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Science & Society

Global Aerial Habitat Conservation Post-COVID-19 Anthropause

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Aerial habitat is increasingly threatened. The coronavirus disease 2019 (COVID-19) anthropause shows that a decrease in human mobility and goods production for even a short period reduces the global anthropogenic impact on air-space fragmentation and pollution. Economic and environmental post-COVID-19 agendas should consider the changes observed in the aerial habitat during the anthropause.

The Need for Aeroconservation

Aerial habitats are becoming increasingly fragmented [e.g., by skyscrapers,

communication towers, power lines, wind farms, aircraft, and unmanned aerial vehicles (UAVs)] and polluted (e.g., by contaminants, noise, and light) [1–5]. Under this scenario, the global lockdown due to the COVID-19 pandemic has represented a remarkable and unique experiment, recently named ‘**anthropause**’ (see [Glossary](#)). The pronounced reduction in human mobility and goods production, and particularly the decrease in fossil fuel use over even a short period, have reduced the impact of human activities on the air-space (e.g., **aerial fragmentation** and **aerial pollution**). Although the short-term positive effects of the anthropause on aerial habitats have been well documented [6], a post-COVID-19 back-to-normal strategy (business as usual) that favors economic recovery could rapidly override them. If we seek to achieve global biodiversity conservation goals and reduce the effects of climate change at the same time as promoting economic recovery, post-COVID-19 economic and environmental agendas must be developed in tandem and we can take advantage of the changes observed in the aerial habitat during the COVID-19 anthropause. Aerial habitat protection requires synergy between science, government policy, industry, and law for the implementation of **aeroconservation** measures.

Aerial Wildlife Contributions

Anthropogenic changes in habitat configuration may have different impacts on terrestrial and aerial wildlife species, affecting **Nature’s Contributions to People (NCP)**[†]. Terrestrial habitat fragmentation greatly impacts the movements of nonflying terrestrial animals [7]. By contrast, given their capacity for mobility, aerial species, including birds, bats, and insects, may partially overcome terrestrial fragmentation. Nevertheless, terrestrial habitat fragmentation often forces birds and bats to fly longer distances during foraging bouts [1,8]. Together with

Glossary

Aerial fragmentation: anthropogenic intrusions into aerial habitats that create barriers, functionally dividing the basoaerial habitat into more or less separated fragments, affecting wildlife movement. This includes permanent (e.g., buildings, windfarms) and temporal fragmentation (e.g., airplanes or drones).

Aerial pollution: anthropogenic contamination of aerial habitats, which degrades their natural condition (e.g., noise, light, gases), affecting wildlife movement and communication, as well as biodiversity and human health.

Aeroconservation: area of conservation biology that seeks to understand the anthropogenic impacts on aerial habitats. It aims to evaluate how those impacts affect the survivorship, behavior, and diversity of aerial species and to develop conservation tools for aerial habitats and biodiversity.

Anthropause: the dramatic reduction in human activity and goods production caused by the COVID-19 pandemic.

Nature’s Contributions to People (NCP): all the contributions of living nature, both positive and negative, to people’s quality of life. Positive contributions include, food provision, water purification, and artistic inspiration among others, whereas negative contributions include disease transmission or predation that can harm people or their assets.

Ozone precursors: chemical compounds, such as carbon monoxide (CO), methane (CH₄), non-methane volatile organic compound (NMVOC), and nitrogen oxide (NO_x), which in the presence of solar radiation react with other chemical compounds to form ozone, mainly in the troposphere.

Paris Climate Agreement: the global framework to avoid dangerous climate change by limiting global warming to well below 2°C above preindustrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C^{xii}.

Post-2020 Global Biodiversity Framework: the framework of the Convention on Biological Diversity, which will be adopted during the 15th meeting of the Conference of the Parties^{xiii}.

Sustainable Development Goals: the plan guiding the actions needed to achieve a better and sustainable future over the next 15 years in 17 areas of critical importance for humanity and the planet^{xiv}.

terrestrial wildlife, many aerial insects, mammal species (like bats), and most birds provide pollination, seed dispersal, disease spread control, carrion removal, and other services [9] that are essential for human beings. The provision of NCP by terrestrial species has already been reduced due to the high anthropogenic

impact on terrestrial ecosystems [7]. Therefore, the responses of flying animals to changes in habitat configuration may be key for the maintenance of several important long-distance NCP [1,8,10] that terrestrial species are failing to provide [7,9]. However, the population decrease in aerial fauna produced by anthropogenic activities [11] may have profound effects on ecological processes and NCP, leading to cascading negative effects on ecosystem function and human health and well-being [9].

Human Disturbance of the Aerial Habitat

Global change drivers currently favor aerial defaunation trends. Long-term surveys have already revealed a net loss in total abundance of 2.9 billion birds across all biomes of North America (abundance reduction of 29% since 1970) [12] and a global decline in butterfly and moth populations (reduction in abundance of 40% over 40 years) [9]. The best-known impacts occur in basoaerial habitats. They include direct physical harm like collisions (e.g., those produced by mobile and stationary structures [2]) and indirect impacts such as the displacement of individuals to lower-quality habitats or the decrease in fitness of aerial wildlife [11,13]. Industrial contaminants that provoke air pollution (e.g., sulfur dioxide, fluoride, ash, and photochemical oxidants in smog) have also had a negative effect on aerial wildlife worldwide since the industrial revolution (e.g., industrial-related injuries and diseases, physiological stress, bioaccumulation, and direct mortality) [11,14]. The recent increase in UAVs and the potential arrival of flying carsⁱⁱ could speed up aerial defaunation, mainly by reducing aerial habitat connectivity and increasing disturbances and direct physical harm, such as that caused by collisions [2,3]. The same effect could be brought about by the synergy between climate change and fragmentation that provoked the death of

migratory songbirds in the USA. The combination of unusual climatic conditions most probably lead to starvation and disorientation, thus causing birds in poor health to fly into objects and buildingsⁱⁱⁱ. The increasing anthropic impacts of fragmentation, climate change, and pollution on the aerial habitat are inevitably associated with an increase in the rate of aerial wildlife losses [11–14].

Anthropause Effects on the Aerial Habitat and Its Wildlife

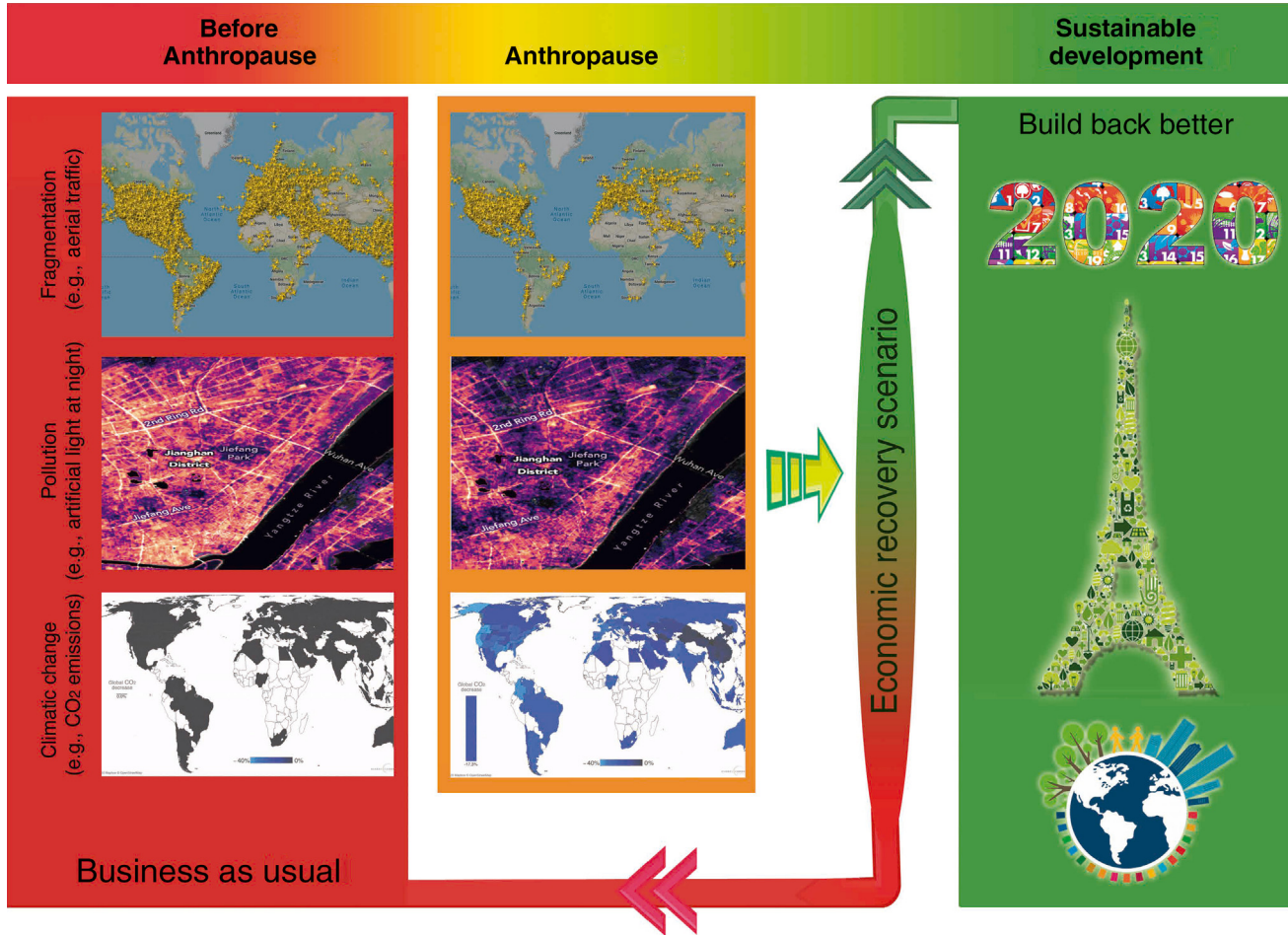
The economic crisis resulting from the drop in economic activity during the anthropause also produced a short-term positive balance for the aerial habitat. During the initial period of restrictions due to the COVID-19 pandemic, mobility declined to an extraordinarily low level^{iv}. Road transport in regions under lockdown dropped between 50 and 75%, global average road transport activity fell by almost 50%, and flights decreased by more than 90% in some countries. Given that mobility consumes 57% of the global oil demand, the decrease in CO₂ emissions in 2020 (~30.6 Gigatons versus 33.2 Gigatons in 2019) is around two times greater than all previous decreases since the end of World War II combined. It is also in line with the ‘Nationally Determined Contribution’ targets under the **Paris Climate Agreement** set for 2025 [6]. These and other reductions in energy demand (i.e., gas and coal) also favored a reduction in other air pollutant emissions, reducing their impact on human [6] and wildlife health [11].

These short-term reductions in aerial fragmentation (e.g., aerial traffic), greenhouse gases (e.g., CO₂, CH₄, N₂O), and aerial pollutants [e.g., artificial light at night (ALAN), noise, **ozone precursors**, particulate matter] during lockdown has had short-term positive effects on aerial wildlife. For instance, a 10-week lockdown in the USA (between March 25 and June 7, 2020) led to a 61% decrease in the

number of aerial wildlife strikes (from 3554 to 1386) compared with the same period in 2019^v. A reduction in noise pollution levels in urban areas has led to songbirds producing higher performance songs at lower amplitudes, maximizing communication distance and salience [15]. These reductions in the impacts of global change drivers around the world have probably had a positive effect on the quality of aerial habitats for invertebrates, birds, and bats [11–16]. These and other impacts affect aerial species directly via physical harm (e.g., wildlife strikes or damage to their respiratory systems, due, for instance, to high levels of tropospheric ozone) or indirectly by decreasing fitness (e.g., reducing habitat quality, affecting animal communication, altering wildlife circadian rhythms and phenology) [11,13]. Without global structural changes these positive short-term reductions in airspace fragmentation, climate change, and air pollutant emissions, and their positive effects on aerial wildlife, will be merely temporary [6], particularly considering the need for economic recovery (Figure 1).

Post-COVID-19 Anthropause Economic Recovery

Until now, world economic strategies have been developed at the expense of biodiversity. Historically, economic recovery in the wake of crises has caused an immediate rebound in aerial traffic^{vi}, greenhouse gas emissions, and air pollutant emissions^{iv}. For instance, the last decade had the highest year-on-year increase in CO₂ records since the recovery that followed the Great Recession in 2010. In the USA alone, economic recovery after the pandemic is likely to release an additional 2500 million metric tons (MMT) of CO₂ from 2020 to 2035 [6]. However, economic recovery should not occur at the expense of ecosystems. In particular, delays or reversals in aerial habitat protection and renewable aerial wildlife-friendly



Trends in Ecology & Evolution

Figure 1. Positive Changes Observed on Aerial Habitat during the Coronavirus Disease 2019 (COVID-19) Anthropause. Positive changes of the reduction in aerial traffic^x, artificial light at night^x, and CO₂ emissions^x could be long-lasting (i.e., sustainable development). They may favor reaching multilateral environmental agreements goals (e.g., Post-2020 Global Biodiversity Framework, Paris Climate Agreement, and Sustainable Development Goals) if post-COVID-19 economic recovery measures are designed under a ‘build back better’ (green path and rectangle) economic scenario instead of ‘business as usual’ (red path and rectangle).

technological investments should be prevented (e.g., electric vehicles, well-designed solar power, etc.) (Table 1).

Build Back Better for the Airspace

We encourage governments to consider the aerial habitat in their post-COVID-19 agenda and plans for economic recovery, including regulation of airspace use and the potential effects of global change drivers. These drivers may produce large mid- to long-term negative effects on NCP, particularly if the associated airspace

ecological processes and conservation actions are not considered after the lockdown. Thus, synergies between scientific and technology agencies, governments, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, the Convention on Biological Diversity, the International Union for Conservation of Nature, and aeronautic and energy industries are urgently needed if we are to achieve global aerial biodiversity conservation goals [3,10]. Little progress had been made in the development of conservation strategies for the skies before the

pandemic; thus, we call for a new focus on the conservation of aerial habitat, particularly in the environmental and economic post-COVID-19 agenda. The positive short-term anthropause effects (on aerial habitat and wildlife) could be used as examples, providing suggestions for decision-makers (e.g., in their economic recovery plans) to turn them into long-term effects (Table 1). For instance, the implementation of aerial reserves, including controls on aerial traffic, noise, and ALAN based on species habitat requirements (e.g., Dark Sky Reserves) [3,4,10], and

Table 1. Human Impact on the Aerial Habitat and the Mid- to Long-Term Potential Effects of the Post-COVID-19 Economic Recovery Measures If Designed under ‘Business as Usual’ or ‘Build Back Better’ Scenarios

Driver	Causes of impact	‘Business as usual’	‘Build back better’ ^{viii}
Fragmentation	Mobile and stationary structures (flights, UAV, Advanced Air Mobility Project, skyscrapers, communication towers, transmission lines, wind farms).	The lack of investment and disinterest in aerial wildlife-friendly infrastructure continues (including new construction of unfriendly buildings and wind farms). Unregulated aerial traffic also increases. Negative consequences impact aerial species, producing wildlife defaunation and loss of nature’s contributions to people.	Higher investment in the development of aerial wildlife-friendly infrastructure. Reduced and regulated aerial traffic (e.g., increased local commerce with reduced transport of goods located at a distance). Aerial species’ requirements are considered and human activities produce less aerial fragmentation, wildlife defaunation, and loss of nature’s contributions to people. Promotion of aerial reserves.
Pollution	Chemical, noise, and light pollution (smog from fossil fuel, gas, and coal use, wildfires, transport, manufacturing, building and mining, artificial light at night).	Increasing pollution coupled with a lack of policies, enforcement, and control. Increasing negative consequences for aerial species due to aerial habitat degradation (but also for other wildlife and human health).	Policies encouraging circular economy, agroecology, and green cities (energy efficiency, more people cycling, limited use of artificial light at night and light artefacts, etc.). Strict regulations, enforcement, and control of pollution.
Climate change	Greenhouse gas emissions (conventional fuel vehicles and aircraft, industries, land use change, and biomass burning).	Delay and lack of investment in renewable energy, while fostering aircraft travel. Increased greenhouse gas emissions and atmospheric concentration of greenhouse gases due to traditionally fueled human mobility and land use change.	Increasing investment in renewable energy production and aircraft energy efficiency, using non-fossil fuel power. Well-regulated aerial traffic and increase in remote working, the train-flight ratio, and the use of non-fossil fuel power for transport.

the development of energy and mobility projects that are aerial wildlife-friendly are urgently needed [1–3]. Aerial conservation strategies like the reduction in CO₂ emission under the **Post-2020 Global Biodiversity Framework, Sustainable Development Goals**, and the Paris Climate Agreement should be prioritized in multilateral environmental agreements. These measures could be developed alongside the post-COVID-19 economic recovery agenda, under the ‘build back better’ approach recently proposed by the Organization for Economic Co-operation and Development (OECD)^{viii} (Figure 1).

Humankind needs to think of a better way of living in harmony with nature and consider the biodiversity conservation crisis and the effects of global change when planning the recovery from the COVID-19 pandemic. We must not simply return to a ‘business as usual’ way of life. The ‘build back better’ approach (*sensu* OECD 2020) considers the reduction in CO₂ emissions under the Post-2020 Biodiversity

Framework and Paris Climate Agreement; however, it needs to foster the development of mobility and energy projects that are aerial wildlife-friendly. We now have an opportunity to rethink and reboot our way of life under the ‘build back better’ approach (Table 1) and this should include the protection of aerial habitats for the long-term future of biodiversity conservation and human health.

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Declaration of Interests

No interests are declared.

Resources

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Letter

Disentangling the Environment in Wildlife Microbiome–Behaviour Interactions: Response to Davidson *et al.*

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There is growing evidence that the gut microbiome strongly influences animal physiology and behaviour. In their recent article in *TREE*, Davidson *et al.* [1] call for research into the relationship between the gut microbiome and behaviour in free-living wildlife to better understand the

mechanisms and evolution of behavioural plasticity. They provide a framework for investigating microbiome-mediated behaviour, including microbiome manipulation to infer causality. While the authors recognise that the environment influences both gut microbiomes and behaviours, we suggest that their proposed framework does not adequately capture the complexity and multiplicity of environment–microbiome–behaviour links. As we argue, any examination of the links between the gut microbiome and behaviour in free-living wildlife demands a more holistic perspective of the role of the environment in shaping gut microbiomes, behaviours, and their interactions.

When discussing the ‘environmental factors’ relevant to gut microbiome–behaviour interactions, Davidson *et al.* [1] largely focus on diet and season. Yet, there are other important pathways through which the biotic and abiotic features of the natural environment affect both the gut microbiome and behaviours of animals. Most importantly, the environmental microbiome (i.e., the microbes found in soil, air, water, and surfaces of the environment) shapes the composition of the gut microbiome of vertebrate animals, including humans [2]. This was demonstrated experimentally; for example, pigs (*Sus scrofa domestica*) [3] and mice (*Mus musculus*) [4] exposed to soil had more diverse gut microbiomes compared with animals exposed to traditional bedding. In natural systems, characteristics of habitats, independent of diet, have also been demonstrated to influence the composition of gut microbiomes in wild animals, for example, in swan geese (*Anser cygnoides*) and American white ibis (*Eudocimus albus*) [5,6]. Finally, environmental microbiomes have been shown to impact both the gut microbiome and behaviour in mice [7]. Any explorations of the gut microbiome–behaviour pathway in artificial environments are unlikely to translate easily to wild animal populations,

where environmental microbiomes impact both the presumptive effector and response variables. These studies provide compelling evidence that realistic environmental microbiomes must be considered when investigating gut microbiome–behaviour links.

Animal behaviour, animal microbiomes, environmental microbiomes, and habitats are interdependent. An approach that recognises this complexity is needed to disentangle these interactions in biologically meaningful ways. Many of the approaches proposed by Davidson *et al.* [1], such as pre- and probiotic treatments, and diet manipulation, are important for identifying mechanisms linking gut microbiomes and behaviours in wild animals. Yet, to address the complexity of the interactions between habitats, environmental microbiomes, gut microbiomes, and behaviour with full ecological relevance, experiments must take place in natural habitats of free-living animals that offer real-world conditions, including realistic diets, social interactions, and habitat and microbiome variation. As Davidson *et al.* [1] point out, controlled laboratory experiments are less messy than natural environments, and there are trade-offs when living laboratories are used to explore questions about microbiome-mediated behaviour. However, with careful study design and appropriate statistical techniques, studies undertaken in natural systems on different species of free-living animals, which measure and incorporate fluctuations in environmental microbiomes and heterogeneity in habitats, can generate answers that are rich, evolutionarily relevant, and translatable [8].

Urban areas are ideal settings for such natural experiments, because they offer variation in environmental microbiomes, and a range of ecosystem characteristics, including habitat fragmentation, noise, light and toxin pollution, temperature and biogeochemical cycle changes, and food supplementation [9], which have been shown to affect behavioural plasticity and