with climate change, but there is sparse information on just how rapidly most species can migrate. Urban's study illustrates that our uncertainty about these processes matters greatly, with assumptions about dispersal and threshold habitat sizes for extinction strongly influencing projected biodiversity loss.

The biggest unknowns about biodiversity loss with climate change arise from processes that are never (or only rarely) included in the predictive models that Urban surveyed. For example, can adaptation or behavior buffer species from the negative impacts of climate change? Given that extinction is not instantaneous, how rapidly will biodiversity be lost (*6*)? Will other global change factors, such as invasive species, exacerbate climate change impacts (see the photo) (*7*, *8*)? Will species interactions magnify biodiversity loss from climate change (*9*) or, alternatively, buffer species from negative impacts of climate change (*10*)? These are challenging questions that biologists are only just beginning to address when considering climate change impacts on biodiversity (*7*).

Midway through what could well turn out to be the warmest decade in the past 170 years (*1*), Urban's study joins many others suggesting that climate change will have enormous impacts on the organisms with which we share our planet. Many uncertainties remain, and biologists will continue to improve forecasts of biodiversity loss with climate change by gathering additional data and incorporating additional complexities into models. However, we should not wait for these forecasts before taking action, preferentially by curbing emissions (*1*) but also by devising strategies to mitigate the negative impacts of climate change on biodiversity (*3*, *7*). If we do not, it is clear that we will soon be able to directly observe the impacts of climate change on biodiversity. ■

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ECOLOGY

Human-wildlife conflicts in a crowded airspace

How can the ecological consequences of the increasing use of airspace by humans be minimized?

By **Sergio A. Lambertucci,[1] Emily L. C. Shepard,[2] Rory P. Wilson[2]**

Over the past century, humans have increasingly used the airspace for purposes such as transportation, energy generation, and surveillance. Conflict with wildlife may arise from buildings, turbines, power lines, and antennae that project into space and from flying objects such as aircrafts, helicopters, and unmanned aerial vehicles (UAVs, or drones) (see the figure) (*1–3*). The resulting collision and disturbance risks profoundly affect species ecology and conservation (*1*, *4*, *5*). Yet, aerial interactions between humans and wildlife are often neglected when considering the ecological consequences of human activities.

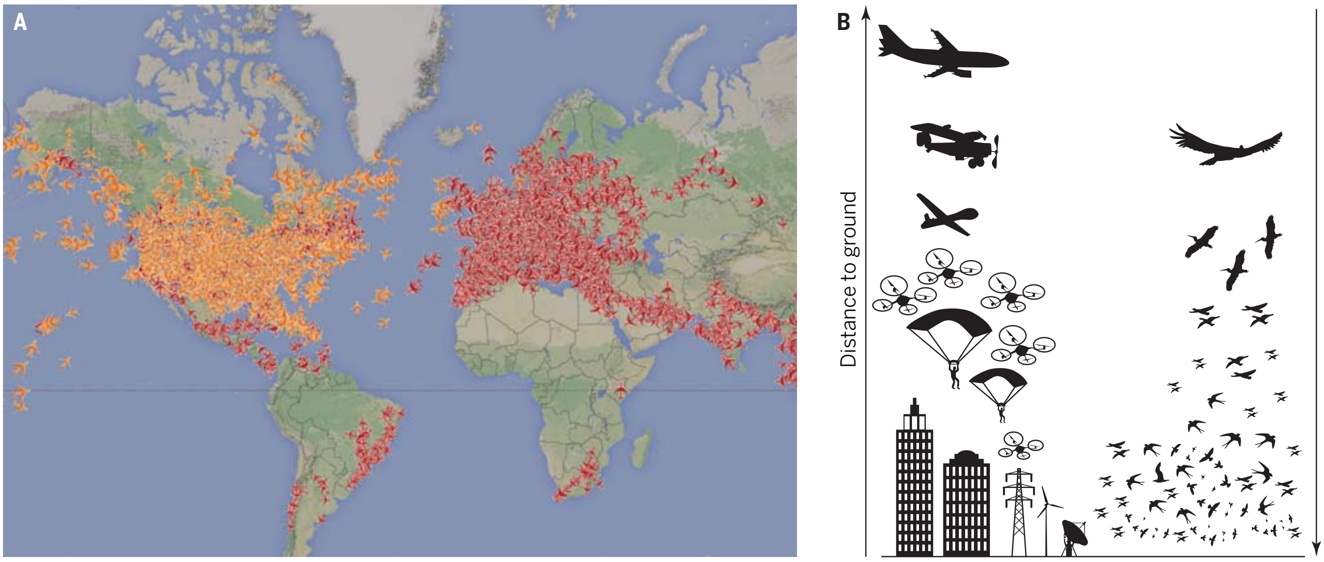
Airspace is needed for key ecological processes and ecosystem services. For instance, billions of individuals from different taxa migrate every year, modulating patterns of biodiversity via the transport of nutrients, energy, toxicants, propagules, and parasites (*6*). Therefore maintaining the diversity, abundance and movement of aerial organisms is vital for a range of ecosystem-level processes.

Most flying animals operate within a hundred meters from the ground, with abundance decreasing with height (*7*). Animals thus move at heights relevant to most human-made structures and moving objects (see the figure). Buildings, power lines, antennae, and wind farms cause millions of animal deaths via collisions annually, both over land and water, and have increased the extinction risk of several vertebrate species (*1*, *5*). Collisions with flying aircraft mostly occur at altitudes of 60 to 120 m during takeoff and landing, although occasional collisions occur at cruising altitudes (*8*). To date, more than two hundred people have been killed globally and thousands of aircraft damaged as a result of bird collisions (*2*). In the United States, the cost of bird strikes exceeds $900 million a year, with strikes increasing six-fold over the past two decades (11,315 recorded strikes in 2013) (*2*).

There are also less obvious effects. For example, buildings and wind farms influence

A seagull sweeps at a Sky TV drone.

PHOTO: MARTY MELVILLE/AFP/GETTY IMAGES



Crowded sky. (**A**) Global distribution of the ~8000 commercial and private aircraft in flight at 10:17 GMT on 25 March 2015. This figure only includes aircrafts that are covered by http://planefinder.net., and the regions of the world with the highest traffic.

(**B**) Schematic distribution of human-made artifacts and relative abundance of flying vertebrates using the same airspace. Artifacts and animals are not to scale.

local airflow regimes, with likely secondary effects on the distribution and habitat use of different species. The airspace is also used by aerial microbiota: organisms from bacteria to algae that are transported in aerosols and may act as cloud and ice condensation nuclei, influencing cloud chemistry and climate (*9*, *10*). The increasing production of industrial gases and pollutants affects aerial microbiota. The resulting changes in precipitation regimes and weather conditions have cascading effects on human and wildlife communities (*9, 10*).

Problems may also arise from UAVs, which are increasingly used in conflict, research, and control tasks and by the media (*11*, *12*). Serious debate on the use of UAVs is lacking in most countries, and almost no concerns have been raised on the influence of UAVs on wildlife (*12*). In some countries (such as Canada and the United States), UAVs are only allowed to fly within 120 m of the ground, where most flying animals are found (see the figure). UAVs can be invaluable for monitoring the physical and biological environment (*12*), and some aquatic birds do not visibly modify their behavior when UAVs approach them vertically (*3*). But other species, such as seagulls or territorial raptors, can be disturbed by UAVs flying close to their nests (see the photo). UAVs might also produce physiological reactions such as stress, but these effects remain to be investigated (*3*).

Effective environmental management of the airspace will require a detailed understanding of the movement of aerial animals at the scales of land development and management. This is a considerable challenge. Currently, more is known about the routes taken by migrating animals that cross continents (*6*) than those taken by animals in parks or towns. The aerial environment is also highly dynamic, and animals respond to airflows in complex ways. Detailed data on how animals use space in both horizontal and vertical dimensions are needed at scales from meters to kilometers. These data should be coupled with information on the sensory capacities [e.g., of birds (*1*)] and physiological mechanisms [e.g., in bats (*4*)] that may allow animals to detect and respond to individual human-made structures.

This knowledge can then guide artifact design, local planning decisions, and mitigation measures. Current measures to avoid harming wildlife include modifying windows using visual markers and removing carcasses from wind farms to reduce the collision risk for scavengers. More recently developed mitigation measures include bird-deterrent technologies using ultraviolet light that birds can easily see for avoiding collisions with windows. More experimental is the use of radar detection of flying animals to allow near-instantaneous mitigation (e.g., through modification of turbine speeds). However, they are still partial solutions that are only applied in a few places, mainly in developed countries. It is important to extend measures to national and regional levels, because many aerial animals routinely travel thousands of kilometers during migration or dispersion.

Management of airspace will also require conservation-focused use of the ground beneath—for instance, avoiding building infrastructure that could be dangerous to passing animals, distracting flying animals (particularly vulnerable species) from risky areas (*1*), and reducing light pollution, which can disrupt animal movement patterns and threaten biodiversity (*13*). Many migratory movements follow well-defined transnational flyways, and restrictions for flying or for operating wind farms in those areas would help to reduce animal deaths. Daily wildlife movements between breeding and foraging areas (*14*) must also be considered when building or using new artifacts that intrude into the airspace.

Although appropriate mitigation measures are important, the focus should be on reducing the need for post hoc management measures. For example, considering the abundance and patterns of habitat use of the flying animals living nearby before building an airport will strongly reduce future conflicts.

There are also strong arguments for the establishment of airspace reserves (*15*), both temporal and permanent, in aerial wildlife hot spots where human-made structures may cause disproportionate damage. In some areas, temporal restrictions for using the airspace may be introduced—for example, to protect migratory birds. The conservation of migratory birds has historically been focused on the ground (breeding, wintering, and stopover areas), but threats found in the airspace have rarely been considered. Permanent reserves, with partial or complete restriction on human use of the airspace, could protect daily animal move-

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ments such as for foraging. However, many air users cover large distances, taking them beyond their reserves (*14*). This complicates efforts to protect them and must be taken into account when designing reserves.

Conservation measures must also consider the sociocultural aspects of human-wildlife conflict. For example, the spring bird hunt in Malta has negative demographic effects on bird species that are migrating to breed. However, it is considered a traditional practice and in a recent referendum, the Maltese population narrowly voted to continue with the practice. This case shows how difficult it is to translate some traditions into current conservation practices. Similarly, military practices may also have negative impacts in areas sensitive for wildlife (e.g., flying through rocky canyons where vultures and many other species fly). These sociocultural conflicts with flying species occur throughout the world and require integrative conservation approaches that go beyond reserves.

There are thus three main levels at which to deal with airspace conflict: identification of pristine airspaces with high aerial wildlife densities where valuable air reserves can be created; identification of airspaces where humans and wildlife are already in severe conflict and where more dramatic measures must be taken to reduce collisions; and a suite of standard measures, such as anti–bird collision light systems, that should be implemented in places when bird strike probabilities are appreciable. Such a combination of strategies will provide a better perspective for airspace conservation. ■

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SUSTAINABILITY

Secure sustainable seafood from developing countries

Require improvements as conditions for market access

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POLICY

Demand for sustainably certified wild-caught fish and crustaceans is increasingly shaping global seafood markets. Retailers such as Walmart in the United States, Sainsbury's in the United Kingdom, and Carrefour in France, and processors such as Canadian-based High Liner Foods, have promised to source all fresh, frozen, farmed, and wild seafood from sustainable sources by 2015 (*1*, *2*). Credible arbiters of certifications, such as the Marine Stewardship Council (MSC), require detailed environmental and traceability standards. Although these standards have been met in many commercial fisheries throughout the developed world (*3*), developing country fisheries (DCFs) represent only 7% of ~220 total MSC-certified fisheries (*4*, *5*). With the United Nations Food and Agriculture Organization reporting that developing countries account for ~50% of seafood entering international trade, this presents a fundamental challenge for marketers of sustainable seafood (see the photo).

Progress toward sustainability means overcoming difficulties DCFs face in complying with MSC-like standards (*6*–*8*). With a limited amount of certified wild-caught seafood available, some firms include seafood sourced from fishery improvement projects (FIPs) (*9*), in which fishers are rewarded with market access conditional on the fishery making progress toward sustainability. Rapid spread of FIPs, which often operate without transparent and independent assessment, raises questions about their effectiveness as a tool to foster environmental, economic, and social improvement.

ACCESS, THEN IMPROVEMENTS. FIPs are varied in their scale and scope, developed and funded by nongovernmental organizations (NGOs) and the private sector. At their core, they are partnerships with the supply chain seeking to source seafood for developed country markets to supplement the stock of MSC-certified products (*6*) (fig. S1). Although FIPs are not formally part of the MSC or any other certification process, they provide fisheries, especially those that might perform poorly during pre-assessment stages of formal certification, an opportunity to be rewarded with access to markets (and potentially higher ex-vessel prices) (*10*). The costs of engaging a fishery in a FIP or MSC process appear similar (*11*, *12*) and de-

The municipal port in Bitung, North Sulawesi. Indonesia.

PHOTO: SIMON R. BUSH/WAGENINGEN UNIVERSITY