Biological Conservation 248 (2020) 108665

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Policy analysis

COVID-19 pandemic and associated lockdown as a “Global Human Confinement Experiment” to investigate biodiversity conservation

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ARTICLE INFO

Keywords:
Human impacts
Sustainability
COVID-19
Protected areas
Wildlife

ABSTRACT

Efforts to curtail the spread of the novel coronavirus (*SARS*-CoV2) have led to the unprecedented concurrent confinement of nearly two-thirds of the global population. The large human lockdown and its eventual relaxation can be viewed as a *Global Human Confinement Experiment*. This experiment is a unique opportunity to identify positive and negative effects of human presence and mobility on a range of natural systems, including wildlife, and protected areas, and to study processes regulating biodiversity and ecosystems. We encourage ecologists, environmental scientists, and resource managers to contribute their observations to efforts aiming to build comprehensive global understanding based on multiple data streams, including anecdotal observations, systematic assessments and quantitative monitoring. We argue that the collective power of combining diverse data will transcend the limited value of the individual data sets and produce unexpected insights. We can also consider the confinement experiment as a “stress test” to evaluate the strengths and weaknesses in the adequacy of existing networks to detect human impacts on natural systems. Doing so will provide evidence for the value of the conservation strategies that are presently in place, and create future networks, observatories and policies that are more adept in protecting biological diversity across the world.

1. Introduction

Remarkable human mobility distinguishes the modern globalized world. Daily, seasonal and long-term migratory fluxes involving billions of humans along with goods valued at US $15 Trillion per year (as of 2019, wto.org) are transported by land, sea, air and below-ground systems. Smart phones, fitted with GPS, have documented modern networks of human mobility, including high levels of travel between regional, national, and international hubs (Bajardi et al., 2011; Hawelka et al., 2014; Belyi et al., 2017; Meekan et al., 2016). Likewise, the advent of Automatic Identification Systems (AIS) and other tracking systems have allowed shipping networks to be described and tracked (Sequeira et al., 2019). The extraordinarily diverse and pervasive transport and economic linkages on Earth connect geographically distant places through socio-economic pathways, and impact natural systems, wildlife, protected areas and the climate system at multiple scales. The effects arising from distant connections and local impacts can have surprising and significant implications for sustainability and our ability to protect biological diversity (e.g., Holland et al., 2015; Hull and Liu, 2018).

The massive local, regional, and international movement of people in a global world also presents a new challenge for humanity - the rapid and encompassing development of epidemics (Bajardi et al., 2011; Eshraghian et al., 2020). In just two months, SARS-CoV-2 spread across the world from the locus of origin in Wuhan (China) infecting approximately 5 million humans by May 20, 2020 (WHO.int). As the virus propagated, interventions to confine human populations and slowdown the rate of epidemic spread were implemented, leading to an estimated maximum 4.4 billion people (57% of the global population) subject to a partial or full lockdown on April 5, 2020 (Fig. 1). In countries with strong lockdown measures, such as Italy, local travel was reduced by more than half (Pepe et al., 2020). Even programs to reactivate the economy announced by different nations still include many restrictions on mobility both nationally and internationally, such as social distancing on trains, buses, and planes, and quarantines following travel. Long-distance travel, such as ecotourism to visit national

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https://doi.org/10.1016/j.biocon.2020.108665
Received 26 May 2020; Received in revised form 3 June 2020; Accepted 5 June 2020
Available online 10 June 2020
0006-3207/

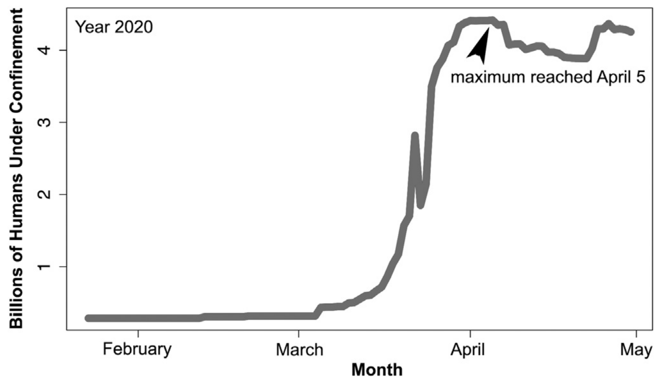

Fig. 1. Time series of the number of humans under confinement across the global population under the 2020 COVID-19 mitigation policies. Data on government responses to COVID-19 across countries and time were retrieved from the Oxford COVID-19 Government Response Tracker (Hale et al., 2020), which also reports where the restrictions on internal movement apply to the whole or part of the country. The global population under confinement of internal movement was calculated by adding up the population of countries where the restriction is general, and 20% of the population of countries where the restriction is targeted, as an estimate of the fraction of the population affected. Population data by country corresponding to year 2020 have been obtained from the Population Division of the Department of Economic and Social Affairs of the United Nations (UN, 2018, https://www.un.org/en/development/desa/population/publications/database/index.asp). Note that the data about restrictions contain missing information for some countries and dates. Therefore, the calculated number of human confinement does not take into account the population of countries with missing information and may thus underestimate the actual number of humans under restriction.

parks in other countries, is likely to be affected for many months or even years (Bakar and Rosbi, 2020).

Enforced confinement and the resulting shifts in human mobility patterns are altering all aspects of society (e.g., Chakraborty and Maity, 2020) and provide an unexpected opportunity to examine feedbacks in coupled human and natural systems (Liu et al., 2007). We could even consider this as an unplanned and unprecedented Global Human Confinement Experiment, in which restrictions on human mobility were abruptly enforced followed by a gradual return to normal levels of activity lasting many months or years. Initial, informal findings point to complex direct and indirect pathways linking shifts in human presence and activity to both positive and negative outcomes for biodiversity and conservation (Corlett et al., 2020; Rutz et al., 2020; Pearson et al., 2020), with potential for cascading flows and feedbacks.

Unprecedented concurrent confinement of humans provides a unique opportunity to identify the effects of human presence on natural systems and wildlife, and to advance our understanding and practice of conservation biology. We advocate approaches that will allow scientists to fully identify the resources needed to investigate the negative and positive effects resulting from the Global Human Confinement Experiment and its subsequent relaxation. First, we propose likely effects of human mobility and activity on biodiversity across scales and biomes and identify feedbacks and cascading processes affecting this relationship. Second, we describe possible data streams and methods (anecdotal observations, systematic assessments, and quantitative data from monitoring programs) that can combine to promote knowledge generation from collection of diverse observations before, during and after the lockdown. Third, the pandemic has spread faster than the typical responses of research proposal and funding cycles. Addressing the impacts of the global human confinements therefore largely depends on the robustness of existing observation and monitoring programs. The confinement experiment can also be considered a "*stress test*" of the strengths and gaps in the observation systems currently in place to detect responses to disruptive events in natural systems, protected areas and conservation programs. The insights gained from this unplanned experiment will therefore inform strategies to promote biodiversity conservation and mitigate climate change that would

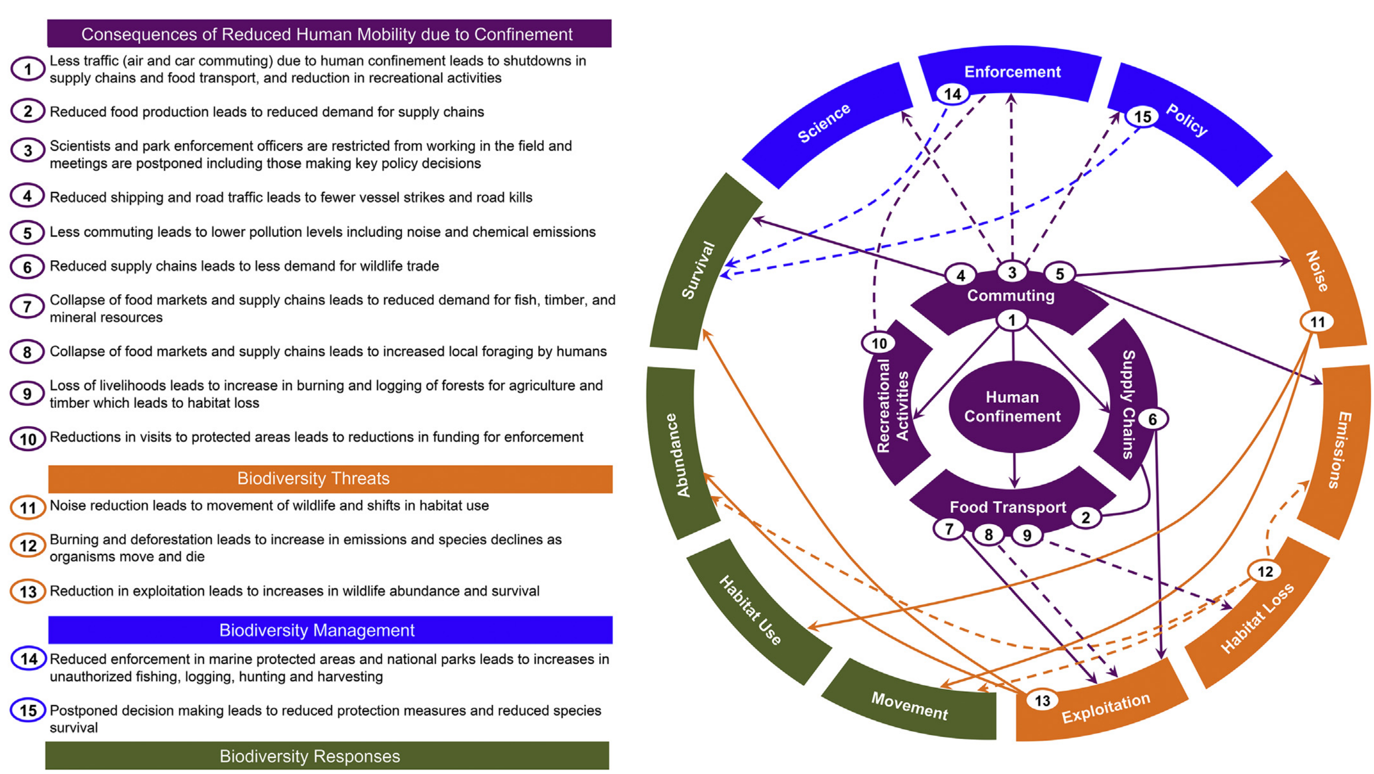

Fig. 2. Emerging examples of cascading effects arising from the large-scale confinement of humans. Effects are positive (solid line) or negative (dotted line) where color identifies the causal mechanism of the proposed change, and the arrowhead indicates directionality. Numbers identify examples (legend) of proposed interactions.

otherwise go undetected.

2. Hypothesized effects of human mobility on biodiversity

The Global Human Confinement Experiment is revealing a suite of effects on wildlife and ecosystems that are directly related to human activities (Corlett et al., 2020; Rutz et al., 2020; Pearson et al., 2020). Many of these effects will be transient and vary across countries due to differences in how the lockdown was implemented and relaxed, and the associated socio-economic context. Yet the various scenarios together offer a collection of diverse evidence for fundamental linkages between humans and nature, and where large-scale societal change can benefit biodiversity conservation. Moreover, stoppages in programs to protect nature and subsequent negative effects provide strong support for the value of conservation strategies already in place.

2.1. Emerging positive and negative effects

Human confinement (*Human Confinement*: Fig. 2) resulted in reduced air, land and water travel (*Commuting*: Fig. 2), with some initial effects on biodiversity being positive. For example, in many places manufacturing and commercial exploitation of natural resources (e.g., fish and timber) subsequently decreased. As a result, air and water quality improved, noise pollution declined (Muhammad et al., 2020; Zambrano-Monserrate et al., 2020), and, in some places, the exploitation of natural resources declined. Most notably, daily global CO_2 emissions have abruptly decreased by 17% in the initial months of the lockdown (Le Quéré et al., 2020, *Emissions*: Fig. 2). Presumably fewer animals are being killed by strikes by ships and vehicles on roads (*Biodiversity Responses*: Fig. 2), and sightings of animals in areas otherwise under heavy human influence, such as harbors and cities, have been attributed to lowered pollution (e.g., *Noise*: Fig. 2) and human activities in protected areas. A decline in manufacturing, the service and retail industries (*Supply Chains*: Fig. 2, e.g., Gray, 2020) and the production and transport of food (*Food Transport*: Fig. 2) have led to reductions (in some cases) in logging activity, wildlife trade and commercial fishing. Some conservation effects of the global human confinement may be transient and disappear soon after confinement relaxes, while others may be long-lasting (Casale and Heppell, 2016), such as strong recruitment success of long-lived, endangered marine species. For instance, anecdotes suggest marked recruitment success of the critically endangered Olive Ridley sea turtles in India due to reduced human activity (fishing and vehicle traffic) on their nesting beaches (B.C. Choundry, pers. comm.).

Restrictions on human mobility are also creating negative direct and indirect impacts through changes to enforcement, science and policy (Fig. 2). Lack of mobility has exacerbated unemployment and economic insecurity, which may explain reports in remote and rural areas of increasing wildlife foraging, illegal fishing, habitat conversion for agriculture, and other resource extraction activities that support livelihoods but also pose biodiversity threats (Fig. 2, e.g., Buckley, 2020). For example, in certain tropical areas of the world, increased cutting and burning of forests is reducing habitat (*Habitat Loss*: Fig. 2). In many places, decreased conservation enforcement because of the pandemic lockdown is facilitaings poaching and illegal fishing (Buckley, 2020). Temporary declines in ecotourism to national parks and other protected areas (*Recreational Activities*: Fig. 2) may influence local revenue, park staffing and funding for anti-poaching and wildlife management programs (Buckley, 2020). In many areas, restoration projects have been postponed or may even be discontinued, which may result in a failure to reach conservation targets. Management programs to control pests may be suspended, leading to outbreaks. For example, the large-scale upsurge of desert locusts in the Greater Horn of Africa and Yemen are being attributed (in part) to the lockdown and the disruption of control efforts (Amir Ayali, pers. comm.), exacerbating food shortages for tens of millions of people and extensive environmental damage (FAO, 2020).

Progress in conservation science and policy platforms is also being impacted. Meetings where key policy agendas and ambitious conservation targets are being discussed, such as the Convention on Biological Diversity post-2020 targets and the 2020 UN Climate Change Conference (e.g., https://sdg.iisd.org/events/2020-un-climate-change-conference-unfccc-cop-26/), have been cancelled or postponed (Corlett et al., 2020). The negative impacts of the lockdown on the economy together with the shift of research funding to provide virus therapies are likely to significantly reduce funding for conservation research, education and restoration programs. Such shifting priorities creates problems for the launch of the UN Decades of Ocean Science (https://en.unesco.org/ocean-decade) and Ecosystem Restoration (https://www.decadeonrestoration.org) scheduled for 2021–2030, and may represent setbacks that impair progress to meet many of the UN Sustainable Development Goals.

2.2. Unexpected effects

While many positive and negative links from humans to nature are now being revealed as the lockdown progresses, research also needs to be open to serendipitous findings that highlight processes and responses that fall outside a priori expectations. For example, in certain areas of China, air quality remained poor even when total emissions were reduced due to local weather factors, such as atmospheric stagnation (Wang et al., 2020). Reduced energy demands have led to an excess of oil, with a growing volume of oil held in supertankers in harbors in the USA and Singapore, increasing the risks of oil spills. The dramatic increase in the use of single-use gloves, masks, gowns, and other plastic materials, enhanced by the suspension of many government bans on single-use plastics, is creating a risk for a surge in plastic waste (Klemeš et al., 2020).

Unexpected outcomes are also arising as humans shift where they spend their time. Many national parks have seen dramatic declines in the number of visitors or in many cases have closed completely, and many urban parks were temporarily closed. However, other unregulated green spaces have experienced dramatic increases in visitation by people living nearby with resulting environmental impacts, such as trampling of vegetation, erosion, widening of existing trails, and creating of new trails. Increased human usage in areas adjacent to urban centers, that have not typically been in the spotlight of previous conservation efforts, may inspire novel strategies to re-wild suburban land and marine ecosystems and enhance the exposure of urban populations to healthier ecosystems. This is much needed to increase appreciation for nature (Schwartz et al., 2019) and to counteract the increasing '*nature deficit disorder*' in which people lose contact with the natural world and adopt a pessimistic outlook on biological conservation (Louv, 2011). Moreover, studies in the field of conservation psychology, which focuses on reciprocal relationships between human and nature to encourage conservation actions (Saunders, 2003), may identify specific changes in how humans conceptualize conservation-related issues before and after the lockdown, such as trade in wild animals and the value of having nearby parks. Tracking how citizens' perceptions of the benefits of exposure to nature, and how environmental policies and institutions react following changes in the relationship between humans and nature forced during the lockdown should be prioritized. Doing so will reveal important connections between human wellbeing and exposure to nature that can lead to societal benefits, and illustrate changes in the attitudes of humans towards nature that may ultimately improve conservation and environmental outcomes.

3. Data streams and methods for detecting responses to shifts in human mobility

We suggest that the hypotheses proposed (Fig. 2) from the Global Human Confinement Experiment be investigated using all available data, from anecdotal to rigorous quantitative assessments, to document

Table 1
Examples of programs providing open data that can be used to assess the impacts of confinement on humans, biodiversity threats, and biodiversity responses. Some data streams are automated and available in near real-time, including from citizen science programs. However, there are only a few examples of data on human activities, and biodiversity threats and biodiversity responses that are available in real-time and at a global scale. Most data streams (across the physical, natural and social sciences) need to be collated from local and regional nodes, analyzed and interpreted before distribution and require strong networks, data pipelines and collaboration. For instance, there are global initiatives emerging where scientists are required to collaborate to understand the interplay of the Earth system across different scales during the COVID-19 outbreak using data from the world's major space agencies (https://covid19.spaceappschallenge.org/). This is also true for social media analyses, geo-located images, and collection of news reports.

Type	Response	Category	Realm	Source
Consequences of confinement to humans	Human mobility	Human mobility	All	Google[1]
Biodiversity threat	Air traffic	Climate change and pollution	All	OAG[2] Flightradar24[3]
Biodiversity threat	Land-based traffic	Climate change, pollution, wildlife interactions	Terrestrial	Mapbox[4]
Biodiversity threat	Ship traffic	Climate change, pollution, wildlife interactions	Marine	Vessel Finder[5] Marine Traffic[6] MariData[7]
Biodiversity threat	Air traffic emissions	Climate change and pollution	Terrestrial	Mapbox[8]
Biodiversity threat	NOx	Climate change and pollution	All	WIND[9] European Space Agency, Copernicus[10]
Biodiversity threat	Air quality index	Climate change and pollution	All	World's Air Pollution[11]
Biodiversity threat	CO2	Climate change and pollution	All	European Space Agency, Copernicus[10]
Biodiversity response	Species occurrence	Species distribution	All	eBird[12] iNaturalist[13]

[1] https://www.google.com/covid19/mobility
[2] https://www.oag.com/airline-schedules-flight-status-data-solutions
[3] https://www.flightradar24.com/commercial-services/data-services
[4] https://www.mapbox.com/traffic-data
[5] https://www.vesselfinder.com/historical-ais-data
[6] https://www.marinetraffic.com/en/p/ais-historical-data
[7] https://www.maridata.com/Default.aspx
[8] https://www.mapbox.com/data-products
[9] https://www.wind.com.cn/en
[10] https://www.copernicus.eu/en
[11] https://aqicn.org/data-platform/covid19/verify/f0ab42bf-06dd-4fd6-ac63-afcde71c059a
[12] https://ebird.org/home
[13] https://www.inaturalist.org

linkages between humans and nature. We are calling on ecologists, environmental scientists and managers to contribute their observations to facilitate the compilation of global data sets addressing all components of the chain of effects from human movement to species and ecosystems. Such an approach requires both traditional approaches, such as wildlife surveys, and modern approaches including remote sensing and citizen scientist networks, and analyses of complementary rather than single data streams including news reports (e.g., LEO Network: https://www.leonetwork.org). Real-time observational data can be obtained from satellites and access through online portals which provide open and rapid access to data products (Table 1), ocean observing platforms (Muller-Karger et al., 2018), networks of animal imaging and tracking devices (e.g., Börger et al., 2020, Rutz et al., 2020, www.bio-logging.net), collaborative citizen-science programs (Table 1), and other observation networks (such as in Fig. 1, Hale et al., 2020).

Various experimental approaches have the potential to investigate changing human impact on natural systems and biodiversity. For ongoing monitoring programs comparisons before and during the confinement period, or on similar time windows in previous unimpacted years, are possible and can provide insights on the immediate changes from the pre-confinement state. Continuing observations after the lockdown ends will distinguish persistent effects. If observations are unavailable prior to the start of the pandemic lockdown or for reference year(s), comparisons can be made during and after the lockdown (i.e., the reference is the post-confinement period). Spatial comparisons between areas impacted by the lockdown with unaffected sites may also detect effects if the reference areas are truly representative. While some countries have already relaxed constraints on local human activities, it will still be possible to gather data during the evolving relaxation period. This might be especially useful for investigating national parks and their species in developing countries while certain restrictions on international travel remain in place.

We further emphasize that the concerted observation effort should be extended beyond traditional empirical data streams to reveal new types of information. Impressions and anecdotes of changes in nature are documented in the social media space, especially Twitter, and citizen science programs, such as eBird and the National Phenology Network, as the general public participates, reports and reacts to changes occurring around them. Geo-located photographs and keyword analyses will provide a complementary understanding to empirical data collected through observation networks.

We therefore call on the research community to use the full range of available data sets to examine how the Global Human Confinement Experiment is affecting biodiversity, protected areas, and ecosystems. Additional approaches include implementing new observation activities if possible as the lockdown continues, and to develop partnerships to share information and data to maximize lessons derived from this disruptive event. Interdisciplinary projects joining the social and natural sciences may provide unexpected progress towards incorporating human dimensions in global change science and conservation (Castree, 2017).

4. Capacity of our global observation systems

The current situation provides a further opportunity that can be conceived as a "*stress test*" of the capacity of human and machine-based observation systems to investigate how the Global Human Confinement Experiment will affect natural systems (such as the pathways proposed in Fig. 2). Identifying opportunities, gaps and implications for monitoring networks related to biodiversity conservation should be prioritized.

Many automated and continuous observation programs based from space, land and the ocean have successfully identified changes in both social and natural systems related directly to the lockdown (Table 1). Vessel tracking systems (https://globalfishingwatch.org/) and networks of camera traps and bio-loggers (e.g., Muhammad et al., 2020) provide the opportunity for global analyses of activities of humans and animals, due to their finer scale of resolution. Certain pre-existing global networks have the potential to provide researchers with the data needed to detect the global impacts of the lockdown (e.g., GEO BON, https://geobon.org/ and MBON, https://geobon.org/bons/thematic-bon/mbon/, described in Muller-Karger et al., 2018) by facilitating rapid communication and dissemination of data across scientists from different regions. Even so, assessing the impacts of global human confinement will challenge the extent to which data are openly available and shared, as collating the multiple data streams required for this assessment requires access to data without embargo periods or complex manipulations. Relatively recent science-policy platforms that are global in scope, such as the International Panel on Biodiversity and Ecosystem Services (IPBES, https://ipbes.net), will provide a suitable outlet for assessments that arise from this period of confinement.

There are well-known limitations in our current observation networks, including less funding and observer capacity in developing countries and strong taxonomic bias in what is being observed which the present situation accentuates (Dornelas et al., 2018). To overcome some of these gaps we advocate for consideration of different data streams to produce multiple lines of evidence (such as by considering anecdotal information), but we will not be able to detect responses in systems that we are unable to observe given the limitations of the collective toolkit available (such as shifts in microbial communities). Such biases will compromise interpretation about lock down effects, and hopefully provide evidence that will improve future funding initiatives.

Several less intuitive lessons are also emerging which identify key limitations in our observing systems, and we explore three here. First, the lack of on personnel on the ground reminds us that the conservation community relies on humans collecting much of the raw data, servicing instruments, retrieving data from instruments, and transforming these data into products that are useful to others. Human-led fieldwork has been interrupted throughout the world, and entire field seasons are being missed. For instance, the global oceanographic and fisheries assessment fleets have been grounded, and research projects have been cancelled or disrupted. Citizens that contribute to citizen-based science programs, such as eBird and iNaturalist (Table 1), are no longer allowed to roam around nature in many nations, biasing where observations are reported. While programs that require personnel to operate equipment or take measurements have an obvious dependency on humans, what was not immediately obvious is that the same applies to autonomous sensing systems. Many automated instruments require periodic servicing and calibration, or downloading data to maintain functionality. Gaps and biases in data series will therefore be forever visible in 2020 due to multiple impacts on field-monitoring programs.

Second, our efforts to identify what data are available within short time frames illustrate a massive gap in the capacity for rapid data processing. In fact, the transformation of raw data to products that can be analyzed by non-experts may take months or even years due to difficulties in downloading, interpreting, and analyzing raw data products. Currently, we have found that very few global data products are available that can be used to rapidly assess the response of both humans and nature to the lockdown (Table 1). This issue is particularly acute for biodiversity observations (species identities and abundance), which are nearly impossible to obtain quickly at a global scale. Important exceptions include citizen science programs which crowd-source observations and automate the data entry and processing using mobile app technology (e.g., eBird and iNaturalist, Table 1). Our initial impressions suggest the lockdown will lead to the recognition that real-time data pipelines allowing on-going assessments are fundamental for dealing with crises and a goal that should be prioritized for the Anthropocene. Healthy data pipelines deliver relevant and up-to-date information so that during any future perturbations, decisions can be generated at the required timescales rather than after significant lags during which damage has already occurred.

Third, the type and resolution of data presently collected by many observing systems in place may fail to detect signatures of restricted human mobility on species, ecosystems, and protected areas. Many survey programs have not been designed to evaluate responses to short-term perturbations, and prioritize long-term data collection over finer time-scale resolution. For example, yearly sampling intervals are typical for the many biodiversity-based surveys that involve humans operating drones and cameras and carrying out field surveys to count species. An annual temporal grain is likely too broad to detect changes occurring over the scale of the several month duration of the Global Human Confinement Experiment. Such lockdown effects may be obscured by variation caused by other drivers, such as climatic variability and natural populations fluctuations, and may only be visible in the future when a number of years before and after this event can be compared.

5. Strong inference on the response of natural systems

Progress in science often comes from formulating critical hypothesis and designing crucial experiments (Platt, 1964). The Global Human Confinement Experiment represents a once-in-a-lifetime experiment to test crucial hypothesis on responses of species and ecosystems to human presence and movement at a global scale and to test which will be transient, and which will persist. We therefore have an unprecedented opportunity to deliver strong inference, replicated across space, of whether rapid shifts in human behavior can lead to profound and positive responses in natural systems (Cohen, 2020). The lockdown shows us that quantum leaps in human behavior and their impacts on the environment are possible. Taking advantage of this opportunity will provide greater understanding of the pathways through which humans interact with nature, and offer practical insights for protecting biodiversity and addressing climate change. Documenting the scale and speed of both changes in human mobility and behavior and biodiversity responses challenges the myth that large-scale societal change must be slow. In doing so, the confinement experiment has the potential to catalyze societal support to dramatically reduce CO_2 emissions, pollution, and disturbance of wildlife. The lockdown further identifies the critical components of societal structures that support resource management and conservation goals, such as the key role of personnel who implement law enforcement within parks, as well as the critical role of visitors to protected areas. These critical pathways illustrate how we can best maximize the potential for humans and biodiversity to coexist on Earth and achieve an agenda of sustainability.

Acknowledgements

We thank the PAN-Environment working group for providing initial discussions that lead to development of some of the ideas included herein. R.J. Command searched for example datasets included in Table 1. T. Bird, R. Corlett, and A. Miller-Rushing provided valuable comments to improve the manuscript. Salary to AEB was from the Canada Research Chairs Program.

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