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**Need for global conservation assessments and frameworks to include airspace habitat**

Sergio A. Lambertucci* and Karina L. Speziale

Grupo de Investigaciones en Biología de la Conservación, INIBIOMA (Universidad Nacional del Comahue -CONICET), Bariloche (8400), Argentina
Both authors contributed equally to the manuscript

***Author for correspondence: Dr. Sergio A. Lambertucci (**slambertucci@comahue-conicet.gob.ar**)** Grupo de Investigaciones en Biología de la Conservación, INIBIOMA (Universidad Nacional del Comahue - CONICET), Quintral 1250 (R8400FRF), Bariloche, Argentina

**Article impact statement:** The pervasive human-driven decline of life on Earth points to the need for transformative change in the airspace.

## Introduction

In a huge international and interdisciplinary effort, IPBES, the Intergovernmental Platform on Biodiversity and Ecosystem Services, has recently presented the final report on the first global biodiversity assessment since 2005 (IPBES 2019). This exhaustive, much-welcomed analysis of the effects of global change drivers on land, freshwater, and marine habitats constitutes an essential guide for the urgent implementation of evidence-based strategies. The IPBES analysis seeks to inform policy formulation, as the International Panel on Climate Change has done over recent decades. The engagement of a wide range of stakeholders, from governments and scientists to indigenous peoples, assures the legitimacy of the assessment, resulting in an informed guide for policy development (Diaz et al. 2019). Despite the intended exhaustive nature of these documents, the terminology used when referring to land and water use change could hinder the transformative change necessary for effective conservation of a distinct habitat: the "airspace", the 3-dimensional region of the troposphere where aerobiological activity occurs (Diehl et al. 2017).

Land, water, and air are interconnected. However, as the processes and impacts that occur in water are different from those occurring on land, the drivers of global change are analysed separately for each of these environments, and even the name of the driver "*land and water use change*" acknowledges this (IPBES 2019). Similarly, airspace has unique characteristics that make it a distinctive habitat, with distinctive threats (Diehl 2013; Lambertucci et al. 2015; Davy et al. 2017). The airspace habitat extends from the land or water surface to the upper limit of the troposphere, and is formed by the basoaerial (up to 1km height), mesoaerial (1–8 km), and epiaerial layers (8 km – tropopause) (Davy et al 2017). The comprehensive assessment already carried out failed to consider this distinct habitat and its fundamental role in the maintenance of biodiversity (Diehl et al. 2017).

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The airspace as a habitat generally goes unnoticed and is not taken into account in conservation strategies neither legislation despite increasing disruption, mainly in the basoaerial layer (e.g., buildings, windfarms, aerial artifacts, pollution; Lambertucci et al. 2015; Wallace & Holman 2019). Given that the documents generated by IPBES will guide the design of conservation strategies and policies in the coming years, inclusion of the airspace is urgently required, to promote comprehensive protection of biodiversity.

## Processes and threats in the airspace

New technology has increased the ways humans can use the airspace, which affects important processes that occur in the air and creates new conflicts between wildlife and humans (Lambertucci et al. 2015). Wildlife from all the kingdoms co-exists in the airspace, and many species use it for breeding, feeding, or dispersing, but some species may even live in the airspace most, or all, of their lives. For instance, the aeroplankton, microbes of the Earth's atmosphere, constitute a highly diverse taxon which live in the air, where they actively metabolize, grow, and/or reproduce at different altitudes (Polymenakou 2012). Vertebrates such as the swifts (*Apus apus*) also spend a great part of their lives in the air as they stay airborne for around 10 months per year (Hedenström et al. 2016). Furthermore, aerial migratory species use the airspace to move between breeding and wintering areas each year. Migratory species represent a high proportion of total bird numbers: 70% of the 630 North American bird species is considered migratory (Horton et al. 2019). Moreover, aerial species (birds, bats, insects, etc.) use the airspace every day to reach their feeding grounds and then return to their roosts. For large aerial vertebrates, the air is a fundamental source of energy that allows them to travel many kilometres, for hours, with the lowest energy expenditure (e.g., condors can fly >5 h and >170 km without landing or flapping; Williams et al 2020). The airspace is also the main habitat for a key process for plants, pollination, particularly for many of the species that produce food for humans (Klein et al. 2007). Any impact on this habitat may therefore disrupt not only key ecological processes but also many of nature's contributions to people. This habitat deserves protection measures for the same reasons as other habitats.

## The airspace and drivers of global change

Global change drivers are having a great impact on terrestrial and aquatic biodiversity, but also on the aerial habitat. Current conservation strategies designed for terrestrial and aquatic environments could be partially effective for aerial species. However, the land use changes resulting from habitat loss and fragmentation, pollution, and climate change that threaten air-dwelling wildlife require different, specially designed conservation strategies (Diehl et al. 2017; Lambertucci et al. 2015). For instance, changes in wind intensity and direction will have some influence on terrestrial and aquatic biodiversity, but will have a stronger impact on ecological processes depending on the air, such as plant pollination, seed and fungus dispersion, aerial vertebrate and invertebrate species migration, and food availability for insectivores (Diehl et al. 2017; Davy et al. 2017). If the distinctness of the species, processes, and threats occurring in the airspace is not considered, we may underestimate unique problems and miss conservation opportunities (Diehl 2013; Lambertucci et al. 2015; Davy et al. 2017).

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Many land use changes have already led to the loss, fragmentation, or severe transformation of large terrestrial habitats such as urban centres or areas for food production (IPBES 2019). Despite big cities or agricultural areas proving to be a barrier for many wild terrestrial animals, several flying species still use these novel environments and the airspaces above them, or pass over them during migration (Medan et al. 2011; Horton et al. 2019). These anthropic areas are generally not considered as conservation priorities for wild terrestrial or aquatic species. However, specially designed conservation strategies could reduce their far-reaching impact for flying species that depend on the airspace, even in these human-modified areas (Davy et al. 2017; Loss et al 2015). The main threats are barriers created by stationary or mobile structures that lead to physical collisions, provoking wildlife casualties. Among them, we find the exponential increase in airplanes, drones, buildings, power lines, and wind farms, which are fragmenting the airspace and increasing human-wildlife conflict in this habitat (Lambertucci et al. 2015; Davy et al. 2017; Loss et al. 2015). For instance, some species of bats are experiencing serious population decline due to wind farms in the United States (Kunz et al. 2007). The fragmentation created by man-made structures may also disrupt the movement patterns of aerial species, forcing them to use more energetically costly or dangerous migration routes (e.g., wind farms on land or water; Kunz et al. 2007, Desholm & Kahlert 2005). These disruptions may impact on species that use the airspace, and require specific conservation strategies (Davy et al. 2017), though more research is needed given diverse species may respond differently.

Pollution and climate change are also considered among the five main drivers of global change on land and water, but they affect processes occurring in the airspace as well. Air pollution – whether due to chemicals, heat, light, or noise – affects wildlife physiology, dispersal, and communication and increases collision risk, etc. (Davy et al. 2017; Horton et al. 2019). Pollution is increasingly becoming one of the most important public health problems, and wildlife is also impacted (Losacco & Perillo 2018). Light pollution attracts nocturnal migrants to urban areas (La Sorte et al. 2017), where birds suffer the greatest overall mortality (Loss et al. 2015). Climate change, for instance, is threatening the survival of pest-controlling bats (Pruvot et al. 2019), and altering the migration patterns and pollination services of aerial species (Magrach et al. 2020).

## Airspace biodiversity in the current agenda

The distinctive impact of global change drivers on the skies must be assessed globally, similarly to land and water habitats, so that effective conservation strategies that include aerial species can be developed, and to address the comprehensive change pursued. The different conservation approaches needed are, for instance, the development of 3-dimensional aerial reserves which could be temporal and mobile (Diehl 2013; Lambertucci et al. 2015), depending on the focal species, the community, or the ecological process to be protected. Some of these conservation strategies have been proposed under the Aeroconservation definition, which integrates key research areas related to aerial habitat and species conservation (Davy et al. 2017). Worryingly, aerial species and habitat are strongly underrepresented in current biodiversity assessments, which are mainly focused on land and water biodiversity threats (e.g., IUCN; Davy et al. 2017). Although the global driver “land and water use change” may partially include some aspects of the airspace, IPBES and other assessments (see below) do not include the evaluation of impact on biodiversity occurring in this newly-defined habitat. For example, migratory flying routes where millions of animals concentrate,

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like Gibraltar, may extend above protected or unprotected land or water, but the airspace along these extensive routes is generally not protected, or in many cases the protection has not been specifically designed for many aerial species (Davy et al. 2017). Another example is when flying routes pass over large human constructions and millions of individuals die, from insects to birds (e.g., passing over cities: Loss et al. 2014; Horton et al. 2019).

In addition to IPBES, another global process involving biodiversity is currently being led by the Convention on Biological Diversity (CBD). A zero draft of the post-2020 global biodiversity framework was circulated in order to receive feedback from the conservation community, and hopefully agree on a final report this year that could guide future conservation strategies. The CBD, like the IPBES report, has not proposed the protection of airspaces among its targets designed to reduce threats to biodiversity. For example, the suggested 2030 #2 action target is to "Protect sites of particular importance for biodiversity through protected areas and other effective area-based conservation measures, by 2030 covering at least [60%] of such sites and at least [30%] of land and sea areas with at least [10%] under strict protection".

Given the current agenda, timing is crucial in considering the concept of aerial habitat and aeroconservation. Including these concepts, although rather new and little known, could make these reports pioneering – moving forward from a crisis discipline that trails in the wake of the problem to the forefront, leading mitigation and preventive strategies. In the case of anthropogenic development of the airspace, our conservation planning could pre-empt several threats. However, some impacts, like skyscrapers or windfarms, are already producing increasingly high mortalities in key species for pollination or seed dispersion, such as many birds and bats (Kunz et al. 2007; Loss et al 2015; Magrach et al. 2020). We propose: 1) changing the name of the main global change drivers to "land, water, and air use change"; and 2) including the impacts of all the drivers on the ecological processes occurring in the airspace, and the associated conservation measures, in the coming assessments. Particularly important is the inclusion of the aerial habitat in the analyses and conservation strategies proposed in the post-2020 targets of the CBD and current IPBES assessments. This suggestion is not minor, given its implications for health, conservation and management. We wish to spread this message before the post-2020 final targets and upcoming IPBES reports are agreed upon and published, in the hope that this and other global biodiversity assessments adopt the airspace habitat in their evaluations. This will aid the design of effective conservation measures and transformative change in all the habitats that support wildlife, given that without healthy airspace, many biological processes that are important for nature and the contribution of nature to human life and wellbeing may become functionally extinct.

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