The Consequences of COVID-19 and Other Disasters for Wildlife and Biodiversity

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Abstract

We review the economic channels by which the COVID-19 pandemic and subsequent policy responses may affect wildlife and biodiversity. The pandemic is put in the context of more than 5,000 disease outbreaks, natural disasters, recessions and armed conflicts in a sample of 21 high biodiversity countries. The most salient feature of the pandemic is its creation of multiple income shocks to rural and coastal households in biodiverse countries, correlated across sectors of activities and spatially. Various research and policy opportunities and challenges are explored .

Keywords COVID-19 · Biodiversity · Pandemic · Disasters · Conflicts · Poverty · Food insecurity · Risk · Correlated shocks

1 Introduction

The COVID-19 pandemic is a stochastic shock simultaneously affecting individuals, households, firms and institutions globally. As of July 2020, more than 11 million cases of infections and 500,000 deaths have been confirmed worldlwide (Johns Hopkins University Coronavirus Resource Center 2020), and the daily case count is increasing exponentially. The policy response has been equally sweeping. International travel restrictions and lockdowns have significantly curtailed economic activity and USD\$9 trillion in emergency fiscal measures have been deployed by 198 countries (IMF 2020).[1]

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[1] Unless otherwise specified, terms like "the pandemic", and "the COVID-19 event" refer to the combination of health, policy and economic disruptions.

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For the first time in 60 years, the global output of emerging economies is set to contract (World Bank 2020b). It is well established that poverty and food insecurity are primary drivers of biodiversity loss (Dasgupta and Mäler 1995; Dasgupta et al. 2001; Barrett et al. 2011). The compounded effects of disease and economic disruption are threatening to throw between 70 and 100 million additional people into poverty (World Bank 2020e), and the United Nations World Food Program (2020) warns that an extra 130 million people could face acute food insecurity by the end of 2020 (nearly double the pre-pandemic number).

It is impossible to predict the course that the disease will take, how deeply and for how long the recession will last, or whether the pandemic will spur major changes in national policies and the general world economic order. Yet, many of the short term impacts already observed raise the possibility of significant consequences for land use, wildlife and biodiversity. People are getting gravely ill and, amid a generalized economic downturn, the demand for natural resources has dropped, nature tourism has been halted, supply networks have been disrupted, and policies have already been implemented to curtail the harvesting and trade of wild animals.

We list many more short term effects of the pandemic in Sect. 2, organizing them by economic pathways that can trigger biodiversity loss. In Sect. 3, we place the pandemic in the context of the background risks faced by households in a sample of 21 low and middle income countries with high biodiversity. The tally of disease outbreaks, economic shocks, natural disasters, armed conflicts, and political crises reveals more than 5,000 shocks since 1970. Research linking these types of shocks to natural resource use and biodiversity loss is instructive. However, the most salient feature of the pandemic is perhaps that it imposes a multiplicity of correlated shocks to many sectors of the economy, to several coping strategies of rural poor, and to nearly all regions of the globe. This raises many interesting new research questions and opportunities, but also poses methodological challenges for modelers and empirical researchers alike. Policy-making in times of great uncertainty will also be daunting. The last two sections of the paper reflect on these topics.

2 Short Term Impacts of the COVID-19 Pandemic

Impacts of the pandemic on wildlife and biodiversity are propagated through economic pathways. Even the direct threat that the virus poses to the health of Great Apes and other species is the result of humans handling live animals and how we are spreading the disease (Kazi et al. 2020; Chandrashekar et al. 2020; Gibbons 2020; CBSNews 2020). On a macroeconomic scale, the global economic slowdown has decreased the demand for many industrially produced commodities and thus reduced direct extractive pressures on the environment. However, the net effects at the local level must account for the myriad of complementarities and substitution possibilities related to the deployment of labor effort, consumption decisions, or the intertemporal tradeoffs inherent to the timing of investments in productive assets, human capital or savings.

As such, we organize the short term impacts around what may be described loosely as the components of a dynamic general equilibrium bioeconomic model of a small open economy subject to stochastic shocks (Conrad and Rondeau 2020). This structure, in which a local economy obtains products and services from natural capital, is easily reconciled with the direct and indirect drivers of biodiversity loss identified by the Millenium Ecosystem Assessment (2005). The study of such complex systems tells us that even

seemingly small short-lived perturbations can produce dramatic changes in future outcomes (Ngonghala et al. 2014). Thus, the import of the list of short term impacts lies not in keeping a score of positive and negative short term effects, but rather, in recognizing that the pandemic sums up to a multi-pronged, system-wide series of correlated shocks.

2.1 Impacts on the Productive Capacity of Households

2.1.1 Disease Burden

COVID-19 is a new addition to the disease burden of rural households. At the time of writing, the case incidence is still rapidly increasing in biodiversity-rich Africa, Latin America and on the Indian sub-continent (Bruce-Lockhart, Anna 2020). The disease incapacitates productive adults and causes excess mortality, reducing household income. Wardens and conservation officers are affected, reducing conservation work and enforcement against illegal resource extraction (International Fund for Animal Welfare 2020).

2.1.2 Significant Change to Production Conditions

- Rhinoceros and elephant poaching syndicates have expanded operations into areas where there are normally too many wildlife-viewing tourists for them to operate undetected (Save The Rhino Foundation 2020; Sishi and Cocks 2020). The sudden absence of tourists has also been cited as a factor in poaching incidents in India (Karmakar 2020) and to explain a surge in illegal logging in Tunisia (Foroudi 2020). The absence of tourists effectively modifies the production function of poachers by opening more territory and increasing the available stock of the target resource. A general increase in labor availability is also a likely contributing factor.
- Finding themselves without income, millions of migrant workers (international and internal) have returned to rural areas throughout the developing world (Kinetz 2020; Ellis-Petersen and Chaurasia 2020; Bank 2020; Chávez Yacila and Turkewitz 2020; Chulov M and Safi M 2020). This arrival increases the total amount of labor time available in local resource-dependent economies. It also increases the local demand for food and other needs. The World Bank warns that many returning migrants will fall into poverty and threaten food security in their home villages (Kray and Shetty 2020).

2.1.3 Demand/Price Shocks for Households as Producers

The rapid onset of a global recession has affected the demand for many goods exported by resource rich developing countries. Drops in demand reduce prices and production, constrain the sectors of activity that local workers can engage in, and lower wage income.

- A sharp decline in the demand for natural resources commodities (US Energy Information Administration 2020) resulted in a significant drop in prices. The Bank of Canada's Commodity Price Index declined by 41% between January and April (Bank of Canada 2020). U.S. crude oil prices even went negative for the first time in history (BBC News 2020).
- Early reporting by the U.N. Food and Agriculture Organization paints a complex set of impacts to the world fisheries (FAO 2020). The demand for fresh fish has been volatile but generally down. On the other hand, consumer demand for canned goods was up

significantly in the early days of the pandemic. Worldwide, high seas commercial fisheries landings were down 6.5% but small scale fisheries were most seriously disrupted by the closure of fresh food markets. Some countries have experienced very different impacts. In Peru for instance (the world's largest producer of fishmeal), commercial fishing effort dropped by 80% after the announcement of self-isolation rules despite fishing being excluded from mandatory lockdowns (Arony 2020). The FAO indicates that the pandemic threatens to make women, migrant fishers and fish workers economically vulnerable.

- By the end of April 2020, all countries had put in place travel restrictions and domestic lock-down orders, effectively halting all tourism (United Nations World Tourism Organisation 2020; Airports Council International 2020). The prospect of a prolonged loss of income from nature and wildlife tourism threatens to undo decades of development work aimed at creating sustainable community-based conservation strategies. Developing countries with biodiversity hotspots are left particularly vulnerable. Nature-based tourism represents more than 10% of the economies of Kenya, Tanzania, South Africa, and Namibia. Nineteen small island nations derive more than 20% of their GDP directly from tourism, where the main attractions are beaches and reef-based activities (Coke-Hamilton, Pamela 2020).
- Direct tourism fees are the primary source of funding for national parks and reserves in most developing countries ($142 million in Africa alone in 2013 according to the World Tourism Organization (2015). The sudden loss of revenue forced the layoff of wardens and rangers in Zimbabwe and other countries (International Fund for Animal Welfare 2020).
- Lockdown measures have created financial emergencies at zoos and wildlife rehabilitation centers, resulting in layoffs of caretakers and further endangering species like the Orangutan of Borneo (Gokkon, Basten 2020; CTVNews 2020).
- The pandemic has bolstered the demand for Traditional Chinese Medicine (TCM). In particular, the Chinese government has endorsed the use of dried bear bile for COVID-19 (The Economist 2020). No claim is made by Chinese authorities that TCM ingredients have therapeutic value but widespread beliefs in their properties are shifting demand upwards. For suppliers of TCM, increased demand/price makes their production more attractive.[2]

2.1.4 Disruptions of Institutions and Supply Chains

The combination of illnesses, border closures, lockdowns and other policies has resulted in disruptions to trade relationships and markets, shifting the conditions under which producers operate and affecting the relative marginal value of labor in different sectors. As previously mentioned, lockdown orders and self-distancing rules have made it difficult for small scale fishers to sell their fresh catch. In addition, a variety of bans and restrictions on wildlife trade (with exceptions for TCM) have been imposed in China since the onset of the pandemic. These policies directly affect the economics of bushmeat hunting and trade and may shift consumer preferences over time.

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[2] Captive bears are commercially reared for bile in China but wild bears are regularly poached around the world for their gallbladder. In 2009 the price of dried bear bile was estimated to be US$400,000/kg on the North American black market (Kim 2009).

2.1.5 Impacts on Households as Consumers

All disruptions impacting the ability of households to produce and generate income feed directly into their budget, endogenously modifying immediate demand within the local economy. Also disrupted are their ability to save and invest in lasting capital like education or farming equipment, with repercussions on the long term dynamics of bioeconomic systems.

One potentially very significant shock to rural economies and resources is a dramatic fall in remittances sent home from migrant workers. The World Bank projects that international remittances will fall by 20% in 2020. For the world's fifteen low or middle income countries designated as megadiverse (UNEP 2020), pre-pandemic remittances averaged 2.1% of GDP (World Bank 2020a, f). For them, the expected shortfall for the year exceeds $50 billion. Remittances originating from within a country are not accounted for in these statistics but should also be expected to decline, further reducing household income.

3 A Broader View of Shocks and Biodiversity

This section has two objectives. First, we step back from the specifics of the current pandemic to situate it and the long list of short term impacts in the broader context of different risks faced by households in biodiversity-rich countries. This includes other disease outbreaks, natural disasters, armed conflicts, major political crises as well as recessions and financial crises. Second, we briefly explore what can be learned from the literature by studying the links between past random events in these categories, household responses, and impacts on nature and biodiversity.

3.1 Random Shocks You Can Count On

Poor households at the interface of nature are not strangers to negative income shocks. In a series of detailed surveys, 64% of 7978 households in the rural areas of 24 developing countries reported suffering at least one negative income shock in the previous 12 months (Wunder et al. 2014). Common shocks included wage loss, crop failure, loss of livestock, other asset losses, serious illness, and death. Similarly, communities dependent on small-scale fisheries report that their vulnerability to diseases is one of the principal threats to their livelihood (Béné and Friend 2011; Mills et al. 2011).

Figure 1 presents a different perspective on risks aggregated at the national level for a sample of 15 developing countries designated as "megadiverse", and 6 others with "biodiversity hotspots" and a heavy reliance on ecotourism. These 21 countries are recognized as among the most biodiverse in the world, but the grouping remains a convenience sample standing in for a larger class of low to mid income biodiversity-rich countries. The NGO Conservation International identifies thirty-six biodiversity hotspots covering 2.4% of earth's surface and 43% of endemic animal species, overlapping with 142 nations (Conservation International 2020; Mittermeier et al. 2011). "Megadiverse country" is a formal designation recognized by the United Nations and given to the top 17 most biodiverse nations of the world (UNEP 2020). Together, megadiverse countries hold more than two thirds of
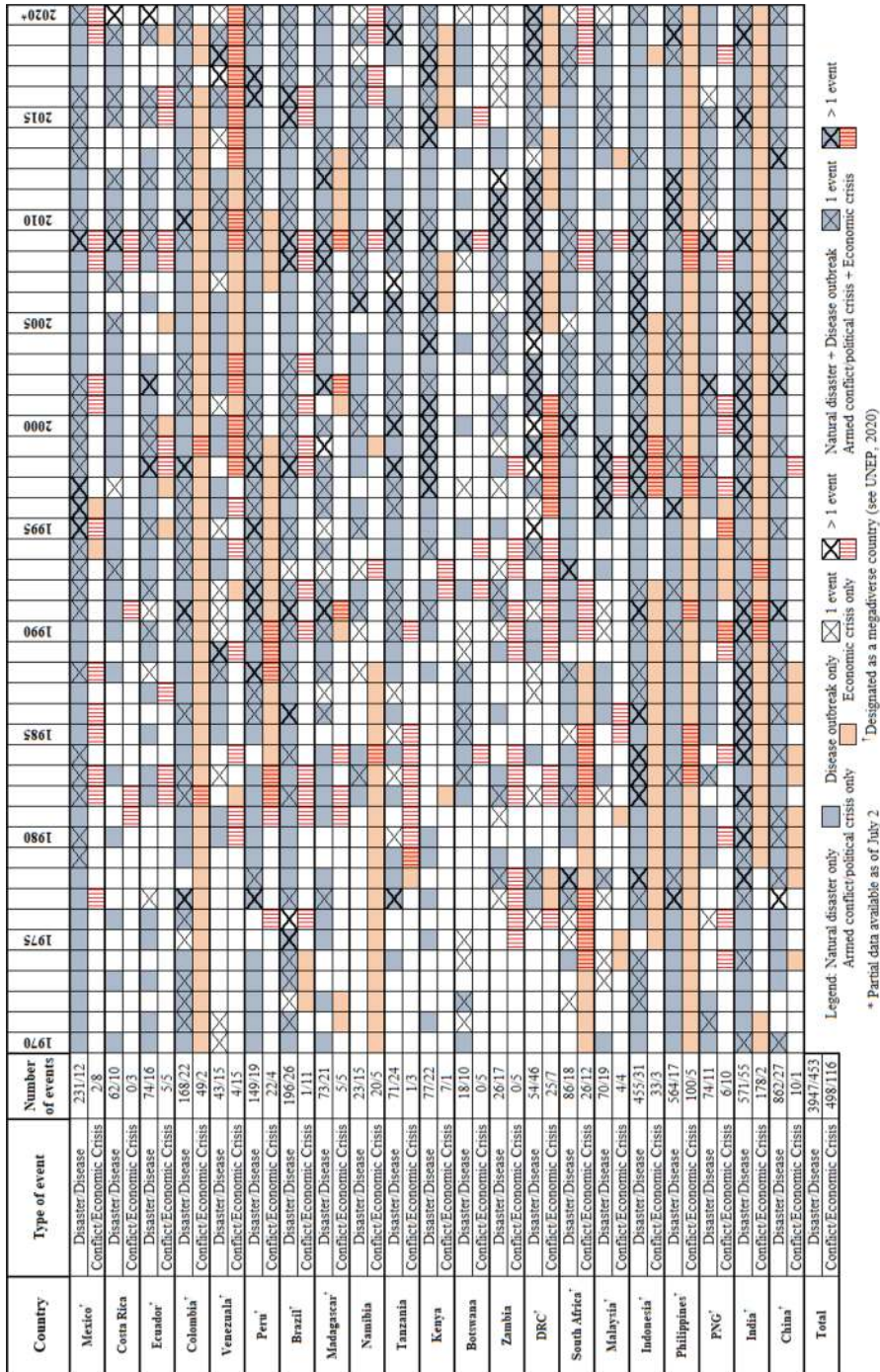
Fig. 1 Shocks in a sample of biodiversity-rich developing countries—1970–2020

all non-fish invertebrate species and three quarters of all plant species. Only the USA and Australia have developed economies and they are omitted from the list for this reason.

Each country in Fig. 1 has two rows presenting data in a time sequence. The first row reports occurrences of natural disasters and disease outbreaks. In a country-year cell, the background is shaded if one or more natural disaster were recorded that year. The cell is also marked by a "X" or "**X**" if one or more disease outbreaks occurred respectively. The second row reports occurrences of armed conflicts/political crises (shaded cells) and economic/financial crises (red vertical line pattern). An event that spans multiple years is recorded for its entire duration in the grid but counted only once in the total tally of events.

The data set underlying Fig. 1 was assembled for this paper and remains preliminary. Although we took a systematic approach, it is not yet fully validated nor ready for formal statistical or econometric analysis. Thus, we introduce Fig. 1 as a synopsis of the data to convey the extent to which human populations in biodiverse countries of the global South are subjected to negative random shocks.[3]

Over the period 1970–2020, we record a total of 5014 events. By far the most common type of events is natural disasters (3947 events). These include droughts, floods, extreme temperatures, insect infestations, landslides, earthquakes, volcanic activity, and wildfires. An event is included in the source data (the EM-DAT database) if it resulted in 10 or more deaths or if 100 or more people were affected/injured or made homeless. On average, a country experienced 3.8 natural disasters per year. Half of all natural disasters affected more than 10,000 people, and of the 419 events affecting more than one million people, 40% were caused by floods, 28% by tropical cyclones, and 19% by drought.

With 498 events, armed conflicts and major political crises are the next most numerous. Armed conflicts took place at some point in 18 of the 21 countries in the sample. A conflict is included when more than 25 battle deaths have been recorded (Pettersson et al. 2019; Gleditsch et al. 2002). Major political crises such as the ongoing crisis in Venezuela are

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[3] Data on natural disasters come from the EM-DAT database (Guha-Sapir 2018) and cover earthquakes, extreme temperatures (heat wave, cold wave, severe winter conditions), flooding events, insect infestations, landslides, storms (tropical cyclones, convective storms), volcanic activity, and wildfires. Primary sources for disease outbreaks are the WHO disease outbreak news bulletin (WHO 2020a), the EM-DAT database (Guha-Sapir 2018), and academic sources. Epidemics and outbreaks of endemic diseases were considered: dengue and dengue hemorrhagic fever, malaria, chikungunya, cholera, yellow fever, Zika [and outbreaks of diseases associated with Zika, Guillain-Barré syndrome and microcephaly (Méndez et al. 2017), Oropouche virus, Marburg virus, typhoid fever, meningococcal disease, diphtheria, smallpox, poliomyelitis, bubonic and pneumonic plague, Ebola and Ebola haemorrhagic fever, Rift Valley fever, Nipah virus, anthrax, hepatitis E, A, B, influenzas [A(H1N1), Asian HPAI A(H5N1), A(H3N2), A(H7N9), B, and myxovirus B], acute respiratory syndrome and SARS, acute neurological syndrome, acute jaundice syndrome, dysentery, Clostridium difficile, gastroenteritis, Schistosoma, listeriosis, leptospirosis, septicaemia, encephalitis, visceral leishmaniasis (Kala-Azar), and COVID-19. Unnamed disease epidemics from the EM-DAT database are also included. Childhood diseases such as measles, rubella, and pediatric diarrheal diseases are not reported, even though they can negatively impact household production. Specific outbreaks of endemic diseases with a heavy disease burden, like malaria, dengue, and cholera are included when the event is referenced in the literature. All sources comply with the general principle that an outbreak of an endemic disease is significant when the case incidence is noticeably above baseline levels. Disease outbreaks with fewer than 40 cases were excluded if the fatality rate was less than 10%. Annually recurrent disease epidemics of up to 10 calendar years were included and counted as a single event in the category totals. As chronic disease, HIV/AIDS excluded. Economic crises include banking, currency, and debt crises, as well as years of negative real GDP growth as reported by the IMF (Kose 2015; IMF. 2020) or the OECD (OECD 2020). Data on armed conflicts come primarily from the UCDP/PRIO Armed Conflict Dataset version 20.1 (Pettersson and Öberg 2020; Gleditsch et al. 2002).

only counted when they have been broadly recognized as having destabilized a country's political and economic systems.

The criterion for including epidemics and disease outbreaks in our data is somewhat less precise. This owes to variations in definitions used by different reporting agencies and research groups. An additional complication comes from the fact that a majority of the 453 disease outbreaks reported Fig. 1 involve endemic diseases such as malaria and denge. Figure 1 does not report endemic diseases per say, but it does include notable outbreaks documented in the literature as events where the incidence of cases significantly exceeded a country's normal baseline level (WHO 2020b). In the case of malaria, for instance, El Niño years are often associated with significantly higher prevalence, leading health agencies and researchers to declare outbreaks (Gagnon et al. 2002). We include these events when experts have determined that they are distinguishable from the usual prevalence of a disease.

Finally, we count 116 instances of economic recessions or financial crises as determined by the OECD or IMF. Most countries in the sample suffered from the 1982 economic recession. Latin America was most affected, leading to the 1980s being dubbed the "lost decade" (Kose 2015). The 1997 Asian financial crisis also reverberated throughout Latin America and Africa (Monitor and Outlook 1998). The 2008–2009 global recession affected half of the sample.

It is worth noting that natural disasters often spark disease outbreaks (Kouadio et al. 2012) and may also lead to conflicts or economic crises. Hence, one should expect that the data harbor some degree of correlation between risk categories, and indeed, that in some cases, there exists a causal relationship between them.[4]

How will the incomplete data look by the end of the year (or in the next few years)? With continued exponential growth of COVID-19 cases across the developing world, all countries in the sample will have suffered a national level epidemic. Second, all countries (possibly with the exception of China) are expected to fall into recession. At no time has this happened in the previous 50 years. Finally, natural disasters and other crises will continue to occur. Unsurprisingly, this paints 2020 as an exceptional year at the country level, leaving us no empirical basis to fully predict the compounding effects of so much disruption. Yet, studies of the impacts of each of the four categories of shocks presented in Fig. 1 remain useful to discern general patterns.

3.2 Responses to Shocks in Bioeconomic Systems

3.2.1 Diseases

It is well documented that cumulative disease burden plays a direct role in the creation and maintenance of poverty traps, and hinders the economic growth of poor countries (Ngonghala et al. 2014; Bloom et al. 1998; Bleakley 2007; Hibbs and Olsson 2004; Sachs and Malaney 2002). Households in low to mid-income biodiverse countries already

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[4] It would be incorrect to think of the events reported in Fig. 1 as independent and identically distributed random shocks. It would be more appropriate to think of the stochastic process in terms of the random arrival rate of any type of event over time, perhaps allowing for conditional probabilities of arrival linking one type of event to another. For instance, a flood may occur with probability x per unit of time, and the baseline arrival rate of cholera might be y per unit of time, but where the probability of an outbreak of cholera increases to $z > y$ once a flood has been observed.

contend with high rates of morbidity and mortality from diseases such as malaria, HIV/AIDS, tuberculosis and a long list of other tropical diseases (Mathers and Loncar 2006).

Even though HIV/AIDS is not included in Fig. 1, its documented impacts on conservation are nearly identical to the short term observations made above for COVID-19: increased poaching and use of natural medicines, increased illness and death of park rangers and conservation workers, and diversion of public funds away from conservation efforts (Rija et al. 2013). At the household level, diseases contribute to food insecurity and reliance on natural resources (Yager et al. 2011). For example, Völker and Waibel (2010) find that health shocks increase the likelihood of forest production by rural households in Vietnam; and McSweeney (2004) reports that indigenous households in Honduras are more likely to sell forest products when afflicted by illness, but less likely following a death or during a long-lasting sickness.

Epidemics also scare visitors away. The World Travel and Tourism Council (2020) estimates the worldwide economic impact of H1N1 on global tourism at US$55 billion. The SARS outbreak imposed losses $30-50 billion on the four affected countries. The Ebola epidemic reduced tourism to East Africa for over two years after the epidemic was declared over, and even affected countries that did not record any infections (Novelli et al. 2018). It took between 10 and 19 months after the end of these epidemics for the number of visitors to return to normal. COVID-19 may continue to scare away tourists from nature destinations for some time, but continued travel restrictions and the possibility that travel insurance may not cover COVID-19 treatment pose new hurdles to the recovery of nature-based tourism.

3.2.2 Economic and Financial Crises

Evidence of the impact of the 2008–2009 recession on biodiversity comes from individual case studies. They point to a reallocation of labor towards natural resource extraction across a broad spectrum of countries and locations: increased illegal shellfish harvesting in Spain (Ballesteros and Rodríguez-Rodríguez 2019); reversion to poaching and slash and burn forestry in Cameroon (Sayer et al. 2012); and a tripling of the rate deforestation due to artisanal gold mining in the Amazon (Asner et al. 2013).

World Bank data show that remittances declined by 5.2% during the 2008–2009 recession (Sirkeci et al. 2012) (roughly one fourth the expected decrease attributable to the pandemic). The decrease in transfers seriously affected food security in Nepal (Tiwari and Joshi 2012). In Mexico, households with lower levels of remittances were more likely to depend on natural resource extraction and other environmental income (López-Feldman and Chávez 2017).

3.2.3 Armed Conflicts/Political Crises

The study of armed conflicts is particularly pertinent to the current situation because of the broad disruptions that they impose. Banerjee and Duflo (2020) recently compared the pandemic to a war. Over the period 1950-2000, 80% of armed conflicts around the world took place in areas classified as biodiversity hotspots (Hanson et al. 2009). Gaynor et al. (2016) reviews the impacts of 144 conflicts on conservation. They find predominantly negative effects on wildlife, habitat, and conservation. The behavior of households whose lives are disrupted by conflicts is found to be the primary source of impacts on the environment. The channels of impacts on wildlife parallel the short term effects of the pandemic: high

resource extraction, poaching and high bushmeat demand by displaced people; disruption of food supply networks; reduced household investments; and reduced ability of local governments and NGOs to manage conservation areas in the face of lost tourism revenue and international support. Similarly, major political crises in Latin America have contributed to poor rural governance and mass emigration, leading to higher rates of land clearance and resource extraction (Wolff 2007; Caraballo-Arias et al. 2018; Combaz 2020).

3.2.4 Natural Disasters

Small-scale farmers at the interface of nature are often affected by pests, floods and droughts. For instance, peasants in the Peruvian Amazon increase their reliance on forest resources, including upland cropping, fishing, and the harvesting of non-timber forest products following flooding events (Takasaki et al. 2004). Wunder et al. (2014) finds that only a minority of households in a panel of 23 biodiverse countries regularly rely on forests to fill seasonal periods of high labor availability and in response to external shocks. However, Noack et al. (2019) finds from the same data that the reallocation of effort towards extracting from common pool resources during periods of drought is nonetheless statistically significant.

The general conclusion that one may draw from the literature on household risk management and impact alleviation is that households try to maintain a diversified portfolio of income sources (agriculture, animal husbandry, wage income, natural resource extraction for home consumption or trading, the receipt of remittances from family members, etc.). Where feasible, households smooth their consumption over time, but the diversification of their income sources and consumption smoothing are hindered by incomplete markets and a lack of access to financial instruments such as crop insurance and personal credit. Households' responses to stochastic shocks do not always imply increased reliance on wildlife and nature, but it is a common coping strategy.

4 Research Opportunities and Challenge

In light of the number of risks that households in biodiverse countries must face, it might be tempting to see the COVID-19 pandemic as "just" another shock. It is perturbing households from their equilibrium behavior and they can be expected to absorb the negative shock with existing mitigation strategies. General wisdom from accumulated knowledge would then suggest that the pandemic will often result in increased reliance on natural resources, bringing with it the strong possibility of habitat loss, increased harvesting and heightened risks of biodiversity loss. However, the pandemic is not like other random events. For many nature-dependent economies, it disaggregates into a large number of disturbances to many economic variables and functions. This brings many research opportunities but also poses some difficult challenges.

- Insofar as the pandemic is a unique event, it raises research questions that could not be answered until now. How does a complete shutdown of wildlife tourism change a local community's attitude towards community-based conservation programs? What is the value of the protection afforded to wildlife by the presence of visitors to protected areas? Will prohibiting the trade in wildlife in China be effective at reducing harvesting, change consumer preferences or limit the risks of zoonotic diseases? How does

the sudden return of migrant workers to rural areas modify household's labor allocation strategies? How does it affect the ability of local communities to resolve resource conflicts? Each of the short term impacts listed in Sect. 2 generates many new research opportunities.

- The multiplicity of impacts will make it challenging for many modeling exercises. For instance, if many parts of a household's portfolio of activities is affected, the standard *ceteris paribus* assumption of partial analysis will no longer be tenable and a general equilibrium approach may be required to analyze households' decisions. At a micro level, households may decide or be forced to completely modify their decision-making process, adopt new parameters (e.g. rate of time preferences) or entirely new strategies (Barrett and Carter 2013; Singh et al. 1986). In addition, many empirical challenges will arise. The simultaneity of shocks brings endogeneity issues, for instance, and no obvious identification strategy may satisfactorily determine causality. Time-series data may no longer exhibit standard assumptions (e.g. ergodicity, stationarity). It will also take some time to establish which impacts of the pandemic are purely transitory (e.g. will all migrant workers eventually returning to cities), and which ones are permanent (e.g. change in preferences for bushmeat following trade bans).

- If we admit the possibility that the pandemic is causing permanent changes to key components of bioeconomic systems, we must also face the reality that many results from past research have become inherently less reliable for modeling, forecasting and policy design. As we often rely on accumulated knowledge, it will be necessary to better assess the relevance and validity of past assumptions and acknowledge that many of our future results will be subject to greater margins of error.

- The value of simply redoing past empirical studies has suddenly gone up since previous results may now be obsolete. The down side of this is that it will be much more difficult for our discipline to demonstrate the replicability of our empirical work (Ferraro and Shukla 2020). Where new results differ from previous ones, it might not be possible to ascertain whether the differences are attributable to actual changes resulting from the pandemic or to a methodological failure.

- While it might be easiest to deploy existing methods, there is also room, and perhaps a need, for bold new experimentation. For instance, the possibility that a package of policies may work better than individual ones in breaking the vicious circle between poverty and environmental degradation in different settings could be analyzed using a multiple-setting-multiple-country set up similar to the approach deployed by Banerjee et al. (2015) to study multifaceted programs to alleviate poverty. It would be useful, for instance, to better understand how cash transfers to rural households modify wildlife hunting effort and to compare this to various combinations of general cash transfers, conservation payments, wildlife conflict alleviation payments or individual job training/skills development. Randomized Control Trials in a particular region would enable an assessment of treatment effects and scaling these up to apply a standardized research protocol across different regions or countries would allow better comparative studies and accelerate learning. Further extending the approach to different natural resources (eg. wildlife harvesting vs. artisanal fisheries) may then reveal the extent to which the fundamental properties of certain mechanisms are robust across space and settings. A similar coordinated approach could be adopted to deploy micro-level field experiments, to study behavioral responses and collect survey data in conjunction with biological assessments of the state of local natural resources.

- Another valuable initiative would be to establish new longitudinal studies. Existing longitudinal studies such as the World Bank's Living Standards Measurement Surveys

(World Bank 2020d) work by CGIAR (CGIAR 2020) and ICRISAT (ICRISAT 2020) should soon detect some of the effects of the pandemic. Unfortunately, the countries and variables covered yield insufficient detail to study interactions between household decisions and surrounding natural resources, and little or none on the state of those resources. New panel data collections that cover natural resource use in detail and that also contain data on the state of natural assets would make it possible to monitor the evolution of complex systems over time, test for stability of parameters, monitor the emergence of poverty traps on environmental indicators, and much more. Adjusting ongoing data collections or creating large new ones would require concerted efforts and take a long time to bear fruits. The professional criteria that we use to define academic success do not properly incentivize such long term endeavors. This militates in favor of organizing a large consortium of economists and scientists in collaboration with an international agency that can ensure continuity and house the data in the public domain.

5 Policy Challenges and Opportunities

Part of the current public discourse on COVID-19 expresses a strong desire to "return to normal". Indeed, there is a need to reestablish pre-pandemic economic conditions. It is also necessary to resume local development efforts, research projects and community-based conservation initiatives. The resumption of anti-poaching efforts, a renewed commitment to fisheries monitoring, and enforcement of illegal logging statutes are all areas where resumption of pre-pandemic activities could help reduce pressure on wildlife and biodiversity.

However, given the depth of the crisis, it would be optimistic to think that returning to business as usual will be sufficient to meet the challenges ahead. Tweaking existing policies at the margin will remain helpful but it is not likely to allow rural households to meet their current and future needs without further degrading natural assets. Besides, the trajectory of many (if not most) bioeconomic systems in the pre-pandemic "normal" was already compromising ecological functions, reducing wildlife and fish stocks, and threatening livelihoods. The harsh reality remains that little can prevent habitat destruction and biodiversity loss if the fundamentals of poverty and food insecurity are not addressed, and if better alternatives are not available for local populations.

To that effect, there is an emerging chorus of voices calling to seize this moment in history to husher in transformational policies aimed at alleviating both poverty (Banerjee and Duflo 2020) and environmental degradation (Stiglitz 2020). In the short run, Banerjee and Duflo (2020) and Ravallion (2020) call for a rapid and forward-looking response, as the pandemic creates war-like conditions demanding a large fiscal response. It is encouraging that large expansionary fiscal and credit policies have been advocated for developing countries and that international institutions have pledged to support their administration (World Bank 2020c). The short-run objectives should be to maintain or restore the food purchasing power of poor households through in-kind or cash transfers delivered on a large scale. Cash transfers may be preferable, but food aid may be more effective in areas where economic activity has been drastically reduced by lockdowns, or where local disruptions of the food supply from the virus or natural disasters compound the severity of the pandemic. The locust plague currently devastating East Africa is a prime example. Where food is in short

supply, cash could only increase the price of available products and encourage bushmeat hunting.

Many countries already have safety nets such as workfare or cash transfers (Ravallion 2016). Existing systems can be improved and made available to greater segments of the population. Enhancements could also specifically target regions with specific biodiversity conservation goals. Deploying conservation payments linked to specific conservation indicators (e.g. number of wild animal carcasses counted at local markets, hectares of uncleared forest, etc.), or to the adoption of given technologies (e.g. species-specific fishing gear to avoid by-catch) are opportunities to support local populations and simultaneously promoet better resource stewardship.

For the longer term, policies that reduce the economic uncertainty faced by households, lower their risk-adjusted discount rate, and allow them to more efficiently invest in longer term economic strategies must be considered. This can be accomplished with generalized income support programs but also via more targeted approaches like crop insurance, investments in improved farming techniques, general economic diversification and achieving higher educational attainment.

However, because the loss of biodiversity is a decentralized problem with global ramifications, slowing the rate of decline will remain difficult without a much stronger commitment to international cooperation. Strengthening the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the International Whaling Commission, addressing climate change, and developing more stringent agreements to monitor illegal fishing and regulate landings from fisheries that operate in international waters are all key to making progress. It may be difficult to be optimistic about the prospects of greater international coordination and cooperation, but existing agreements and new initiatives like the FAO's multi-stakeholders framework for eradicating poverty in small scale fisheries (FAO 2015) provide the basis for action.

There is perhaps one transformational approach to policy making that would only require deploying basic economic principles. Nations around the world continue to directly and indirectly subsidize natural resource exploration, extraction, land conversion and other activities harmful to biodiversity, with a welfare cost estimated in the trillions of dollars annually (United Nations 2020; Coady et al. 2019; van Beers and van den Bergh 2001). A serious commitment by national governments and international organizations to stop subsidizing activities that generate negative externalities would follow basic principles of efficiency, but could also deeply reshape our impact on nature (Stiglitz 2020). Properly taxing externalities and subsidizing economic activities that produce positive externalities sounds basic because, after all, it is. We must remain mindful of the fact that any change to complex dynamic bioeconomic systems can have deep, unintended and lasting impacts. However, if the COVID-19 pandemic spurs governments to rethink fiscal and international organizations to reorient aid dollars away from ecologically harmful subsidies, then perhaps the pandemic will have served one positive purpose.

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