildayana E, Armanto ME. 2018. Formulating popular policies for peat restoration based on
1758   livelihoods of Llocal farmers. *Journal of Sustainable Development* 11:85-95. DOI:
1759   10.5539/jsd.v11n3p85
1760 Wiseman V, Thabrany H, Asante A, Haemmerli M, Kosen S, Gilson L, Mills A, Hayen A,
1761   Tangcharoensathien V, Patcharanarumol W. 2018. An evaluation of health systems
1762   equity in Indonesia: study protocol. *International Journal for Equity in Health* 17:138.
1763   DOI: 10.1186/s12939-018-0822-0
1764 WorldPop. 2020. Open Spatial Demographic Data and Research. (accessed 13 June 2020.
1765   www.worldpop.org

1766 Worobey M, Gemmel M, Teuwen DE, Haselkorn T, Kunstman K, Bunce M, Muyembe J-J,
1767  Kabongo J-MM, Kalengayi RM, Van Marck E, Gilbert MTP, Wolinsky SM. 2008. Direct
1768  evidence of extensive diversity of HIV-1 in Kinshasa by 1960. *Nature* 455:661-664. DOI:
1769  10.1038/nature07390
1770 Wu X, Nethery RC, Sabath BM, Braun D, Dominici F. 2020. Exposure to air pollution and
1771  COVID-19 mortality in the United States. *medRxiv* 2020.04.05.20054502. DOI:
1772  10.1101/2020.04.05.20054502
1773 Yusoff NM, Muharam FM, Khairunniza-Bejo S. 2017. Towards the use of remote-sensing data
1774  for monitoring of abandoned oil palm lands in Malaysia: a semi-automatic approach.
1775  *International Journal of Remote Sensing* 38:432-449. DOI:
1776  10.1080/01431161.2016.1266111
1777 Zhou F, Yu T, Du R, Fan G, Liu Y, Liu Z, Xiang J, Wang Y, Song B, Gu X, Guan L, Wei Y, Li
1778  H, Wu X, Xu J, Tu S, Zhang Y, Chen H, Cao B. 2020. Clinical course and risk factors for
1779  mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort
1780  study. *The Lancet* 395:1054-1062. DOI: 10.1016/S0140-6736(20)30566-3
1781

Figure 1

Summary illustration of key points and linkages regarding the potential for future EID emergence from tropical peatlands, and potential threats to tropical peatland conservation and local communities from the current COVID-19 pandemic.

Box outline and fill colours indicate contents corresponding to labels of the three circles. Dashes indicate pre-existing factors or factors arising from the COVID-19 that impact upon solid boxes. Shaded boxes indicate potential major ultimate impacts, which as implied by the three circles are closely linked and thus potentially mutually reinforcing. See text for further details, explanations and discussion of additional points and linkages omitted here for reasons of space. Photo credits: Sara Thornon (tropical peat-swamp forest), Susan Page (peatland communities & livelihoods) and Philippa Steinberg for the Innovative Genomics Institute (EIDs / COVID-19: Steinberg, 2020).
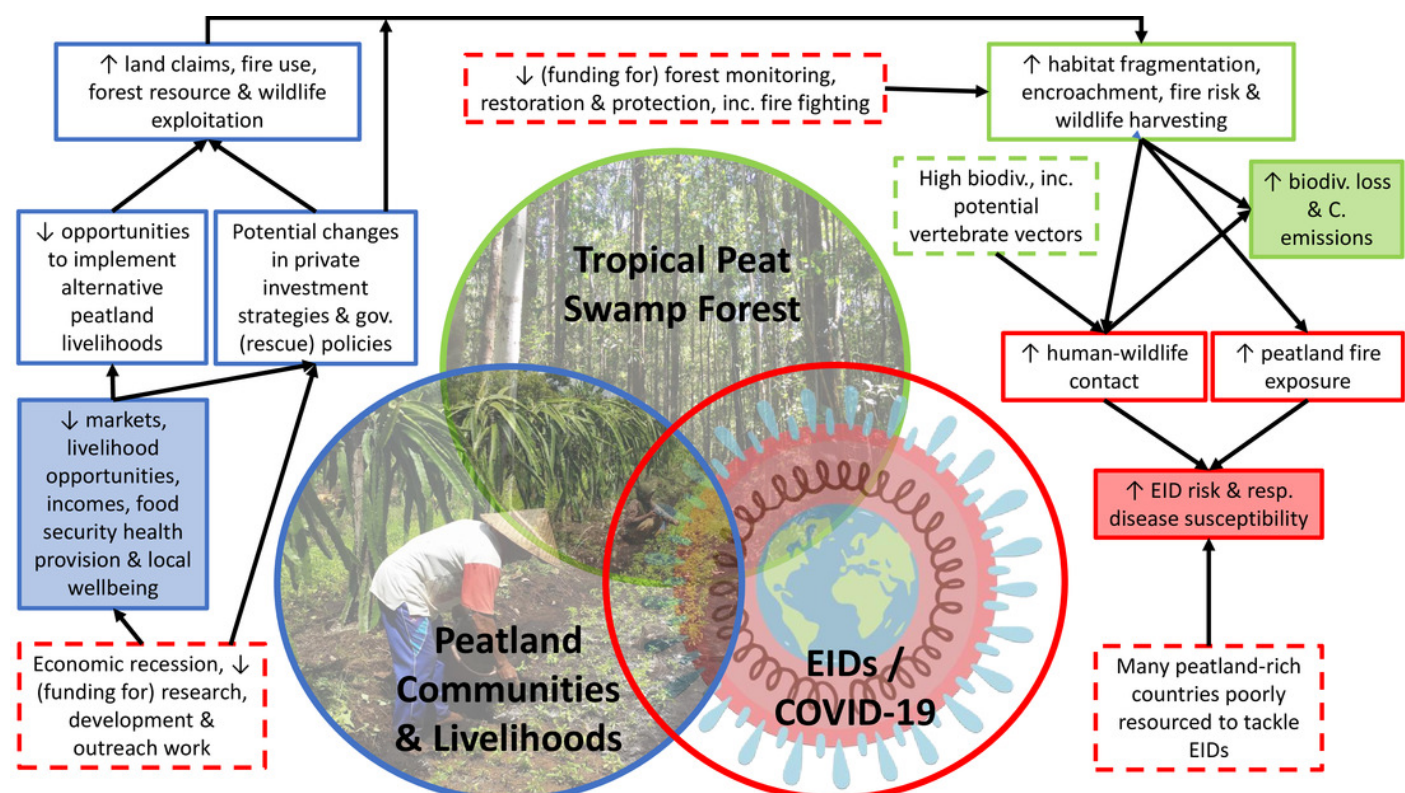
Figure 2

Map of tropical and subtropical peatlands (a) following Leifeld & Menicetti (2018), with close-ups of the Congo Basin (b) and Riau province, Sumatra, Indonesia (c).

In (b) and (c) the satellite image is a false colour composite of Landsat 7 and 8 imagery from 2016 to 2017 created in GoogleEarth Engine. Human population density per square kilometre (Gaughan et al., 2013; Linard et al., 2012; WorldPop, 2020), is overlaid with colours ranging from pink with a density of one person per square kilometre to greater than 50 in red. Peatland boundaries are indicated by yellow lines and purple indicates treeless areas. Most of the Congo Basin peatlands have low population density, but there is Mbandaka city in the centre (red), plus a growing population in the periphery on the northeast and east. In Riau, there are large population centres, plus growing populations and plantations directly adjacent to the peatlands. Map data: Google, USGS;Gaughanet al., (2013); Linardet al. (2012); Leifeld & Menicetti (2018); WorldPop (2020).
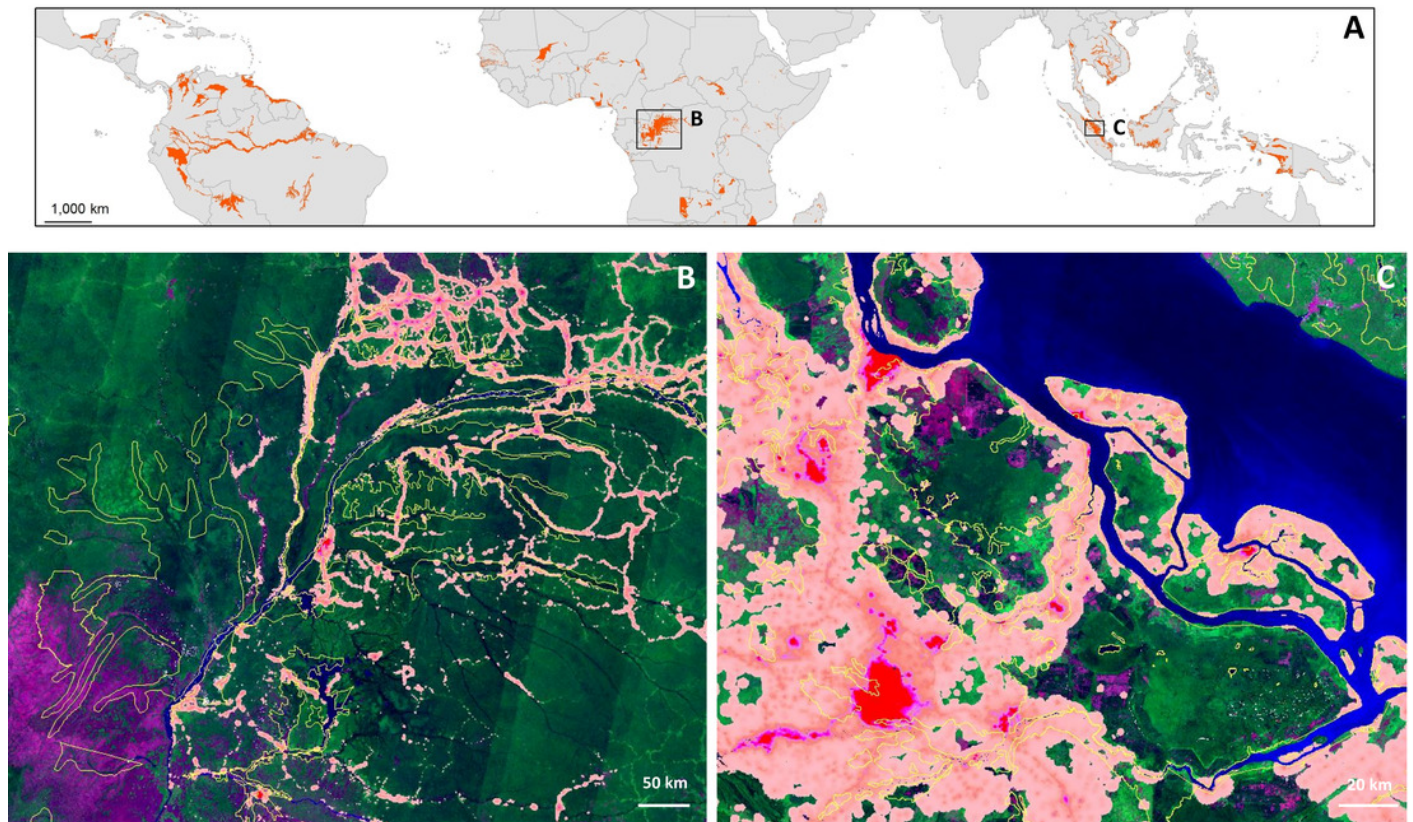
Figure 3

Figure 3. A remote tropical peatland community in Buenos Aires (a), within the Pacaya Samiria National Reserve, Peruvian Amazon, which is accessible only by boat.

People living here and in neighbouring communities rely heavily on resources extracted from the surrounding peat-forming *Mauritia flexuosa* palm swamps. Urarina indigenous groups living in peat-rich areas, harvest palm leaves from which to make textiles (b); important both practically and culturally for these isolated communities. The palms also offer plentiful food for wild fauna and thus the palm swamps in which they grow are important hunting spaces for people, providing bushmeat in locations far from the nearest market. Photo credits: Lydia Cole.

Figure 4

Figure 4. Peatland fire encroaching into forest (a) and local fishers working under thick haze conditions from peatland fires (b) in Central Kalimantan, Indonesia.

Note in (a) the immediate fire damage to the forest on the top side, and older fire damage on the bottom side, of the river. Photo credits: (a) Markurius Sera/Borneo Nature Foundation Indonesia and (b) Suzanne Turnock/Borneo Nature Foundation Indonesia.