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With a focus on Europe

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Preface

The COVID-19 crisis has changed the daily life and routine for everybody around the world. Billions of people have needed to cope with the different challenges that lockdown, global economic impact and the potential health threats posed to us and our families. The situation highlights how closely mankind is connected to nature and how vulnerable we are as an integral part of it. In this instance, we are being exposed to invisible threats and mutations from this virus spreading around the whole world in nearly uncontrollable ways. The high death toll of the virus and the serious consequences that an infection can have, necessitated the lockdowns and the strict confinement measures, and made them if not tolerable, then at least acceptable for the majority of the population. The whole world changed its way of living and how it carries out its daily activities, almost overnight. In scientific terms, this could be called a huge involuntary and unplanned experimental design by accident. *De facto,* it has enabled an unprecedented opportunity to investigate the relationship between people's daily routines and activities and the resulting reaction by the environment and nature.

Many research groups, nature conservationists and environmental institutions took the opportunity to research this, and this report investigates the first results published on the impact that lockdowns have had globally with regards to nature and ecosystems. All this happens in Europe at a time of renewal of our environmental policy under the European Green Deal. A new biodiversity strategy for 2030 provides new targets and new ambitions for halting the loss of biodiversity and to protect and restore Europe's ecosystems. The results from COVID-19 related research can help to define a baseline for a biodiversity in recovery and the respective socio-economic effects and benefits, and hopefully, it also contributes to keeping biodiversity high on the agenda of the recovery plans for the post COVID-19 times.

Beate Werner
Biodiversity and Nature
European Environment Agency
Copenhagen

Summary

The COVID-19 pandemic has resulted in large-scale restrictions in human activities globally, with drastic, sudden, and widespread confinement of people to their homes during lockdowns. These have led to significant reductions in road-, water- and air traffic, the closing of national parks and other protected areas, and restricted access or the closing off of other areas in the countryside (such as viewpoints, lakesides, country parks, monuments, etc) that in normal times are popular meeting places or visitor locations.

As Europe faced lockdowns of varying degrees of intensity, many anecdotal stories were shared about the apparently changing behaviour and distribution of wildlife, often in the popular press and on social media. An opportunity has, therefore, presented itself for us to examine the impact, positive or negative, of changes in human presence and activities, including; human density, light, noise, and pollution, on wildlife. In addition, the situation has provided the potential for a change in human perceptions of nature, and the value that it provides in times of restricted human contact, increased confinement and enforced changes in (human) behaviour. While it is not the main purpose of this document, we have noted that the maintenance or restoration of healthy ecosystems may help to prevent zoonoses from occurring, or may mitigate their impact in relation to both regulating human-to-human disease transfer and the management of future disease outbreaks.

We have reviewed existing literature and references to data compilation linked to monitoring and other activities related to wildlife in the pandemic to explore what the effect of the COVID-19 measures have been on wildlife, including how people have benefited from nature, with a focus on Europe. Subsequently, we have asked what lessons could be learned for improving our management of human-wildlife interactions, both in relation to the circumstances that apply in pandemics, such as this, and in the context of more general wildlife and natural area management. In order to achieve this, we have carried out a scan of past and current literature, with a focus on issues in relation to mitigating and compensating for disturbance post-COVID-19, where possible, based on peer-reviewed literature (in an attempt to maximize study quality and to ensure that all relevant information is included in the articles) and also other reports. We searched for studies that address the (potential) impacts of the COVID-19 lockdown on wildlife, directly or indirectly. Internet searches and weblinks on webpages with relevant news were also examined for news on the impact of the COVID-19 pandemic on wildlife. A short questionnaire was developed and sent to a variety of experts across Europe, to survey current (research) initiatives that aim to assess the impact of the COVID-19 lockdown on wildlife. Finally, we interviewed a number of scientists at EU research institutions. Our aim was to receive information on COVID-19 related research that had not yet been published and, from the survey, a summary of ongoing research on the impact of the pandemic and associated measures on wildlife in Europe was compiled.

The lockdown resulted in significant changes to air- and water-quality. As business and industry slowed down and some factories, shops and other retail outlets temporarily closed, air-, road- and waterborne traffic declined, and the emissions of pollutants – such as NO, NO_2, NH_3 and NO_x – reduced significantly in cities, such as Madrid, Barcelona, Rome, Milan and Paris. High levels of NO, NO_2, NH_3 and NO_x cause eutrophication of natural areas and subsequent loss of plant diversity; the observed reduction in their levels during the pandemic is, therefore, likely to be beneficial. Conversely, the higher measured levels of ozone (O_3) that have been observed during lockdowns are likely to reduce plant growth and functions. Reduced air pollution may positively influence the breeding success of insectivorous birds that benefit from higher numbers of insects, as evidenced by observations of Common swifts in Italy. Reduced levels of industrial effluent and less boat traffic during lockdown improved water-quality and, for example, in Venice, Italy, the clarity of the water in the canals improved considerably due to a pause in industrial effluent discharge and restrictions in boat traffic; such effects may have positive impacts on marine benthic ecosystems in the area, including the growth of phytoplankton. However, despite the changes to air- and water-quality, the relatively short period of lockdown has, so far, not resulted in any measurable changes in vegetation or associated fauna.

The COVID-19 lockdowns have been characterized by numerous reports of increased poaching (both subsistence and commercial) and illegal resource extraction, both globally and in Europe. During the 'anthropause'[1], large parts of Europe's countryside lacked patrols and monitoring by scientists, rangers, hikers and tourists, who normally help deter poaching. The reduced ability to detect and combat threats has increased opportunities for the illegal killing and persecution of wildlife species, notably resulting in a resurgence of shooting of migratory birds in Italy, in particular, the killing of birds of prey, as well as sturgeon overfishing in a number of countries. Restrictions to travel within and from Europe have had significant effects on ecotourism and associated income streams, particularly at local level. There have also been impacts on wildlife at the tourism destinations and elsewhere. In Africa, the COVID-19 pandemic has resulted in reduced income from tourism and other funding and has imposed restrictions on the activities of conservation agencies, such as anti-poaching operations, which considerably hampers conservation efforts. The pandemic may also lead to illegal persecution of wildlife suspected to be involved in the spread of disease.

The most notable change during the lockdowns has been a reduction in human mobility. One of the most rapidly visible phenomena resulting from lockdown and the associated containment of people in their homes was that wildlife relatively quickly 'took over' or returned to areas that had previously been subject to high levels of human disturbance. There were multiple online reports of wolf, wild boar, and dolphin being recorded at sites where they were previously had not been seen. The impact of reductions in human mobility during lockdowns have been especially visible in urban areas, with likely influences on urban wildlife. Indeed, wild animals appeared to venture into cities worldwide during periods of lockdown. However, some behavioural changes may have already occurred before the lockdown; detection rates may simply have increased during the lockdown, because animals became more conspicuous due to factors, such as reduced levels of ambient noise. In addition, more people may be on the lookout for wildlife during a lockdown, so the increase in urban sightings of wild species could also be due to increased observation effort. Some behavioural shifts in response to the reduction in human activity were well documented; for example, increased activity of deer and other normally nocturnal species was reported during daylight. The proportion of records of crested porcupines in urban areas of Italy increased greatly in 2020 compared to previous years, whereas the number of observations in non-urban settings did not change. A similar change in distribution was recorded for breeding Kentish and Ringed Plovers and Little Terns that occupied areas, which had previously been subject to too much disturbance. Another study found that birds did not increase in urban areas during the lockdown, but a change in the birds' daily routines occurred in response to quieter conditions. These observations indicate that urban birds show high behavioural plasticity and can rapidly adapt to novel environmental conditions, such as those imposed by COVID-19 lockdown measures.

Significant reductions to road traffic during lockdowns are anticipated to have decreased the ecological impacts of roads on wildlife populations, especially for those species that are highly susceptible to road-killing, such as amphibians, reptiles, passerines, birds of prey and owls, rodents and carnivores. A significant decrease in the number of road-killed amphibians and reptiles was reported on Italian roads during lockdown. Studies outside Europe show similar trends in relation to road deaths in these animal groups. Reductions of mortality may have important population-level consequences; although it should be noted that the absence of roadkill may not benefit scavenger species. A decrease in road traffic density may also have been beneficial to insects. One of the United Kingdom's biggest bee farms noticed that their bees thrived during the COVID-19 pandemic, likely caused by a decrease in traffic and lower levels of pollution. It has been noted that rare wildflowers and declining bee populations could have also started to recover during the COVID-19 lockdown periods, because roadside verges were left uncut; in combination with lower levels of traffic, this could also have benefitted butterflies, birds, bats and insects that depend on roadside flowers for survival, although few studies have quantified such impacts. Finally, reduced levels of traffic may also have impacted wildlife due to lower levels of light and noise pollution, with positive consequences for animals impacted by such disturbance.

[1] Note: This period of unusually reduced human mobility was named the 'anthropause' by Rutz et al. (2020). Anthropause was selected by Oxford Languages as one of 2020's Words of an Unprecedented Year.

In addition to the impact on wildlife, there are indications that people's appreciation of wildlife may have changed during the pandemic. When excursions from household confinement are allowed, nature can provide people with opportunities to enjoy positive effects that increase their well-being, while at the same time allowing them to maintain social relationships (in circumstances of social distancing). The soothing role of nature may have been especially important in counteracting the effects of stress and anxiety arising from confinement, domestic conflicts, or job and income losses, which could lead to a mental health crisis. The appreciation of nature was reflected in leisure activities during lockdowns in Europe. For example, pedestrians and cyclists in Norway showed evidence of intensifying their activities on trails with attractive natural vistas and tree canopy cover, in city parks and peri-urban forests, but also in protected areas. There has been a large increase in the desire to spend time in nature among adults in the UK, with 72% of women and 60% of men reporting that they are more likely to do so in the future, following lockdown. Importantly, 70% of respondents said that they will be more likely to notice nature in their local area in the future. In a survey of consumers in seven European countries (France, Germany, Italy, Poland, Spain, Sweden and the UK) 70% of respondents stated that they specifically looked forward to participating in outdoor activities like hiking, climbing, cycling, snow sports and other mountain activities after lockdown eased. Specific leisure activities, such as bird-watching have also changed; respondents from developed countries, including European nations, reported that they currently spend more time bird-watching than before. Online searches also point toward a greater appreciation of and awareness for nature, as nature-related topics were more highly searched after the onset of the pandemic; this could also lead to support for conservation. For example, 75% of interviewees in the Netherlands believed that the number of nature areas should be increased, while 73% held the opinion that nature investments should become an integral part of the economic recovery from COVID-19. Despite a positive shift in public awareness of nature-related topics, it may be short-lived. It will, therefore, be important to incentivize a long-term change by, for example, supporting urban schemes for greening built infrastructure and by creating 'liveable cities'. In general, support for wildlife conservation may be enhanced if people are better informed about the cause of the COVID-19 outbreak.

A questionnaire was sent to a variety of experts across the EU; of the respondents, only three persons indicated that they are currently collecting data on the effects of COVID-19 on wildlife, including on the distribution of animal species, population size and trends, habitat use and movements. Their objectives for doing so were: to address the impact of human disturbance and pollution; the effects of COVID-19 on human disturbance on wildlife and wildlife crime, notably illegal persecution of raptors; and to gather general, relevant data on the impact of the COVID-19 pandemic on the environment. A number of participants described their experience or assessment of the impact of a COVID-19 lockdown on wildlife. Firstly, the impact of a lockdown appears to be strongly influenced by its severity. A complete lockdown, during which people are either forced to stay at home or are only allowed out for essential reasons (and are, therefore, prevented from accessing natural areas), were said to result in behavioural changes in birds and large mammals, such as movements closer to human settlements. However, when the lockdown only restricts people from going to work or to public buildings and cities, people are likely to crowd nature reserves. This effect was mentioned by various respondents. Most of the experts from the countries participating in the survey stated that people visited more natural areas during lockdown, and that a redistribution and increase of recreation is likely to have caused increased disturbance of wildlife.

The COVID-19 pandemic and lockdown effects resemble experimental set-ups (in which study areas are excluded from the effects of certain factors, in this case, all kinds of disturbance), and provide a unique opportunity to study the impact of human activities on wildlife. This opportunistic use of the current situation for shedding light on the sensitivity of species to human activities has been highlighted by various authors. The current situation allows the opportunity to answer questions related to the movements of animals in modern landscapes, and whether they are predominantly affected by built structures, or by the presence of humans. Much of the impacts on wildlife still require quantification and our surveys among European researchers describe various studies that have been initiated. The international research community has taken this chance to examine how changes in human activities affect wildlife, especially because it allows us to gain mechanistic insight into these processes. We have illustrated this by describing various collaborative research initiatives that are currently forming to facilitate coordination, and there are others in the process of being developed.

These include the COVID-19 Bio-Logging Initiative and the COVID Camera-trap Comparison Collaboration, global initiatives to assess changes in movement and distribution among wildlife in response to the anthropause. These larger initiatives plan to collate data using 'bio-loggers' and field-deployed camera-traps for this purpose, and strive to conduct before-and-after-controls in defined areas in order to detect effects. Studies that were established before the pandemic hit, and lockdowns occurred, and that continued during and after lockdowns, will be particularly important for quantifying the impact of human activities.

Europe has a role to play in preventing future outbreaks from happening. Firstly, the ecological footprint (in terms of our consumption of environmental resources outside the region) of European countries may, to a certain extent, cause detrimental land-use changes in areas where risks for zoonosis are high. Secondly, Europe has a responsibility and role when it comes to the Convention of Biological Diversity (CBD), including the development of strategies for the conservation and sustainable use of biodiversity globally. Hence, the current virus outbreak and global pandemic should initiate a stronger plea for ecosystem preservation during the upcoming fifteenth meeting of the parties to the Convention – known as Conferences of the Parties (COP 15) – to be organised in China, in 2021.

A key question for wildlife conservation relates to the lessons that might be learned from the current pandemic and which human activities have most influence on wildlife; in particular, what, if anything, can be maintained in terms of the positive effects that have occurred during the pandemic? Once the situation reverts back to normal, human activities and disturbance are likely to reverse these. Animals that were venturing into previously unoccupied areas, because of lower disturbance levels, are likely to vanish when such disturbances bounce back to former levels. Similarly, traffic will resume normal levels, as will the frequency of roadkill and its negative impact on particular species. Some measures or adjustments to human behavioural patterns would obviously be beneficial and could theoretically be implemented on a larger scale to retain some of the positive effects of the pandemic on wildlife. For example, measures such as wildlife crossing structures at roads and railroads can help to prevent road casualties. Management of natural areas through guiding human activities to where their impact is limited, or lower than elsewhere, may receive more attention than before given the beneficial consequences for wildlife. The anthropause also illustrates well the importance of having people, and law enforcement staff in particular, in the field to prevent poaching. In general, many positive impacts are likely to vanish as the pandemic ends and the situation reverts back to normal, leading to a rebound of noise, air, and water pollution, greenhouse gas emissions, and the many other adverse human impacts on nature. Presently, however, there is scope for exploiting the growing public engagement with wildlife losses, which can be one element in driving the development of a lasting and legitimate long-term policy response to COVID-19.

One of the aspects that has become clear during the pandemic is that we cannot keep humans out of nature, and neither should we wish to, as contact with nature during this period of restricted travel has, in many countries, provided important benefits for human health and well-being. However, visitor numbers to natural areas have increased significantly, particularly in north-west Europe and a number of states within the US. With this, increased pressure on habitats and species and a consequent need to provide for their sustainable management in the short-, medium- and long-term have arisen. Building on existing knowledge and expertise in relation to recreational management, further research into how to manage human populations in these extraordinary situations is, therefore, desirable, if not essential, to identify the best priority actions (and policies) for effective protection and shared use of the (ultimately limited) resources provided by nature.

1 Introduction

The coronavirus disease (COVID-19) pandemic has resulted in global restrictions to human activities (Rutz et al. 2020). This has included national 'lockdowns' that have been applied all over the world, and have been drastic, sudden, and widespread, with millions of people being confined to their homes apart from essential journeys. Countries have responded in broadly similar ways across large parts of the world, which has led to significant, concomitant reductions in road-, water- and air traffic, as well as human mobility in general. Despite this globally similar response, there were regional and local differences. In some countries, a preventive lockdown was applied that forced people to stay at home. In others, partial lockdowns were announced, encouraging people to work from home whenever possible and limit their social interactions. In some parts of the world, national parks, protected areas and other areas in the countryside (such as viewpoints, lakesides, country parks, monuments, etc.) that were normally popular meeting places or visitor locations were closed; while in other parts, parks and reserves remained open. While in the first situation, visitor numbers dropped dramatically, in the latter, visitor numbers often increased as the closure of amusement parks and other recreational destinations caused natural areas to be one of the few places that could still be accessed. This period of unusually reduced human mobility — which Rutz et al. (2020) coined 'anthropause'[2] — may provide important insights into human–wildlife interactions in the twenty-first century.

As Europe faced lockdowns of varying degrees of intensity, many anecdotal stories were shared about the apparently changing behaviour and distribution of wildlife, very often in the popular press and on social media. Some of these are better supported (with evidence) than others. An opportunity has, therefore, presented itself for us to examine the impact, positive or negative, of human presence and activities, including; human density, light, noise, and pollution, on wildlife. In addition, the situation has provided the potential for a change to human perceptions of nature, and the value it provides in times of restricted human contact, increased confinement and enforced changes in (human) behaviour. In this report, we have reviewed existing literature and references to data compilation linked to monitoring and other activities related to wildlife in the pandemic to explore what the effects of the human-targeted COVID-19 measures have been on wildlife, including how people have benefited from nature, with a focus on Europe. Subsequently, we have asked what lessons can be learned for improving our management of human-wildlife interactions, both in relation to the circumstances that apply in pandemics such as this and in the context of more general wildlife and natural area management.

In order to achieve this, we have: (1) carried out a scan of past- and current peer-reviewed literature (in an attempt to maximize study quality and to ensure that all relevant information is included in the articles), as well as other reports, internet searches, and weblinks on webpages with relevant news; (2) developed and circulated a short questionnaire to a variety of relevant experts across Europe, to survey current (research) initiatives that aim to assess the impact of the COVID-19 lockdown on wildlife; and (3) implemented a small number of interviews with biologists on their observations from ongoing field-studies that focus on the issue at hand.

The methods we used are described in Chapter 2. Although the focus is here on the impacts of mitigating measures, such as lockdowns, in Chapter 3 we have briefly addressed the relationship between biodiversity conservation and the origin of the COVID-19 pandemic. Chapter 4 presents the findings of the review. As well as the direct and indirect impacts of the lockdown on wildlife, we have also focused on the health and social benefits that nature provides, which have received increasing recognition during the COVID-19 lockdown. In Chapter 5, the outcome of the questionnaire is summarised. Chapter 6 provides an insight into the research opportunities that have emerged as a result of the pandemic, primarily quantifying impacts of human activities. We conclude with a set of key findings (Chapter 7) and recommendations (Chapter 8), including actions that could be taken to prevent or mitigate negative impacts of human activities in the post-COVID-19 era.

[2] Note: This period of unusually reduced human mobility was named the 'anthropause' by Rutz et al. (2020). Anthropause was selected by Oxford Languages as one of 2020's Words of an Unprecedented Year.

2 Methods

2.1 Introduction

In order to qualitatively assess the impacts of COVID-19 lockdown on wildlife, we carried out a literature review; surveyed news published online and through social media; submitted questionnaires to experts across the EU; and interviewed scientists at EU research institutions.

2.2 Review of the scientific literature

We searched for studies that address the (potential) impacts of the COVID-19 lockdown on wildlife, either directly or indirectly. Wherever possible, we have based this part of the review process on studies published in peer-reviewed scientific journals (in an attempt to maximize study quality and to ensure that all relevant information was included in the articles), but we have also included other relevant published reports.

Literature searches were conducted in the ISI Web of Science database (reference date: September 15, 2020), using the following keyword string: TS=(COVID* OR corona*) AND TS=(fauna OR flora OR wildlife OR ecosystem OR biodiversity OR animal OR plant) AND TS=(disturbance OR activity OR "breeding rate" OR behaviour OR behaviour OR traffic OR noise OR pollution OR stress OR mortality OR movements). We limited our search to the year 2020, as COVID-19 did not appear within the EU until January 24, 2020 (ECDC 2020). No particular country or language constraints were applied, although only English language search terms were used. We also searched Google Scholar (100 first hits, reference date: September 15, 2020) using combinations of the keywords included in the above search string. In addition, reference lists of all the sources that we reviewed were examined.

Primary empirical studies in which the effects of the COVID-19 lockdowns on wildlife were assessed were included, as well as reviews and policy papers. We included papers that: reported on both (potential) direct impacts and (potential) indirect impacts on wildlife, e.g. impacts through abiotic changes; and papers on terrestrial/fresh water and marine/coastal ecosystems and species. Although our primary interest was Europe, we also included papers from other regions, as the scientific output on the issue is still limited and the findings collected elsewhere may very well also apply to Europe.

Our search resulted in 319 scientific papers. After closer examination, 18 of these appeared to be relevant for the purpose of this report. Of these, ten papers addressed abiotic impacts, such as effects of the lockdown on air- and water-quality, which may affect wildlife. Three papers addressed issues of health, zoonosis or pest control. Three papers addressed issues that relate to wildlife conservation. And two papers addressed economic consequences, such as the tourist sector, that may affect wildlife.

2.3 Review of online news

Internet searches were conducted, using Google (reference date: October 1, 2020), using combinations of three (strings of) words: [COVID OR corona OR pandemic] AND [fauna OR flora OR wildlife OR ecosystem OR biodiversity] AND [disturbance OR human activity OR breeding success OR behaviour OR lockdown OR traffic OR noise OR pollution OR stress OR mortality OR movements OR species persistence]. Only English language search terms were used. We examined only the first 25 hits for each search string. In addition, where weblinks led to webpages with relevant news, these were also examined.

2.4 Questionnaire

We developed a short questionnaire, to be sent to a variety of experts across the EU, to survey current research initiatives that aim to assess the impact of the COVID-19 lockdown on wildlife. Our intention was to collect information on COVID-related research that had not yet been published. In addition, we were hoping to gain an insight into possible changes in human perception of wildlife and nature as a result of the COVID-19 pandemic. The questionnaire consisted of 21 questions (see Annex 1). The first eight questions were related to collecting personal information of the interviewee (see reference to the privacy statement below and in full on page 45), followed by thirteen questions related to collecting information on initiatives that target COVID-19 impacts on wildlife, such as studies that had been initiated, study background, specific objectives, type of data collection and potential collaborative actions. Furthermore, we surveyed if a horizon-scanning analysis on the impact of COVID-19 on wildlife at the national level had been carried out or was planned. In addition, we explored if there were indications that the appreciation of nature by people had changed during lockdown.

The questionnaire was sent to biodiversity experts and practitioners, notably professionals at environmental agencies and biologists, throughout the European Union. The questionnaire was sent to the European network of Nature Conservation Agencies (ENCA) and to the European Environment Information and Observation Network (EIONET), a partnership network of the European Environment Agency (EEA) and via the commission to the Coordination Group for Biodiversity and Nature (CGBN) and the Expert Group on the Birds and Habitats Directive (NADEG)[3]. In total, the questionnaire was sent to more than 900 experts. Experts were given three weeks to send in their responses. We received 27 responses, originating from 18 countries, between the 25th of September and the 15th of October 2020 (Annex 2).

2.5 Interviews

We approached a number of experts across Europe to provide a summary of ongoing research on the impact of the pandemic and associated measures on wildlife in Europe. In total, 13 experts, affiliated with universities or research institutes, were asked for information and seven replied (Annex 3).

2.6 Specific privacy statement

The full privacy statement that accompanied the questionnaire is set out on page 45. All personal data submitted to the project team/the EEA in the context of the consultation referred to above was processed in accordance with Regulation (EU) 2018/1275 of the European Parliament and of the Council of 23rd October 2018 on the protection of natural persons with regard to the processing of personal data by the Union institutions, bodies, offices and agencies and on the free movement of such data, and repealing Regulation (EC) No 45/2001 and Decision No 1247/2002/EC.

[3] Specifically, the groups were selected in discussion with the EEA as they contained relevant experts and knowledge holders representing all Member States and EEA countries.

3 Biodiversity conservation and the origin of the COVID-19 pandemic

Zoonotic coronaviruses, including SARS-CoV-2, which causes the COVID-19 disease, have become an increasing threat to human health (Perlman 2020). The outbreak of the COVID-19 pandemic has led to a global discussion about the possible reasons for a pandemic to occur. To prevent the occurrence and spread of zoonoses it is important to determine the precise origins of the virus and the vectors through which it is transmitted (Shereen et al. 2020). The exact source of virus outbreak is still unknown, however, it very likely originates from bats, as recently shown by Chinese researchers (Zhou et al. 2020, Sun et al. 2020). An important question is: *How did this virus provide the source for a major human pandemic?* As shown by Lorentzen et al. (2020), the interval of human diseases that originated from bats has had the tendency to shorten since the outbreak of Rabies in 1931. Lorentzen et al. (2020) describe that the possible reason for this shorter interval between outbreaks is climate change and the decline in biodiversity (habitats and species), as climate change may force species to explore new habitats and thereby bring wild animals, such as bats, closer to humans and their livestock.

Although the exact drivers behind the development of zoonoses are beyond the scope of this review, there appears to be a strong link with biodiversity conservation, as degraded ecosystems are frequently pointed out as the source of zoonoses. For example, McMahon et al. (2018) state that changes in land-use, animal populations and climate, primarily due to increasing human populations, drive the emergence of zoonoses. In general, habitat destruction and industrial agriculture play key roles in increasing zoonotic disease transmission, as people and their livestock come into ever closer proximity to wild species and pathogens (Petrovan et al. 2020). Everard et al. (2020) add that contemporary livelihood and market patterns tend to degrade ecosystems and their services, especially in tropical areas, driving a cycle of degradation in situations where socio-ecological systems are becoming increasingly tightly linked. This contributes to reductions in the natural capacities of regulating ecosystem services in limiting disease transfer from animals to humans. Consequently, maintaining or restoring healthy ecosystems may help to prevent zoonoses from occurring or may mitigate their impact. In this respect, Everard et al. (2020) explored the significance of disease regulation ecosystem services and their degradation in the emergence of COVID-19 and other zoonotic diseases. Furthermore, they have pointed out the importance of the protection of natural resources as mitigating contributions to both regulating human-to-human disease transfer and treatment of disease outbreaks. From this analysis, they identified a set of appropriate response options, recognising the fundamental roles of ecosystems and the services they provide in risk management. The importance of biodiversity conservation is also emphasized in a recent report of the European Environment Agency on COVID-19 and Europe's environment, which states that biodiversity loss and intensive food systems make zoonotic diseases more likely (EEA 2020a).

The study by Roviello & Roviello (2020) is also interesting in this respect. It shows lower COVID-19 mortality in humans in forested areas when compared to industrialized landscapes in Italy. One explanation, suggested by the authors, might be human exposure to higher levels of fine particulate matter (PM) in the air in industrialized and less forested landscapes, which may increase the likelihood of mortality. Their study also suggests that evergreen Mediterranean forests and shrubland plants could have protected the rural population through emitting immuno-modulating volatile organic compounds and, when eaten as foodstuffs, the provision of dietary sources of bioactive compounds. They emphasize that their results highlight the importance of nature conservation for protecting potential sources of natural antivirals (that may yet to be discovered).

4 Impacts of COVID-19 induced lockdowns

4.1 Changes in air- and water-quality impacting wildlife

Lockdowns have resulted in changes to air- and water quality worldwide (Corlett et al. 2020). As business and industry slowed down and some factories, shops and other retail outlets temporarily closed, air-, road- and waterborne traffic declined, and the emissions of pollutants reduced significantly in cities, such as Madrid, Barcelona, Rome, Milan, and Paris (Bar 2020, Collivignarelli et al. 2020, Tobias et al. 2020) and across Europe generally (EAA 2020b). As a result of the strict, national lockdown measures imposed across Europe, various European cities are showing an average decrease of 45% of atmospheric concentration of NO_2, with a drop of 54% in Paris (ESA 2020). Ghosh & Ghosh (2020) reviewed fifteen empirical research papers from four different continents – Europe, Asia, North America and South America (including, most notably: Baldasano 2020, Collivignarelli et al. 2020, Dantas et al. 2020, Gautam 2020, Jia et al. 2020, Kerimray et al. 2020, Kondo Nakada & Urban 2020, Zangari et al. 2020). They found that during the lockdown period, in general, there was a trend of decrease in the level of concentrations of PM_{10}, $PM_{2.5}$, CO, NO, NO_2, NH_3, NOx, SO_2 and an increase in the concentration level of ozone (O_3) compared to either the pre-lockdown period, or records from previous years (see also Archer et al. 2020, Bera et al. 2020, Muhammad et al. 2020, Selvam et al. 2020a, Metya et al. 2020). During the lockdown phase, the concentration of ozone increased in the lower atmosphere due to low consumption of O_3, leading consequentially to less emission of NO_2 from anthropogenic sources (Bera et al. 2020). High levels of NO, NO_2, NH_3 and NO_x cause eutrophication of natural areas and subsequent loss of plant diversity, as in many cases, ruderal, fast-growing weeds outcompete plants that require nutrient-poor substrates. The relatively short period of lockdown, however, is unlikely to result in any measurable changes in, e.g., vegetation or associated fauna (Anonymous 2020a), however, the observed reduction in their levels during the pandemic is likely to be beneficial. Conversely, the exposure to increasing levels of O_3 is known to reduce photosynthesis, growth, and other plant functions (Felzer et al. 2007, The Royal Society 2008a, 2008b).

For a measurable effect to occur, a permanent reduction in nitrogen emissions or an increase in ground-level O_3 is required, as well as management measures that address nitrogen loads that have already accumulated in natural areas. As also stated by Filonchyk et al. (2020), lockdown temporarily improved air-quality in the short-term, but as soon as coal consumption at power plants and refineries returned to normal functional levels, pollution levels returned to their previous level. This is supported by a recent briefing of the European Environment Agency, which states that the lockdowns during the COVID-19 pandemic may have some direct, short-term, positive impacts on our environment, especially in terms of emissions and air-quality, but that these are likely to be short-lived (EEA 2020a). Nonetheless, the impacts of the lockdown provide an insight into the potential reductions in nitrogen emissions that could be established through energy transitions, such as the replacement of fossil-fuelled cars by electric ones (when the electricity production is also from alternative energy sources). The situation is similar for the measured reductions in greenhouse gasses, such as CO and CO_2. These pollutants cause global warming, which indirectly affects biodiversity through global changes in climate. However, measurable effects for these pollutants on planetary warming are unlikely, as diminished concentration levels will only lead to changes in global temperatures in the long-term.

Reduced air pollution may positively influence the breeding success of birds, notably of species that depend on insects that are negatively affected by air pollution. Manenti et al. (2020) monitored the breeding success of the Common Swift (*Apus apus*) at a breeding site in northern Italy, where up to 80 pairs breed each year in nest boxes. Like many other locked-down areas, northern Italy experienced a significant decrease of several air pollutants in March and April 2020, including NO_2, benzene and SO_2, which apparently resulted in higher breeding success for the swifts during the lockdown. In fact, the frequency of four-egg clutches during 2020 was much higher when compared to

the results for 2017–2019. The authors suggest that the breeding success was linked to improved air-quality, which through its effect on insect numbers improved the survival of chicks.

Reduced levels of industrial effluent and less boat traffic during lockdown improved water-quality, but studies from Europe are scarce. In Venice, Italy, the clarity of the water in the canals improved considerably due to a pause in discharge of industrial effluent and restrictions in boat traffic (Braga et al. 2020). Braga et al. (2020) note that increased water transparency may have positive impacts on marine benthic ecosystems in the area, including the growth of phytoplankton (see also Mack 2020).

Changes in water pollution were also obvious in other parts of the world, such as from waters in India. Thus, Yunus et al. (2020) reported a 15.9% decrease in suspended particular matter in a lake compared to the previous year, while Selvam et al. (2020b) found a significant decrease in ground-water pollution. Selvam et al. (2020b) studied both chemical- and biological groundwater quality parameters. They found significant reductions in selenium (42%), arsenic (51%), iron (60%) and lead (50%), probably owing to no, or considerably reduced wastewater discharges from metal-based industries, seafood-based industries and thermal power plants during lockdown. Reduction in nitrate (56%), total coliforms (52%) and faecal coliforms (48%) was also assessed, indicating less organic sewage from the fishing industries. Contents of chromium, copper, zinc, cadmium, and fluoride showed similar reductions. Furthermore, no significant alterations were observed in Escherichia coli and faecal *Streptococci* occurrence, as domestic sewage production during lockdown remained the same, which is in line with expectations. While no direct link with biodiversity is made by the authors, significant reductions in nitrate and metal levels in groundwater may, in the long-term, positively affect plant and animal life. The study also implies that groundwater is under active interaction with surface waters and, thus, should anthropogenic activities cease, a quick revival would be observed.

4.2 Illegal killing and persecution of wildlife species

COVID-19 lockdowns have been characterized by numerous reports of increased poaching (both subsistence- and commercial-) and illegal resource extraction, both globally and in Europe (Hockings et al. 2020, Athumani 2020, Badola 2020, Bendana and Brown 2020, Cherkaoui et al. 2020, Gardner 2020, Ghosal and Casey 2020, Marchall 2020, Neupane 2020, Corlett 2020; Conservation International 2020, WCS 2020, Whitehead 2020). Though wildlife crime typically evokes images of elephant tusks, rhino horns or pangolin scales intended for Asian markets, illegal shooting, trapping, and poisoning of animals in Europe also appear to have increased during COVID-19 lockdown. During the anthropause, large parts of Europe's countryside lacked patrols and monitoring by scientists, rangers, hikers and tourists, who normally help deter poaching. As a consequence of this reduced ability to detect and combat threats, opportunities for illegal killing and persecution of wildlife species have increased (Manenti et al. 2020, Corlett 2020, Buckley 2020, Bendana and Brown 2020, Hockings et al. 2020).

Within Europe, a number of examples of the increased poaching threat due to reduced 'policing' during the pandemic have been noted. These include a resurgence of shooting of migratory birds in Italy (Manenti et al. 2020), but in particular the killing of at least eight species of birds of prey and owl in the U.K. and eastern Europe (Wordley 2020, Hollenstein and Lucius 2020, Marchall 2020). Apart from raptors, the loss of jobs during lockdowns in Romania, Bulgaria and Ukraine may have caused a surge in illegal fishing for lucrative sturgeon caviar (Wordley 2020); sturgeon numbers have suffered major declines in the past from the negative impacts of overfishing and poaching in Europe. It is important to note that the data described above provide just a first indication of the impact of illegal killing and persecution of wildlife species in Europe, and that quantitative information on poaching and associated trends during lockdowns are scarce (although assessments are pending, Rutz, pers. comm. 2020).

Travel restrictions within and from Europe, have had significant effects on ecotourism and associated income streams, particularly at local level; there have also been impacts on at the tourism destinations and elsewhere. Lindsey et al. (2020) have pointed out that, in Africa, the COVID-19 pandemic has resulted in reduced income from tourism and other funding, and has imposed restrictions on the activities of conservation agencies, such as anti-poaching operations. They have

acknowledged that restrictions in human movement may benefit biodiversity conservation in some ways, but they believe that, on the African continent, the net conservation impacts of COVID-19 will be strongly negative. Firstly, they have pointed to a surge in illegal killing of wildlife as a result of loss of resources and restrictions on movement on the continent; notably through loss of tourism revenues that fund a lot of conservation and help to protect wildlife (Newsome 2020). This view is supported by Rondeau et al. (2020), who reviewed the economic channels by which the COVID-19 pandemic and subsequent policy responses may affect wildlife and biodiversity. They have concluded that the most salient feature of the pandemic is the creation of multiple income shocks to rural and coastal households in biodiverse countries, correlated across sectors that represent different tourism-related activities, and spatially. Lindsey et al. (2020) have proposed a set of actions necessary to safeguard African wildlife and landscapes and associated rural populations during and beyond the COVID-19 crisis. They have provided specific recommendations required to: (1) manage the immediate crisis; (2) tackle environmental destruction and address the ongoing threats of habitat destruction and illegal, unsustainable and/or unsafe wildlife trade; and (3) address systemic flaws in the current conservation model.

The pandemic may also lead to illegal persecution of wildlife suspected to be involved in the spread of disease. At present, evidence is lacking on the source of the disease, although SARS-CoV-2 related coronaviruses have been found to be circulating widely in bats and pangolins (Sun et al. 2021), (see also Chapter 3). Still, while the pandemic spread, requests for hibernating bats in or near their houses to be destroyed have increased dramatically, in China, Peru and elsewhere (Dalton 2020, Zhao 2020). Exterminating colonies of bats because they were considered a possible source of COVID-19 could be counterproductive and even expose people to greater risk of new viruses. Jiguet (2020), has pointed out that typical controls do not succeed in reducing animal numbers and the associated damage they may cause, and that controlling bats or other presumed vectors can be counter-productive by increasing the infection risks for humans and livestock. In addition, bats serve many critical roles in ecosystems, by consuming large quantities of insects, and contributing to pollination and seed dispersal for many important plants (Zhao 2020). As such, the proposed elimination of bat colonies could lead to negative, cascading impacts on ecosystems.

4.3 Shifts in the distribution of wildlife

The most notable change during the lockdowns has been a reduction in human mobility. One of the most rapidly-visible phenomena resulting from lockdown and the associated containment of people in their homes was that wildlife 'took over' or returned to areas that had previously been subjected to high levels of human disturbance (Rutz et al. 2020). The first reports of such behaviour came from Italy, during the first European lockdown. Wolves were seen in a park in the industrial centre near Florence, and fallow deer invaded a golf course on Sardinia, even using the swimming pool (The Economist 17 April 2020). At Cagliari on Sardinia, bottlenose dolphins entered the, by then much calmer, port during the lockdown, and residents of Istanbul in Turkey have said that dolphins were coming further up the Bosporus than usual. Wild Boar were seen foraging for food around Haifa in Israel, and downtown Barcelona in Spain, during the pandemic, encouraged by the absence of humans, according to residents (Haaretz 13 April 2020, Kretchmer 2020). As noted by Zellmer et al. (2020), lockdowns may be detrimental to some species that thrive in cities, especially those that depend on humans for food.

Few changes in animal behavioural patterns following lockdowns have actually been quantified. In northern Italy, increased activity of deer and other normally nocturnal species was reported during daylight, as a possible response to the reduction in human activity (Stockstad 2020). Animals not only changed their daily activity patterns, but researchers also noticed a shift in animal distribution towards areas that were normally avoided, similar to changes reported after the nuclear disasters of Chernobyl and Fukushima, when wildlife took advantage of the sudden decline in human activity (Higley 2006). Manenti et al. (2020) analysed data from a long-term, citizen-science project monitoring the distribution of crested porcupine (Hystrix cristata), comparing the number of records of these porcupines in March–April throughout Italy in the years before the pandemic with the situation in 2020. Although the total number of records of porcupines in 2020 was similar to that recorded in

previous years, the proportion of records in urban areas increased greatly in 2020 compared to previous years, whereas the number of observations in non-urban settings did not change. A similar change in distribution was recorded for Kentish Plover (*Charadrius alexandrines*) nests, indicating a shift toward the highly touristic and normally unsuitable area, which was never occupied in previous years of monitoring (Manenti et al. 2020). The same authors counted waterbirds during four census sessions in April 2019, and again in 2020, at an artificial lake that is normally subjected to recreational disturbance. Overall, only two species were observed in 2019, whereas 10 species were observed in 2020. The abundance of these 10 species was significantly higher in 2020 compared to 2019, and several species were found breeding for the first time.

A partial lockdown in the Netherlands meant that there was a strong advice from Government not to go to work. Furthermore, sports were not allowed, and bars, restaurants and most shops were closed. As a consequence, visitor numbers in most nature reserves increased, except the ones that had been closed for the public (Strijbosch 2020). On the beaches of the Maasvlakte in the Netherlands, a decrease in human disturbance is likely to have been the reason behind why Ringed Plovers (*Charadrius hiaticula*) and Little Terns (*Sternula albifrons*) started breeding in an area in which these species are usually almost never seen breeding (Anonymous 2020b). Both species are known to be sensitive to disturbance, and tend to avoid areas with high disturbance (Liley & Sutherland 2007, Medeiros et al. 2007). Such results appear to suggest that, under lockdown measures, animals do occupy areas that are generally avoided due to high levels of human disturbance.

Equivalent effects were also seen outside Europe (Stockstad 2020). In Thailand, on the Island of Phuket, which is a tourist hotspot, 11 sea turtle nests were found, representing the highest number of nests recorded on this beach during the past 20 years (Guy & Walsh 2020). In Florida, it also seems that greater numbers of sea turtles were nesting on the beaches (Ebrahimji 2020). Human disturbance is known to affect both nesting success and nest site selection by sea turtles (Antworth et al. 2006).

It is important to acknowledge a change in the detectability of animals that may skew results. Some behavioural changes may already have occurred before the lockdown, and detection rates may have increased during the lockdown, for example, because animals became more conspicuous due to reduced levels of ambient noise (Brambilla et al. 2020, Zellmer et al. 2020). For species that are detected mainly based on acoustic surveys, like birds, the strong increase of observation effort during the lockdown could explain a substantial part of the increase in species richness and in first sightings of many species in urban areas (Manenti et al. 2020). In addition, more people may have been 'on the lookout' for wildlife during a lockdown, so the increase in urban sightings of wild species could also have been due to increased observation effort (Zellmer et al. 2020). Similarly, many data on medium- and large-sized mammal species recorded during COVID-19 lockdown do not necessarily represent changed patterns of behaviour or distribution.

4.4 Impacts on urban wildlife

The impact of reductions in human mobility during lockdowns are especially visible in urban areas, with likely influences on urban wildlife. Indeed, wild animals appeared to venture into cities worldwide during periods of lockdown. Deer, wild boar, jackal, buffalo, lemur, sealion and dolphin are just a few of the species reported exploring urban areas – in search of food or new habitat (see for example: The Guardian 22-4-2020, BBC News 28-4-2020). In Chile, four native carnivores were recorded in cities during partial lockdowns, which had not been previously linked to urban areas (Silva-Rodríguez et al., in press). Although a correlation may seem obvious, the authors emphasize that it is difficult to determine if these records were influenced by partial lockdowns. They call for caution in the interpretation of seemingly novel sightings during periods of lockdown.

The anthropause may also have affected behavioural patterns of wildlife in cities, such as in birds. Urban songs are shorter and sung faster than songs in forests, and often included atypical song types (Slabbekoorn and Den Boer-Visser 2006). Anthropogenic noise is most likely a dominant factor driving these dramatic changes. Such adaptations reveal a behavioural plasticity that may be key to urban success; the lack of such plasticity may explain the detrimental effects observed on bird communities

that live in noisy urbanized areas or along highways. To further investigate how urban noise impacts bird song, Gordo et al. (2020) compared the occurrence and detectability of birds during the Spring 2020 lockdown with baseline data from previous years in the same urban areas in Spain. They found that bird numbers did not increase in urban areas during the lockdown. However, an increase in bird detectability during early morning and other times of the day, indicated a change in the birds' daily routines in response to quieter conditions in urban areas. Derryberry et al. (2020) found that the reduction in traffic sound in the San Francisco Bay Area of California had led to a shift in song frequency in white-crowned sparrows. They conclude that this shift was especially notable because the frequency of human-produced traffic noise occurs within a range that interferes with the highest performance and most effective song. These observations indicate that urban birds show high behavioural plasticity to enable rapid adaptation to novel environmental conditions, such as those imposed by the COVID-19 lockdown measures.

Conversely, the pandemic may have created new challenges for some species. Thus, urban-dwelling species that have become very reliant on food discarded or provided by humans (e.g. such as rats, gulls or monkeys), may struggle to survive under current conditions (Rutz et al. 2020).

4.5 Reduction in road impacts

COVID-19 caused a European wide reduction in road traffic (European Data Portal 2020). Significant road traffic reductions during lockdowns was expected to decrease the ecological impacts of roads on wildlife populations, especially for those species that are susceptible to road-killing, such as amphibians, reptiles, passerines, birds of prey and owls, rodents and carnivores (Hels & Buchwald 2001, Beebee 2013). Such reductions in mortality may have important population-level consequences. Indeed, roads are one of the main causes of modern-day vertebrate population decline and for the decrease of viability between generations (Crooks and Sanjayan 2006). For Iberian lynx, road kills are the principal cause of death among cubs in Spain (Ferreras et al. 1992), and a similar pattern is seen for badgers near urban zones in Britain (Clarke et al. 1998), where road fatalities have also contributed to otter population declines (Philcox et al. 1999). European roads are also a major source of mortality for smaller mammals, such as hedgehogs (Moore et al. 2020). Road fatalities are among the major causes of mortality for owls and may affect the survival of the populations of some species (Ramsden 2003). For example, Spanish barn owl populations decreased by 70% over a 10-year period, mainly due to road casualties (Fajardo 2001).

Few studies have quantified the effect of the anthropause on road kills in Europe. Manenti et al. (2020) compared the number of road-killed amphibians during the spring breeding migration at eight sites in Italy, which were surveyed both during 2019 and 2020. They recorded a significant decrease in the number of road-killed amphibians across these sites, which suggests that more amphibians could reach breeding sites in 2020 than in previous years. Across all sites, 408 common toads *Bufo bufo* and 16 agile frogs *Rana dalmatina* were found dead in 2019, whereas only 38 common toads and no agile frogs were found dead in 2020. These results, albeit with small sample sizes, agree with previous studies that revealed a negative correlation between the relative abundance of amphibians and traffic density (Fahrig et al. 1995, Carr and Fahrig 2001, Hels and Buchwald 2001). In addition, transect survey data of road-killed lizards (common wall lizards *Podarcis muralis* and western green lizard *Lacerta bilineata*) showed that mortality was ten-fold higher in 2019 compared to 2020 (number of detected dead lizards: 11 in 2019, 1 in 2020 – although the small sample size requires acknowledgement).

Studies outside Europe show much the same. For example, one study in the Western U.S. found that road collisions with wildlife have declined by 21-45% following government stay-at-home orders and strong reductions (circa 63-73%) in traffic densities (Nguyen et al. 2020). The researchers used traffic and collision data collected in California, Idaho and Maine, and concluded that under lockdown conditions, about 5,700 to 13,000 fewer large mammals could be killed each year in those states, and 50 fewer mountain lion deaths per year in California.

A decrease in road traffic density may also be beneficial to insects. One of the United Kingdom's biggest bee farms had noticed that their bees appeared to thrive during the COVID-19 pandemic, likely caused by a decrease in traffic and lower levels of pollution (Walden 2020). A review performed in 2015 showed that many insect species are influenced by road traffic, where an increased traffic volume in many studies showed an increase in dead and damaged insects and a decrease in insect populations (Muñoz et al. 2015). It has been noted that rare wildflowers and declining bee populations could also start to recover during COVID-19 lockdown, because many municipalities have left roadside verges uncut (Plantlife UK 2020). In combination with lower levels of traffic, less spring verge-cutting could also benefit butterflies, birds, bats and insects that depend on roadside flowers for survival, although few studies have quantified such impacts.

Reduced levels of traffic may also have positive consequences for wildlife impacted by disturbance, such as light and noise pollution. For example, traffic noise is known to reduce the foraging efficiency of owls (Senzaki et al. 2016, Mason et al. 2016), or acoustic communication in other bird species (Leonard and Horn 2005, Mockford and Marshall 2009), with negative impacts on reproductive success (Halfwerk et al. 2011). Furthermore, roads and traffic cause a barrier effect that may prevent animals from crossing, thus, isolating populations. Although no studies have been published on this issue yet in relation to lockdown measures, reduced traffic volumes may also decrease the barrier effect of roads.

4.6 Appreciation of nature

In addition to the impact on wildlife, there are indications that people's appreciation of wildlife may have changed during the pandemic. The COVID-19 pandemic has caused unprecedented changes to mobility, economic activity and with an associated impact on the environment (Muhammad et al. 2020, Venter et al. 2020a). Governments have enacted policy measures during lockdowns aimed at preventing the transmission of the virus, like limiting transport and public mobility (Musselwhite et al. 2020). Half of the world's population has been under some form of confinement (Sanford 2020).

It has become obvious that the appeal of outdoor activities has been boosted by enforced COVID-19 restrictions. For example, Norway allowed its citizens to spend time outdoors during the lockdown. This resulted in a 291% increase in recreational activity during lockdown in Oslo. Both pedestrians (walking, running, hiking) and cyclists showed evidence of intensifying their activities on trails with attractive natural vistas and tree canopy cover. It was observed that pedestrian activity not only increased in city parks and peri-urban forests but also in protected areas (Venter et al. 2020b). In a survey of consumers in seven EU Member States (France, Germany, Italy, Poland, Spain, Sweden, UK) 70% of respondents 1,000 per country) stated that they specifically looked forward to participating in outdoor activities, like hiking, climbing, cycling, snow sports and other mountain activities after lockdown had eased (European Outdoor Group 2020). Similar figures were found in the Netherlands where 60% of the citizens stressed the importance of nature recreation during the lockdown, while 75% even agreed that the number of nature areas should be increased (Motive Action 2020). It is obvious that an increasing demand to enjoy nature could be observed among the public in many European countries during and (immediately) after lockdown. These increased visitor densities, in some countries, but not others (Figure 4.1), have probably also resulted in an increased ecological impact within the protected areas concerned. This new situation may necessitate an evaluation of visitor management and/or an increase in natural areas that are available for recreation, particularly if this can reduce the pressure on existing protected areas with fragile and highly valuable habitats and species.

However, figures to substantiate this observation and whether it concerns short-term or long-lasting impacts, are unfortunately not yet available. In some cases, outdoor enjoyment of nature has changed considerably, depending on the extent of the lockdown, suggesting that lockdowns with strict regulations may severely impact on leisure activities. Randler et al. (2020) analysed 4,484 questionnaire survey responses from 97 countries focusing on bird-watchers, which showed that the most significant change in bird-watchers' behaviour was related to the geographic coverage of birding activities, which became more focused on yard (garden) bird-watching than before.

Respondents from developed countries, including European nations, reported that they currently spend more time on birding, especially on birding alone or with their spouse, and bird watching at local hotspots. The percentage of people reporting that COVID-19 changed their birding behaviour was lowest (68% and lower) in Czech Republic, Denmark, Finland, Norway, Poland, and Sweden, while 96%-100% of the participants reported changes from France, Italy, Spain, and the UK. In other countries, spatial changes were mostly related to birding closer to home, such as in Czech Republic, Denmark, Finland, Norway, Poland, and Sweden (Randler et al. 2020).

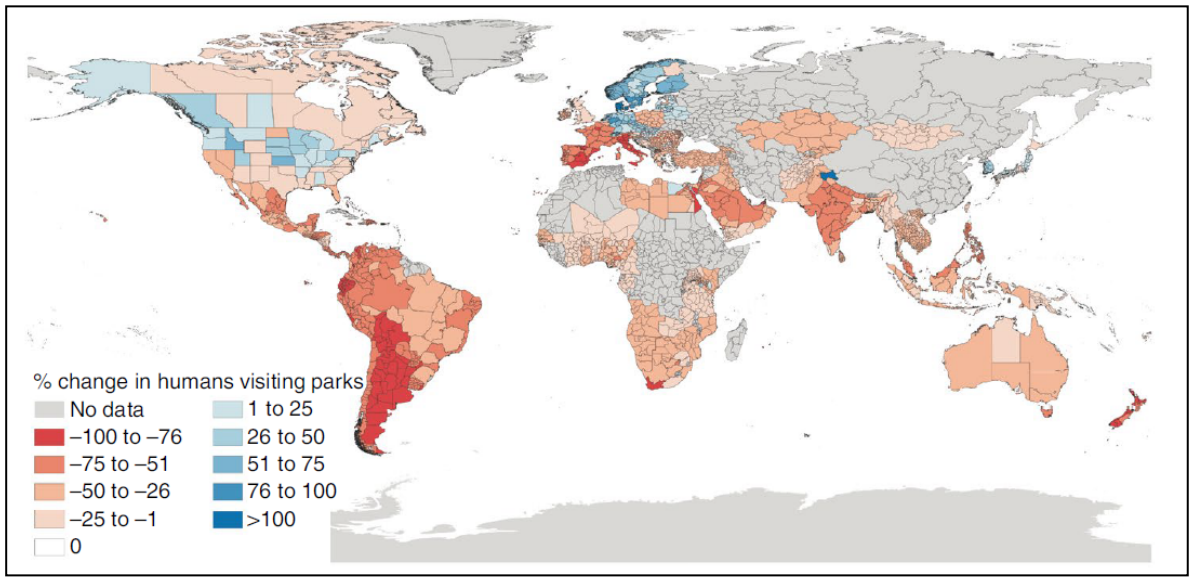

Figure 4.1 *Median percentage of change based on daily values (with reference to the data provider's default baseline from the five-week period between 3rd January and 6th February 2020) in visits to places like local parks, national parks, public beaches, marinas, dog parks, plazas and public gardens for the month of April 2020. As noted by Rutz et al. (2020), these preliminary data should be interpreted cautiously. Source: Rutz et al. 2020, who plotted data from Google COVID-19 Community Mobility Reports.*

Rousseau and Deschacht (2020) analysed online search behaviour in twenty European countries, and found that nature-related topics were more highly searched after the onset of the pandemic, suggesting that public awareness of nature had increased. Lemmey (2020) found that there has been a large increase in desire to spend time in nature among adults in the UK, with 72% of women and 60% of men reporting that they are more likely to do so in the future following lockdown. Lockdown saw all age groups spending more time each day in nature, focusing mostly on birdsong, watching wildlife or specifically observing bees or butterflies. More than a third of respondents had intentionally studied nature in detail during the lockdown, for instance by learning to identify trees or birds. Taking photographs, or discussing nature with friends and family had also been much more frequent during the lockdown than before (Lemmey 2020). Importantly, 70% of respondents said that they will be more likely to notice nature in their local area in the future and only 0.1% stated that they will be less likely to do so. In addition, the majority of respondents said they are now more likely to encourage nature in their garden. Finally, parents or carers are now considerably more likely to encourage their children to spend time in nature in future, according to the survey results. These results suggest experiences during lockdown may be associated with increased nature-connectedness among the UK adult population.

Another study, conducted in the Netherlands (Vogelbescherming 2020), showed that 75% of interviewees thought that the number of nature areas should be increased, while 73% were of the opinion that nature investments should become an integral part of the economic recovery from COVID-19. These figures support the EU's goal to protect 30% of land and sea by 2030, as stated in the Biodiversity Strategy 'Bringing nature back into our lives'.

Despite a positive shift in public awareness of nature-related topics, it may be short-lived as choice determinants and context change when the situation reverts back to normal. Rousseau and Deschacht (2020) have suggested that, in order to benefit from the increased support for nature and biodiversity, it may be important to act quickly and to incentivize a long-term change by, for example, supporting urban schemes for greening built infrastructure and creating liveable cities.

Increased human–wildlife interactions during lockdowns may have multiple psychological benefits and could reshape people's understanding of, and relationships with, local species (Zellmer et al. 2020). When excursions from household confinement are allowed, nature can provide people with opportunities to enjoy positive effects that increase their well-being, while at the same time allowing them to maintain social relationships (in circumstances of social distancing). The soothing role of nature may be especially important as stress and anxiety arising from confinement, domestic conflicts, or job and income losses, could lead to a mental health crisis (WHO 2020). Nature, thus, plays a critical role in local social resilience during this crisis by maintaining physical and mental well-being, particularly in urban centres (Samuelsson et al. 2020).

Support for wildlife conservation may be enhanced if people are better informed about the cause of the COVID-19 outbreak. It is important to understand the impact that stories and narrative shared in online news and social media have on people, since this is where they increasingly obtain information about public health and environmental issues. Shreedhar & Mourato (2020) investigated if online narratives in which the cause of the COVID-19 pandemic is presented in different ways affects pro-wildlife conservation outcomes. They found that when the narrative gave the cause as a combination of animal- and human factors, this elicited significantly greater pro-conservation policy support, especially for bans in the commercial trade of wildlife, than for the control group that was presented an animal cause only. The authors discuss that possible mechanisms driving this effect are that animal/human cause narratives were less familiar, elicited higher mental and emotional engagement, and induced feelings that firms and governments are responsible for mitigating wildlife extinction. The results from this experiment have suggested that this type of conservation narrative is more likely to grow public engagement with extinction, which may have relevance for crafting a durable and legitimate long-term policy response to COVID-19.

5 Questionnaire survey

A total of 27 people filled in the online questionnaire. The majority of the reactions came from national governments (67%), other responding organisations were regional governments and research institutes/universities. We received responses from 14 EU countries and four European countries outside the EU (Israel, Turkey, Scotland and Switzerland). All countries had only a single respondent, except for Croatia with five respondents, Turkey with four respondents and Poland with three respondents. Most of the participants indicated that they worked within multiple habitat types; only three respondents indicated that they worked on a single habitat (urban and protected areas) and three participants indicated working in all habitats. The habitats most frequently referenced by the participants were grassland (20 participants) and forest (19 participants). An overview of the survey statistics is presented in Annex 2.

Of the respondents, only three people indicated that they are currently collecting data on the effects of COVID-19 on wildlife. The respondent from Israel described that they are investigating the effect of COVID-19 on the distribution of animal species, population size and trends, habitat use and movements, with the objective of addressing the impact of human disturbance and pollution. The respondent from Scotland indicated that they are collecting data on the effects of COVID-19 on human disturbance on wildlife and wildlife crime. This initiative had already received reports of illegal persecution of raptors, which lead to the creation of a systematic listing of all reported incidents to determine any impacts of COVID-19 restrictions. The reports from Scotland are partly derived from satellite-tagged raptors. The respondent from Slovenia stated that they are collecting all relevant data on the impact of the COVID-19 pandemic on the environment, from every possible source. The respondents from Israel and Scotland indicated their willingness to share their data.

A number of participants described their experience or assessment of the impact of a COVID-19 lockdown on wildlife. While the sample size is small (and this must be acknowledged in assessing the responses), a number of aspects were clear. Firstly, the impact of a lockdown appears to be strongly influenced by the severity of the lockdown. A complete lockdown, during which people are either forced to stay at home, or are at least banned from nature, was said to result in behavioural changes in birds and large mammals, such as movements closer to human settlements. Nesting shorebirds were reported to benefit from the lack or reduction of human activity around coastal areas. However, when the lockdown only restricts people from going to work or to public buildings and cities, people are likely to crowd nature reserves, as was mentioned by various respondents.

Most of the respondents, from almost all participating countries, stated that people visited more natural areas during lockdown. In Switzerland, a partial lockdown resulted in increased human activity in natural areas. The Danish Nature Protection Agency performed a survey that showed an increase of 12,000 bookings of shelters within state-owned nature areas, when compared with 2019. In some countries, people moved around more within protected areas, which enabled them to appreciate the reserves more, but also increased disturbance levels. In countries, such as Hungary, hiking was allowed during lockdown; however, the Hungarian Government advised people to avoid large groups, so hikers showed up in areas that are infrequently visited under normal circumstances, such as deep forest, major grasslands and agricultural areas. Such visits to previously quiet terrain may have led to increased disturbance, for instance, to breeding birds.

Respondents disagreed on the reasons for the increase in visitation rates to nature reserves. It was suggested that people had more ‘time on their hands’ and, therefore, had increased opportunity to visit and enjoy nature reserves during the anthropause. Respondents expected that many people visited natural areas because they had ‘nowhere else to go’, as most shops and touristic sites had been closed. This group of people was held responsible for higher levels of disturbance and pollution of natural areas.

Respondents suggested various ideas for studies that would compare the situation before and after the COVID-19 lockdowns, with the period during the lockdown, including a comparison of mammal and bird activity based on camera trap imagery, bird breeding success, change of human perception of wildlife, and of the distribution of species as a result of a change in the number of visitors to natural areas.

6 Research opportunities

6.1 Quantifying impacts of human activities

The COVID-19 pandemic has significantly reduced levels of human activity and mobility worldwide. Across continents, countries have imposed similar sanctions with substantial, far-reaching and immediate effects. With such global changes to human behaviour, a situation arose that is impossible to recreate using standard experimental set-ups, and which, therefore, provides a unique opportunity to study the impact of human activities on wildlife. This opportunistic use of the current situation in shedding light on species' sensitivity to human activities has been highlighted by various authors (Rutz et al. 2020, Corlett et al. 2020, Zellmer et al. 2020).

Rutz et al. (2020) coined the term 'anthropause' to describe the current period of reduced human mobility and proposed how the international research community can use the changes in human mobility to gain mechanistic insight into how human activities affect wildlife. The current situation has provided us with an opportunity to answer questions related to the movements of animals in modern landscapes, and if they are predominantly affected by built structures, or by the presence of humans. Previously, the presence of humans was usually confounded by the presence of buildings and *vice versa*, making it impossible to study the impact of each on wildlife separately. As preliminary data seems to suggest that even relatively elusive animals are moving into urban areas, their avoidance of built-up areas may be related to the presence of humans, rather than the urban landscapes per se; but this remains to be seen for the majority of species. Of great significance is the opportunity that these new circumstances have offered for identifying species that have the capacity to recover and respond to the change (specifically a reduction in human activity and disturbance), and those that cannot and can, therefore, be classified as particularly vulnerable. As there may likely be a lag in how wildlife populations respond to the human confinement, researchers should continue to monitor populations after lockdowns end to evaluate these longer-term patterns in behaviour and distribution. Furthermore, if lockdowns lead to lasting shifts in human activities, such as reduced traffic as more people work from home, then perhaps they will also have longer lasting effects on wildlife.

As the occurrence of a pandemic and associated lockdown measures are hard, or even impossible, to identify before the event, such studies on anthropause effects will only be feasible if data collation networks are already available and the set-up of these networks allows for *post hoc* analyses on lockdown impacts. Hence, it may be highly beneficial if future, long-term measuring networks are designed in such a way that research questions beyond the scope of the particular project at hand can be answered, including impacts of sudden changes in human activity.

6.2 Collaborative research initiatives

Wildlife biologists, human mobility researchers, bioinformaticians and other experts have initiated platforms for ambitious large-scale analyses that assess the impact of human mobility and activity on wildlife.

In April 2020, Francesca Cagnacci, Matthias-Claudio Loretto and Christian Rutz initiated the COVID-19 Bio-Logging Initiative, to analyse global animal tracking data collected during the pandemic. The consortium was launched under the umbrella of the International Bio-Logging Society (www.bio-logging.net), in close partnership with the Max Planck–Yale Center for Biodiversity Movement and Global Change, the Max Planck Institute of Animal Behavior, the Senckenberg Biodiversity and Climate Research Centre, the Movebank data-sharing platform, and several other institutions. The aim of this community-driven collaborative project is to investigate how wildlife responded to altered levels of human activity during the COVID-19 pandemic, using data collected by

so-called 'bio-loggers' — miniature animal-attached tags that record animals' movements, activity patterns and behaviour (Rutz et al. 2020). Specifically, the team will use bio-logging data collected before, during and after lockdowns, and from less-impacted 'control' sites, to detect anthropause effects. A call for collaboration, which was initially posted to the >1,000 members of the International Bio-Logging Society, indicated the potential availability of bio-logging datasets for almost 200 animal species across more than 320 study populations, ranging from small birds to whales, and covering all of the world's continents and major oceans. In addition to a large number of individual research teams, several major research networks have joined the initiative, or are in the process of joining, including EUROMAMMALS, the European Tracking Network (ETN), and the Ocean Tracking Network (OTN). With funding from the Gordon and Betty Moore Foundation and the National Geographic Society, the COVID-19 Bio-Logging Initiative currently focuses on harmonising submitted animal tracking datasets, inviting additional data contributions, sourcing high-resolution data on human mobility and road and vessel traffic, and developing a portfolio of complementary sub-projects. For the marine arm of its activities, the team is planning to seek endorsement from the United Nations Decade of Ocean Science for Sustainable Development (2021–2030). A first set of sub-projects will be launched in early 2021, to examine a variety of animal responses (e.g. distance travelled per day; home-range size; habitat use; crossing of roads or shipping routes; daily activity patterns) across different taxa, habitats, and regions. The COVID-19 Bio-Logging Initiative has the potential to bring about a step-change in our understanding of human–wildlife interactions. It will examine — with an unprecedented degree of replication and control — how humans affect the movements and behaviour of a wide range of terrestrial and marine animals, paving the way for evidence-based conservation interventions, environmental planning and policy making.

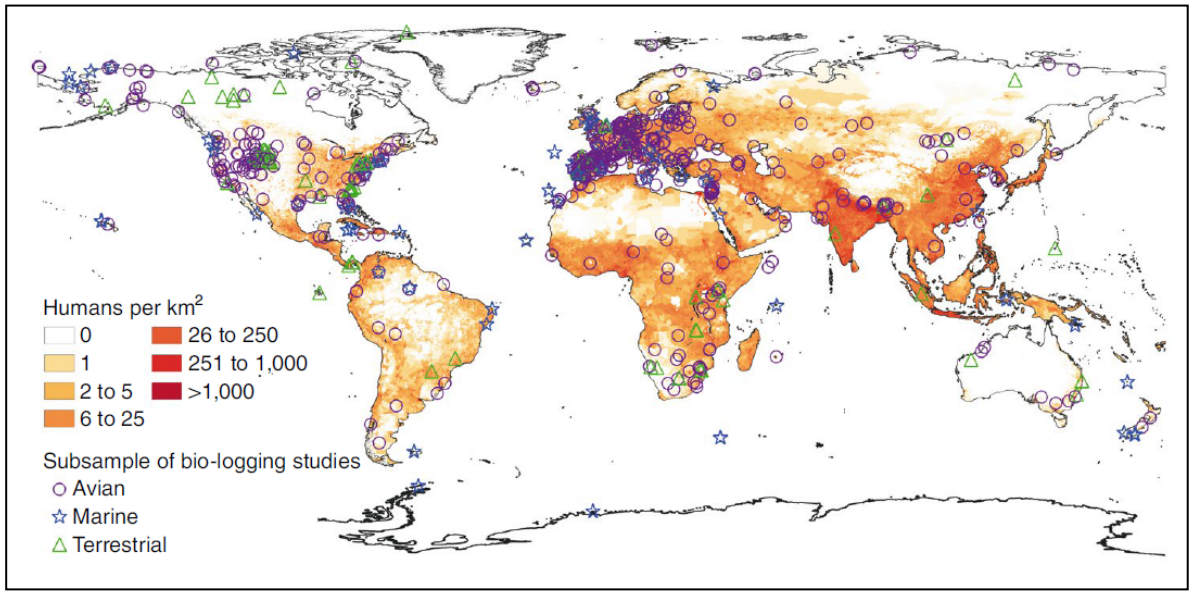

Figure 6.1 *Locations of a subsample of 801 active animal tracking ('bio-logging') studies overlapping with the COVID-19 period superimposed on human population density. Some of these studies may be used for collaborative projects organised by the COVID-19 Bio-Logging Initiative. Source: Rutz et al. 2020.*

The COVID Cameratrap Comparison Collaboration seeks to document changes in animal behaviour and habitat use before, during, and after COVID-19 lockdowns across geographic regions and land use types (e.g. gradients of urbanisation, protected area status). This initiative is coordinated by Cole Burton, University of British Columbia, Vancouver BC, Canada, and Roland Kays, North Carolina State University, Raleigh NC, US, in collaboration with Francesca Cagnacci, Marco Heurich, and Stefano Focardi of the EUROMAMMALS network, who are coordinating European data contributions. Researchers are invited to join the collaborative effort by making available camera trap data before and after the pandemic and lockdowns. The aim is to measure changes in animal behaviour, habitat use, and abundance using a Before-After-Control-Impact (BACI) design. Accordingly, the coordinators are calling for the contribution of camera trap datasets that sampled animal responses across the

anthropause (i.e. before/during/after lockdowns) or that contrast responses between areas with different degrees of change in human activity. To strengthen the scope of inference, they aim to engage with a large group of collaborators who can contribute data across the diverse geographic regions and land use types mentioned above. At a minimum, the coordinators ask that the datasets include sampling at the same locations before and during the anthropause. They are also interested in data collected during the anthropause from at least two areas with markedly different changes in human activity (e.g. one with a large decrease and the other with no change). Finally, to control for seasonality and interannual variability, the coordinators are requesting that the datasets contributed to the initiative include spatially and temporally matched data from previous years, if available. A manuscript with analyses of the data is planned for June 2021.

As part of this larger initiative, the EUROMAMMALS network is assessing changes in the spatio-temporal behaviour of wildlife during the COVID-19 lockdown in European mammals using existing monitoring networks, with the lockdowns providing an additional 'lens' for evaluating impacts and changes. The coordinators aim to use camera trap data with information on species, time and date of collection, and GPS-location collected in 2019 and 2020, or ideally, also data collected in earlier years, to answer the following questions: (1) Did the lockdown lead to modifications of the spatio-temporal distribution and activity patterns of wildlife species in relation to the decrease of human activities?; (2) How quickly did these changes, if any, occur and were there differences between species regarding their behavioural response to the lockdown?; and (3) Does increasing human activity following the lockdown phase lead to spatio-temporal distributions and activity patterns of species similar to the ones observed during the same period in previous years? They hypothesise that, during the lockdown, wildlife and especially herbivorous species, such as roe deer and red deer, will shift their activity patterns towards the daytime due to decreasing human activity and/or will have a larger temporal window of activity. Moreover, decreasing human activity during the lockdown in certain areas will result in a more frequent use of those areas by wildlife compared to before and after the lockdown. Potential changes of the spatio-temporal distribution and activity patterns of species will take place over time and will not be instantaneous. The expectation is that nocturnal species (e.g. badger) will be less affected than diurnal ones. Due to an increase of human activity after the end of the lockdown, wildlife species are expected to shift their spatio-temporal distribution, as well as their activity patterns toward patterns similar to those observed in previous years.

In the Netherlands, Wageningen University is using camera trap data to study the impacts of a partial lockdown of the National Park De Hoge Veluwe in the spring of 2020 on wildlife activity patterns (P. Jansen, WU, pers. comm.). The main focus will be on activity patterns and habitat use of ungulate species: red deer, wild boar, fallow deer, roe deer and mouflon. Wageningen Environmental Research is comparing the use of wildlife overpasses of major roads during the partial lockdown with their pre-pandemic use of these crossing structures (E.A. van der Grift, WENR, pers. comm.).

Another initiative led by the PAN-Environment working group is planning to assess impacts of human mobility and activity on species and ecosystems by integrating a wide array of information, including data generated by species monitoring programs, protected area networks, sensor networks and citizen science initiatives. Community science may provide a suitable basis for teasing apart the drivers for change in the activities and activity-patterns of wildlife based on observations recorded by citizens during the shutdown (Zellmer et al. 2020), and biodiversity databases such as iNaturalist (www.inaturalist.org) and eBird (www.ebird.org), have data sets with worldwide coverage that have their beginnings well before the shutdown. These data could be used to assess how wildlife observations and wildlife observers differ from previous and future years.

Specific animal taxa may be more suitable than others for quantifying the impact of changing levels of human activity during the pandemic. For example, apex predators such as birds of prey have been shown to be relatively sensitive to disturbance and are therefore potentially suitable as indicator species for assessing changes in environmental health; in addition their widespread occurrence and the likelihood that they will be seen (they are often highly 'visible' species), has stimulated their monitoring at global level (Sergio et al. 2008). Such monitoring datasets gathered before, during and after lockdown now provide an opportunity for addressing key questions about the impact of COVID-

19 on ecosystems across geographic regions. The "Global Anthropause Raptor Research Network", therefore, aims to coordinate such large-scale analyses (Sumasgutner et al. under revision).

6.3 Factors that constrain research

These global initiatives obviously have their challenges, for example because the response to the pandemic and the timing of measures varies greatly between countries and regions. They require collaboration for standardisation of methods, exchange of expertise and coordination of data collection (Rutz et al. 2020, Zellmer et al. 2020). Rutz et al. (2020) suggest that researchers keep detailed records of official restrictions on, and changes to, human mobility, as such information is vital for interpreting behavioural changes in wildlife. Field observations are needed to validate the changes in human behaviour that are provided by big data sources.

The studies that assess the impact of human activities on wildlife also have to deal with numerous challenges. Field projects must continue data collection during the changes in human mobility that we will likely witness over the coming months and beyond. However, field biologists are themselves hampered by the lockdown conditions, with safety precautions and travel restrictions complicating data collection. Rutz et al. (2020) mention the need for swift permitting and funding to support collaborative research; including for field data collection, data-management infrastructure and support, and complex data analyses. Follow-on field studies are not normally considered a priority by funding agencies, but these will now contribute critically important data series to allow comparisons of before and after lockdown conditions.

7 Conclusions

7.1 Impacts on wildlife

The COVID-19 pandemic has caused unprecedented changes to mobility, economic activity and associated impact on the environment in Europe and globally. We have found numerous examples of positive impacts on wildlife as a result of the measures that have been taken to manage the outbreak – such as lockdown and partial lockdown – in Europe and beyond:

- Lower nitrogen emissions may benefit plant diversity;
- Reduced air pollution may also positively influence the breeding success of insectivorous birds;
- A reduction in the discharge of industrial effluent and boat traffic during lockdown has improved water quality, which can benefit aquatic ecosystems;
- Reduced human disturbance in natural areas has apparently increased the movements of wildlife into areas where they had previously not been seen, notably mammals and birds, with apparent behavioural shifts and habitats that had previously been disturbed now being occupied for the first time.

In addition, significant reductions in road traffic during lockdowns decreased the effects of roads on wildlife populations, especially for those species that are highly impacted by road-killing, such as amphibians, reptiles, and birds of prey and owls. Reduced traffic has already proven to be beneficial for amphibians and reptiles, lowering the numbers of road casualties, which may have positive effects on population numbers if traffic density remains low for a sufficiently long period of time. Reduced volumes of traffic may also increase habitat connectivity between areas that are separated by the road which may result in strengthening ecological networks, resulting in an increase of gene flow and viability of populations (see also EEA 2020c). At the same time, a decrease in traffic and lower levels of pollution also appears to enhance the quality of road verges and habitats beyond the edges of the road for insects and plants, as do lower levels of light and noise pollution.

Importantly, most of these positive impacts remain to be quantified. Some of these apparent shifts, such as behavioural and distribution changes in wildlife, may be due to an observer effect, as people are seeing wildlife more often from home and lockdowns may enhance the visibility and audibility of wildlife, especially in urban areas.

On the downside, the pandemic has also led to negative impacts on wildlife:

- The absence of rangers and tourists in many areas has meant that poachers were able to seize the opportunity to carry out illegal activities. Indeed, many reports across Europe suggest that the COVID-19 lockdowns have been characterised by increased levels of poaching, for example of raptors and sturgeons;
- The decreased travel of European tourists and loss of tourism revenues abroad has also affected countries and specific locations and areas that depend on such resources for anti-poaching operations and management of protected areas;
- Increased poverty among rural communities in Europe, and beyond, is likely to further increase pressure on wildlife from illegal hunting and timber and wood-fuel extraction;
- The pandemic has also led to illegal persecution and widespread attempts to eliminate species suspected of involvement in the spread of disease, as reported for bats.

7.2 Appreciation of nature

There are clear indications that people's appreciation of wildlife may have changed during the pandemic. Nature has played a critical role in providing social resilience during this crisis by maintaining physical and mental well-being, particularly in urban centres, and in the context of

increased stress and anxiety arising from lockdowns, job and income losses. Various studies have indicated that the appeal of outdoor activities has been boosted by enforced COVID-19 restrictions, with people spending more time outdoors generally and specifically in nature, enjoying and noticing birdsong, watching wildlife, bees or butterflies receiving specific attention, with an associated increase in public awareness of nature.

An increased appreciation for nature and consequently higher visitor numbers in natural areas may force us to reconsider the size and configuration of nature reserves. A number of options exist here; areas may need to be enlarged to provide sufficient space for both humans and wildlife, but also so that sensitive and fragile areas and species can be avoided or excluded altogether from human access. Also, areas may need to be better connected to allow for more resilient and viable ecosystems, but also to provide for a more favourable distribution of visitors that impacts less on wildlife within and between sites. Such measures fit very well with the targets set in the *EU Biodiversity Strategy for 2030* (European Commission 2020), including the establishment of protected areas for at least 30% of both land and water in Europe, which states in its introduction: *"Healthy and resilient societies depend on giving nature the space it needs. The recent COVID-19 pandemic makes the need to protect and restore nature all the more urgent. The pandemic is raising awareness of the links between our own health and the health of ecosystems. It is demonstrating the need for sustainable supply chains and consumption patterns that do not exceed planetary boundaries. This reflects the fact that the risk of emergence and spread of infectious diseases increases as nature is destroyed. Protecting and restoring biodiversity and well-functioning ecosystems is therefore key to boost our resilience and prevent the emergence and spread of future diseases."*

Despite such a positive shift in public awareness of nature-related topics, it may be short-lived if the situation quickly reverts back to 'normal', which suggests that it is important to act quickly and to incentivise a long-term change by, for example, supporting schemes for greening built infrastructure. Although mitigation of, for example, the impacts of roads and railways is receiving increasing attention, current ecological networks often still lack sufficient coherence and connectivity to foster viable ecosystems. In general, if no targeted measures are taken, many positive impacts of the lockdown measures are likely to vanish as the pandemic ends and the situation reverts back to its previous state, leading to a reestablishment of noise-, air- and water pollution, greenhouse gas emissions, and the many other adverse human impacts on nature. Presently, there is scope for exploiting the growing public engagement with wildlife losses, which can be one element in driving the development of a lasting and legitimate long-term policy response to COVID-19.

The dangers of habitat degradation and the increased human impacts on natural systems are, more than ever before in the spotlight, because they are seen as reasons for the spread of zoonotic disease. As such, there is an opportunity to remind people of the links between healthy, resilient ecosystems and human well-being. Simultaneously, such insights could lead to more support for the protected area system in Europe and beyond and may help foster the above-mentioned implementation of the *EU Biodiversity Strategy for 2030*, including the establishment of larger and more resilient protected areas.

7.3 Research opportunities

As a result of the drastic, sudden, and widespread effects of the COVID-19 pandemic, a situation has occurred that would have been impossible to recreate using conventional experimental design, thereby providing a unique opportunity to study the impact of human behaviour on wildlife. Much of these impacts remain to be quantified and our surveys among European researchers describe various studies that have been initiated. The international research community has taken the opportunity provided by the situation to examine how changes in human activities affect wildlife, especially because it allows us to gain mechanistic insight into how human activities operate. We have listed various collaborative research initiatives that are currently forming, and we mention others that are in the process of development. These include the COVID-19 Bio-Logging Initiative and the COVID Cameratrap Comparison Collaboration, both of which are global initiatives to assess changes in movement and distribution among wildlife in response to the anthropause. These larger initiatives plan

to collate data using 'bio-loggers' and field-deployed camera-traps for this purpose, and strive to conduct before-after-controls in defined areas in order to detect effects. Those studies that were set up before the pandemic unfolded, and lockdowns occurred, and that continued during and after lockdowns, will be particularly valuable for quantifying the impact of human activities.

The opportunity for new research provided by the situation that the world currently finds itself in, provides the possibility, for example, to answer questions related to the movements of animals in modern landscapes, and whether they are predominantly affected by built structures, or by the presence of humans. Scientific knowledge gained during this pandemic will allow us to develop innovative strategies for sharing space, with mutually beneficial effects, for wildlife and humans. At the same time, priority must be given to the development of scientific capacity during these times, and to make sure that early career researchers and practitioners, on whom future conservation depends, have opportunities to continue to grow their contributions to the field.

8 Recommendations

Most of the recent zoonoses have been linked to the developing world, particularly to tropical areas where land use changes have accelerated the degradation of those ecosystem services that might otherwise help to suppress disease propagation. Local practices, such as bush meat markets, have been pointed out as potential risks for wildlife-to-human transmissions of viruses. However, Europe has an important role to play in preventing such outbreaks from happening. Firstly, the ecological footprint of European countries may, to a certain extent, be one driver of the detrimental land use changes in those tropical areas where the risks of zoonosis are high. Secondly, Europe has a responsibility and a role in relation to the delivery of the Convention of Biological Diversity (CBD), including developing strategies for the conservation and sustainable use of biodiversity globally. Hence, the current virus outbreak and global pandemic should initiate a stronger plea for ecosystem preservation during the upcoming fifteenth meeting of the parties to the Convention – known as the Conference of the Parties (COP 15) – to be organised in China, in 2021.

A key question for wildlife conservation is: *What lessons might be learned from the current pandemic and which human activities influence wildlife the most; and especially what, if anything, can be maintained in terms of positive effects?* Once the situation reverts back to normal, human disturbance is likely to negate the positive effects that have occurred during the pandemic. Animals that were venturing into previously unoccupied areas because of lower disturbance levels are likely to vanish when such disturbance returns to former levels. Similarly, traffic will return to normal patterns, as will the frequency of roadkill and its negative impact on particular species. However, the realisation that particular changes to people's daily routines may have profound consequences for our environment, and for the wildlife that shares this space with us, will likely remain for some time. This may promote innovative thinking among policy makers when it comes to limiting the effects of, for instance, pollution, traffic and other forms of human disturbance on wildlife.

Some measures or adjustments to human behavioural patterns would obviously be beneficial and could theoretically be implemented on a larger scale in order to retain some of the positive effects of the pandemic on wildlife. For example, permanent measures that mitigate road effects, such as the construction of structures that facilitate wildlife crossing and the installation of wildlife-warning systems, which alert drivers to reduce speed if animals have been detected in the road verge. Or measures that aim for zoning human use within natural areas, guiding human activities to parts where their impact on wildlife will be reduced. In this respect, research outcomes can be used as the basis for: providing guidance and general education for people; the provision of information; and the establishment of voluntary and statutory agreements and zoning, in order to limit the impact of disturbance as much as possible. Social science can play an important part in aiding our understanding of human behaviour in relation to human-wildlife interactions; knowledge which can be combined with the ecological sciences in order to provide the potential for more effective management of the impacts of human disturbance (Marzano and Dandy 2012).

The anthropause also led to increased poaching; with fewer potential witnesses and less patrolling and monitoring by scientists, rangers, hikers and tourists, illegal shooting, trapping, and poisoning has become easier. This illustrates the importance of having people and in particular law enforcement staff in the field during lockdowns to prevent poaching, the example of raptors is particularly relevant in Europe. The anthropause also came with the onset of spring, when raptors are most conspicuous and at a greater risk from shooting and poisoning, as well as nest destruction or egg theft. The observed crimewave is likely to fuel a long-standing debate over raptor killings. Many conservationists want to see increased fines and prison sentences for raptor persecution. And some are calling for mandatory licensing for shooting estates, where hunters are provided with specially bred game, or even a complete ban on some forms of shooting.

One of the aspects that has become clear during the pandemic is that we cannot keep humans out of nature and we do not wish to do so. Contact with local nature during this period of restricted travel opportunity has, in many countries, provided important benefits for human health and well-being. However, visitor numbers to natural areas have increased significantly, particularly in north-west Europe and a number of states within the US. With this has come increased pressure on habitats and species and a consequent need to provide for their sustainable management in the short-, medium- and long-term. Building on existing knowledge and expertise in relation to recreational management, further research to look into how to manage human populations in these 'beyond normal' situations is therefore desirable if not essential in order to answer questions about what are the most important actions (and policies) to take for the protection and 'shared' use of the (ultimately limited) natural resources provided by nature.

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Annex 1 Questionnaire

COVID-19 and Wildlife in the EU

Fields marked with * are mandatory.

Introduction

Questionnaire to assess the impact of the COVID-19 situation on wildlife in the European Union

This questionnaire forms part of a project commissioned by the European Environment Agency (EEA) for Wageningen Environmental Research (WENR) to carry out a preliminary assessment of the impact of the current human pandemic on wildlife. In addition to information on the impact of the lock down period on wildlife, we also examine whether appreciation for nature has changed during the lockdown. It is focused on the European Union but is also collecting relevant observations/information from beyond the EU.

It is being sent to biodiversity experts and practitioners, such as protected area and national park managers, farmers, fishermen, and biologists, throughout the European Union. You are therefore being approached because you are either an expert in the field or an individual with knowledge of, personal experience or involvement in this subject. We kindly ask you to complete the questionnaire in as much detail as possible, which will allow us to determine what information is presently available, or what information is being collected, to assess the impact of the COVID-19 situation on wildlife in the European Union. Even if you are not directly involved in any ongoing studies, we are still interested to know whether you have any knowledge of developments in your country or network even if only anecdotal commentary, or would like to share your experience of the impact of COVID-19 on wildlife in the free text box below.

We estimate that it will take you around 20 minutes to fill in. We plan to use this data to provide an overview of the information that is currently available to quantify the impact of the pandemic on wildlife in the EU. We wish to know whether you would be willing to share the data you might be collecting in this regard; or to collaborate in a wider study. WEnR and EEA thank you in advance for any information.

Once completed, please submit the information **before 15 October 2020.**

Specific privacy statement for the consultation on the EU assessment of the impact of COVID-19 on wildlife

Any personal data you submit to the EEA in the context of the consultation referred to above will be processed in accordance with Regulation (EU) 2018/1275 of the European Parliament and of the Council of 23 October 2018 on the protection of natural persons with regard to the processing of personal data by the Union institutions, bodies, offices and agencies and on the free movement of such data, and repealing Regulation (EC) No 45/2001 and Decision No 1247/2002/EC.

Processing operations are under the responsibility of the Nature Reporting project managers in the EEA, acting as data controllers, with assistance from task managers of European Topic Center on Biological Diversity (ETC/BD) acting as processor on behalf of the EEA, regarding the collection and processing of personal data.

Purpose(s) of the processing
Your personal data are kept and further processed for the purpose of having a public consultation for the COVID-19 impact on wildlife and for ensuring that you can be reached in the eventuality of a request for clarification on submitted comments. Only the minimum amount of personal data needed is involved in the process.

Recipients of the data processed
For the purpose detailed above, access to your personal data (name, institution, Member State and submitted comments) is open to all visitors of the Web Tool used for the consultation. Access to remaining personal data (e-mail address, eionet username) is only available to the administrators of the consultation, which are the researchers at Wageningen University and Research, which are bound by the same data protection rules. No personal data is shared with third parties for direct marketing purposes. Comments could be transmitted to other bodies for further consultation under the condition that they will abide by the data protection principles instructed to them by the EEA.

Categories of data processed
The only personal data further processed is the comments you submit to the Web Tool. EEA needs the other personal data (name, organization, e-mail) for contacting you in case a clarification is needed as regards your submitted comments.

Modalities for the processing operation
Comments are provided by you online at the Web Tool used for the consultation. Comments and other personal data (name, organization, e-mail) can be exported from the Web Tool only by the administrators of the consultation. All data in electronic format are stored on the servers at EEA which guarantee the security and confidentiality of the collected information.

Right of access and rectification
You have no direct access to the data stored, though if you wish to personally modify or delete your comments, you can do it only as long as the consultation is open. If you wish to modify or delete any of your personal data or your comments after the consultation is over, you should address your request in writing by email to the administrator of the consultation Ralph Buij (ralph.buij@wur.nl). If you wish at any time to withdraw your consent to the process, you should address your request in writing by email to the administrator of the consultation. The withdrawal of your consent does not affect the lawfulness of processing based on consent before its withdrawal.

Legal basis
The processing of your personal data is necessary for the performance and support of the numerous tasks carried out by the EEA as mandated by Regulation (EC) No 401/2009 of 23 April 2009 on the EEA and Eionet. In addition, by submitting your comments, you express explicitly your consent to the processing operation (Article 5(d) of Regulation (EU) 2018/1725).

Data retention
Your name, email address, organization and comments will be stored until the follow up actions to the consultation are completed, i.e. publication of the final report of the COVID-19 impact on wildlife. This retention period is appropriate to the purpose of managing the comments while the assessment is still ongoing and communicating with the participants in case the EEA wishes to ask for clarifications. Six months after the final publication of the report only anonymous comments, linked to the organization of the comment providers will be retained in the Web Tool.

Right to appeal
You are entitled to have recourse at any time to the European Data Protection Supervisor (https://edps.europa.eu; edps@edps.europa.eu) if you consider that your rights under Regulation(EU) No 2018/1725 have been infringed as a result of the processing of your personal data by the EEA.

You may also contact the EEA's Data protection Officer (DPO) in case of any difficulties relating to the processing of your data at the following email address: DPO@eea.europa.eu.

Personal information

Please note that any personal data you submit to the EEA in the context of this consultation will be processed in accordance with Regulation (EU) 2018/1275 of the European Parliament and of the Council of 23 October 2018 on the protection of natural persons with regard to the processing of personal data by the Union institutions, bodies, offices and agencies and on the free movement of such data. Full details are provided in the '**Specific privacy statement**' section.

*3.1 Name

*3.2 Name of organisation

*3.3 Type of organisation

- National government
- Regional Government
- Local government
- NGO
- Research Institute / University
- Private company
- Other

*3.4 Please specify

*3.5 Email

*3.6 Telephone number

10 character(s) minimum

*3.7 Profession

- ○ Government expert on environment
- ○ Protected area manager
- ○ Farmer
- ○ Fisherman
- ○ Project developer
- ○ Ecologist
- ○ Researcher / consultant
- ○ Other

*3.8 Please specify

*3.9 Which type of habitat does your expertise and experience relate to?
(multiple answers possible)

- ☐ Alpine
- ☐ Forest
- ☐ Grassland Heathland
- ☐ Fresh water
- ☐ Wetland
- ☐ Coastal
- ☐ Marine
- ☐ Agricultural landscape
- ☐ Other

*3.10 Please specify

*3.11 Country

Please note that UK countries are included separately. If you want to add information for a country that is not yet in the list, please send an email to the contact email address displayed at the top of the right column.

- Albania
- Andorra
- Armenia
- Austria
- Azerbaijan
- Belarus
- Belgium
- Bosnia and Herzegovina
- Bulgaria
- Croatia
- Cyprus
- Czechia
- Denmark
- England
- Estonia
- Finland
- France
- Georgia
- Germany
- Greece
- Hungary
- Iceland
- Ireland
- Israel
- Italy
- Kazakhstan
- Kosovo
- Latvia
- Liechtenstein
- Lithuania
- Luxembourg
- Malta
- Moldova
- Monaco
- Montenegro
- Netherlands
- North Macedonia
- Norway

- ○ Poland
- ○ Portugal
- ○ Romania
- ○ San Marino
- ○ Scotland
- ○ Serbia
- ○ Slovak Republic
- ☐ Slovenia
- ☐ Spain
- ☐ Sweden
- ☐ Switzerland
- ☐ Turkey
- ☐ Ukraine
- ○ Vatican city
- ○ Wales

Information on COVID-19 and its impact on wildlife

*4.1 Are you or any of your colleagues currently involved in collecting data with the purpose of carrying out an impact assessment of the COVID-19 situation on wildlife?

- ◯ Yes
- ◯ No

*4.2 What type of data do you collect for the impact assessment of the COVID-19 situation on wildlife? (multiple answers possible)

- ☐ Distribution of animal species
- ☐ Distribution of plant species
- ☐ Distribution of habitats and ecosystems
- ☐ Population size and trends
- ☐ Population demographics (breeding and mortality rates)
- ☐ Habitat use and movements Other

*4.3 Please specify

*4.4 What are the issues you intend to address in your study in relation to the impact of the COVID-19 situation on wildlife? (multiple answers possible)

- ☐ Human disturbance
- ☐ Poaching
- ☐ Pollution
- ☐ Traffic
- ☐ Wildlife crime
- ☐ Habitat destruction
- ☐ Other

*4.5 Please specify

*4.6 What initiated your study – what problem or knowledge gap emerged?

500 character(s) maximum

*4.7 Would you be willing or are you planning to share the data you are collecting in this regard; or to collaborate in a wider study?

- Yes
- No

*4.8 Besides your own study, or if you are not involved in a study to quantify the impact of COVID-19 on wildlife, do you have (anecdotal or other) information or ideas that could potentially be suitable for addressing questions related to the impact of the COVID-19 situation on wildlife? (For example policy responses, financial support, etc)

- Yes
- No

*4.9 Please explain

500 character(s) maximum

*4.10 Are you aware of studies or horizon scanning analyses on the impact of COVID-19 on wildlife at your national level, or initiatives to do so?

- Yes
- No

*4.11 Please explain

500 character(s) maximum

4.12 What data (apart from the data you may be collecting yourself) you propose should be collected in order to assess the impact of the COVID-19 situation on wildlife?

500 character(s) maximum

*4.13 Which of the following do you consider important conditions to achieve a successful evaluation of the impact of the COVID-19 situation on wildlife? (multiple answers possible)

- Communication between experts of different sectors
- Support from stakeholders
- Political support
- Availability of funding
- Availability of all relevant (spatial) data Other

*4.14 Please specify

*4.15 Did you find any indications that the appreciation of nature has changed during the lockdown?

500 character(s) maximum

*4.16 Do you have any further comments on data collection for the evaluation of the impact of the COVID19 situation on wildlife that may help us to get the full picture?

500 character(s) maximum

*4.17 Could we please contact you for more details on your studies as part of a follow-up request for information?

- Yes
- No

4.18 You are welcome to include references or links to relevant published documents or websites.

Annex 2 Outcome of the questionnaire

Introduction

The overview below summarises the results of the EEA survey on the online survey on the effects of the COVID-19 measures on wildlife. The survey was prepared using the EU-survey tool and conducted between 25 September and 15 October 2020. A total of 28 reactions were received of which one directly by mail, saying no information was available. The information on the 27 completed surveys was retrieved from the EU-survey database on the 28th of October. This overview does not include any private information of the respondents, and all specific non-relevant references to countries have been omitted. The included figures were automatically generated by the EU survey tool.

Where relevant the provided information is ordered according to severeness and length of lockdown periods. Table A2.1 provides an overview of these periods for the countries from which responses were received. It is based on information available on the website of the European Centre for Disease Prevention and Control (ECDC) for EU countries and on information found on Wikipedia for non-EU countries. The ECDC information distinguishes between formal, enforced stay-at-home orders for the general population, partial stay-at-home orders for which the ECDC provides no further specific information, and stay-at home requests. The ECDC however notes on its website that the actual enforced or voluntary measures and restrictions are very heterogeneous.

Table A2.1 *First COVID-19 wave lockdown information for the countries represented in the survey, ordered according to severeness and length. Data for EU countries obtained from ECDC: https://www.ecdc.europa.eu/en/publications-data/download-data-response-measures-covid-19 and for non-EU countries from Wikipedia.*

Country	Stay home (days)			(National) parks closed	2020		
	Order		Request		March (from 9th)	April	May
	Full	Partial					
Italy	56			Y			
Hungary	53			Y			
Spain	52	8	5				
Scotland	47	56	15				To 4-7
Slovenia	47						
Israel	47						
Czech republic	40						
Poland	28		15	Y			
Sweden			100				May still be in force
Turkey			99				No info on end date
Estonia			66				
Netherlands			55				
Croatia			49	Y			
Germany			49				
Bulgaria				Y			
Denmark							
Slovak republic							
Switzerland							

Personal information

This section only includes some general statistics. For information on the individual respondents please refer to the actual survey results.

Professions and representation (questions 3.2, 3.3, 3.4, 3.7 and 3.8; Figures A2.1 and A2.2)

The majority of the reactions, 16, were from government expert on the environment. 13 of those indicated the national government as the organisation they represented, a further 5 respondents with other professions also indicated to represent a national government. 3 persons gave ecologist as their profession, two searcher/consultant, one protected area manager, one project developer and 4 other (project manager, veterinarian, biologist, administrator for outdoor life in protected nature).

	Answers	Ratio
National government	18	66.67%
Regional Government	3	11.11%
Local government	0	0%
NGO	0	0%
Research Institue / University	3	11.11%
Private company	0	0%
Other	3	11.11%
No Answer	0	0%

Figure A2.1 *Type of organisation.*

	Answers	Ratio
Government expert on environment	16	59.26%
Protected area manager	1	3.7%
Farmer	0	0%
Fisherman	0	0%
Project developer	1	3.7%
Ecologist	3	11.11%
Researcher / consultant	2	7.41%
Other	4	14.81%
No Answer	0	0%

Figure A2.2 *Profession.*

Countries (Q 3.11)

Responses were received from 14 EU countries and from 4 European countries outside of the EU (Israel, Turkey and Scotland and Switzerland). Mostly there was just one response per country, but 5 responses were received from Croatia (two government experts representing national and regional governments, a researcher from a research institute, an ecologist from a museum and a project developer from a regional government), 4 from Turkey (veterinarian, biologist, government expert and project area manager, all representing national government) and 3 from Poland (project manager of a national park, ecologist and administrator for outdoor life etc. representing national government).

Habitat types (Q 3.9 and 3.10; Figure A2.3)

Only three respondents indicated a single habitat type, in all three cases a type not in the original list (given as species, urban and protected areas). One more respondent added protected areas, but indicated that all habitat types within those areas were covered. Three respondents indicated they (or their organisation) covered all habitats. Grassland and forest were the habitats most indicated with 20 and 19 indications, marine was the least indicated with 6 times.

	Answers	Ratio
Alpine	8	29.63%
Forest	19	70.37%
Grassland	20	74.07%
Heathland	8	29.63%
Fresh water	10	37.04%
Wetland	12	44.44%
Coastal	10	37.04%
Marine	6	22.22%
Agricultural landscape	12	44.44%
Other	7	25.93%
No Answer	0	0%

Figure A2.3 *Habitat types the respondent's expertise relates to.*

COVID-19 and wildlife

Data collection by the respondents or their organisation (Q 4.1 to 4.7; Figures A2.4 and A2.5)
Only two respondents indicated to be involved in data collection. Both are willing to share data or collaborate. One respondent indicated he is / they are involved in collecting data on the distribution of animal species, population size and trends, habitat use and movements with the objective to address human disturbance and pollution. This was initiated by the questions: '*How human presence change birds and mammals abundance in protected areas; activity hours of animals when humans are lock down; the impact of traffic load on mammals crossing overpasses; the impact of onshore fishing on fish populations sizes; benchmark values of light pollution along the coast; CO2 benchmark values in a stalactite cave during lock down; noise benchmark values in protected areas'*. The other respondent indicated she is / they are collecting data on human disturbance and wildlife crime with the objective to investigate human disturbance and wildlife crime. '*Shortly after the COVID lockdown we (and the Police) received reports of illegal persecution of some raptors (in areas where public access was curtailed) and this led us to ensure that we would develop a systematic listing of all reported incidents (some derived from remotely sensed data from satellite tagged raptors) to determine any impacts of the COVID restrictions. More broadly, we have not collected any wildlife data that appears to be relevant. Our information is available to you*'.

	Answers	Ratio
Distribution of animal species	1	3.7%
Distribution of plant species	0	0%
Distribution of habitats and ecosystems	0	0%
Population size and trends	1	3.7%
Population demographics (breeding and mortality rates)	0	0%
Habitata use and movements	1	3.7%
Other	1	3.7%
No Answer	25	92.59%

Figure A2.4 *Type of data collected.*

	Answers	Ratio
Human disturbance	2	7.41%
Poaching	0	0%
Pollution	1	3.7%
Traffic	0	0%
Wildlife crime	1	3.7%
Habitat destruction	0	0%
Other	0	0%
No Answer	25	92.59%

Figure A2.5 *Issues addressed.*

Information or ideas on other COVID-19 and wildlife questions (Q 4.8 and 4.9)
This question was answered with yes by 8 respondents who can all be approached for further information. The answered are listed below according to the order of severity and length of lockdown as shown in Table A2.1.

Stay home orders:
- *During lockdown hiking was allowed in […], but government called people to avoid larger groups. Thus, most people avoided official (designated) hiking trails and tried to be away from other people. As a result, people showed up regularly literally everywhere from deep forest, through major grasslands to intensive agricultural areas (where usually no people occurs regularly) disturbing wildlife in reproduction period;*
- *I have personal observations of wildlife behaviour during confinement time due to COVID-19;*

- *Anecdotal reports suggest that disturbance-sensitive species, including shore-nesting birds, benefitted from lack of human and dog disturbance, and that species sensitive to road traffic e.g. common toad and hedgehog suffered lower than usual mortality. As indicated above reports also suggest an increase in wildlife crime, though the data may prove to be inconclusive;*
- *We are collecting all data we can get on the covid19 topic, from all possible sources, according to the impact of the epidemic disease on environment;*
- *The period of several weeks, when access to the park was forbidden for tourists, caused that the behaviour of birds and large mammals changed visibly. The presence of deer in the vicinity of mountain shelters was observed. The animals showed less timidity. The change in behaviour was noticeable just a few days after the tourist movement was stopped.*

Stay home requests:
- *Universities work on covid-19 pandemic in curiously as worldwide. There are articles and projects on impact of covid-19 pandemic;*
- *In my city people started going in the nature due to lockdown, I think it was disturbing few natural sites around city.*

No order or requests:
- *A survey in The […] Nature Protection Agency has shown the amount of bookings of shelters on state owned nature areas and forests has increased by 12.000 stays: https://naturstyrelsen.dk/nyheder/2020/september/vi-er-vilde-med-at-sove-i-naturen/*.

Awareness of studies or horizon scanning analyses (Q 4.10 and 4.11)
Four respondents replied positively to this question. All can be contacted for information:
- *Various studies have been conducted to understand how the relationship with green areas (and nature in general) changed during the pandemic. For example at ENEA, at the Institute for Bioeconomics of the CNR of Bari and at the Department of Agricultural, Forestry and Food Sciences of the University of Turin;*
- *We are aware of this study, and work with the lead investigators: https://www.cam.ac.uk/research/news/study-identifies-275-ways-to-reduce-spread-of-coronavirus-following-lockdown, and see https://www.sciencedirect.com/science/article/pii/S016953471930299X?via%3Dihub;*
- *Yes, there are scientific studies and articles which have been conducted by universities on impact of covid-19 pandemics;*
- *There was no strict lockdown in […]. This means that we had more people outside in nature in April than ever before. If anything, it impacted the Wildlife more than usually. We are running some analyses to understand how people experienced the outdoors, but not on wildlife.*

Suggestions for data collection (Q 4.12)
Fifteen respondents made the following suggestions:
- *Mass GSM cell data from mobile phones (without individual IDs, of course) to map how people "invaded" nature during the lockdown in spring;*
- *All possible data we can get;*
- *I think it would be interesting to analyse the change in the distribution of wild species in more urbanized contexts (cities and peri-urban areas) where the lockdown has allowed a less disturbance and therefore a greater ease of sighting of wildlife. It would also be interesting to understand how people's perception of wildlife has changed;*
- *Disturbance by humans (number of forest visitors);*
- *Air pollution, level of species disturbance;*
- *Given the proved impact of COVID-19 on species like farmed American Mink, it would be useful to test impact on native endangered species like European Mink;*
- *Any data (if possible) which can prove significant impact of COVID-19 situation on wildlife;*
- *Intensity and number of visitors to protected nature areas during a pandemic;*
- *Increasing the number of visitors to protected areas;*
- *Visitors in protected areas (Natura 2000) - and the rate of illegal activities like unleashed dogs, illegal paths etc.;*

- *A comparative analysis of the mammalian and bird observations made with camera traps. The comparison should concern the period of the anti-COVID-19 restrictions and the corresponding (one or more) period in previous (or/and following) years;*
- *We are missing the general data from napping and monitoring of wild species and habitats, so it is difficult to say, what should go beyond this basic collection of data;*
- *Inventory of some selected species should be gathered to compare with the pre-COVID situation. Also it is important to detect whether there is an impact of COVID-19 on wildlife in terms of contagiousness;*
- *It may be possible to compare breeding success of nesting birds in areas with traditionally high disturbance levels with those that were normally relatively undisturbed e.g. offshore islands;*
- *Human mobility, human activity, animal responses. Impacts of human mobility and activity on species and ecosystems by integrating a wide array of information, by species monitoring programmes, protected area networks, sensor networks*.

Conditions important to achieving a successful evaluation (Q 4.13 and 4.14; Figure A2.6)

	Answers	Ratio
Communication between experts of different sectors	24	88.89%
Support from stakeholders	10	37.04%
Political support	13	48.15%
Availability of funding	15	55.56%
Availability of all relevant (spatial) data	20	74.07%
Other	3	11.11%
No Answer	0	0%

Figure A2.6 *important conditions to achieve a successful evaluation of the impact of the COVID-19 situation on wildlife.*

The following three explanations were given by the three respondents who checked 'other' in Q 4.13:
- *Setting a hierarchical system of national and international fora to identify, collect, canalize and process all available data.*
- *All of these will be important, and robustly addressing the null hypothesis that there is no impact of COVID on wildlife will be key.*
- *"Potrzeba dokładnego i przejrzystego opisania metodyki zbierania danych. Inaczej ciężko będzie porównywać poszczególne zestawy danych i robić jakiekolwiek analizy agregujące dane z różnych źródeł".*

Indication for a changed appreciation (Q 4.15)
Three respondents answered this question with a simple 'No'. The other replies, combined by country and again ordered according to severity of lockdown following Table A2.1, are listed below.

Stay home order:
- *Yes. Especially in urban areas, the perception of green areas has changed and they are now perceived as key places to resume sociality. In addition, the possibility of spotting wild species has increased even in highly urbanized contexts (see studies cited at 4.11);*
- *Yes, but it was two-sided. People "appreciated" going into nature more, but most of them did not appreciated (or understood) nature itself (e.g. deliberately or accidentally disturbing wildlife, leaving waste behind, illegally using motorized vehicle e.g. cross-motors in nature much more, etc.);*
- *Yes, for people living in small apartments in cities there is an appreciation of what it means to have a little backyard or garden, or to live near a park or a wooded area;*
- *Considerable number of reports in the media of far greater connectivity between people and nature resulting in positive benefits for health and wellbeing;*
- *Animals change their distribution - less crows/foxes/boars next to camping sites (no food), mammals heavily penetrating human settlements (boars, ibex). probably no change in birth rates;*
- *Yes, the visits of nature in lock-down in CZ increased significantly;*
- *A greater percentage of visitors to protected areas due to the limitations of social life in closed spaces (the other two reactions from Poland where negative).*

Stay home request:

- *Yes. Large increase in numbers of visitors in many protected areas (as well as in other nature). The indication is also many unexperienced visitors, new visitors. I think nature has played an important role for both physical and psychological health as well as making it possible to meet people - with a distance. At it will continue to play an important role;*
- *'At first, when there was complete lockdown and people were not going out of their homes, we saw indirect effects like air quality change, free roaming of some wild animals in city centres etc. This has caused in some fraction of the public an increase in awareness. However, we also see some negative effects like dropping of masks and other personnel hygienic materials into the nature'. 'The reason why wild animals were active at night was human pressure and fear of humans during the day. Noise, traffic and people were a factor in hiding some animals. The withdrawal of people to their homes with the epidemic caused animals to emerge during the day and reappear in the living spaces that we have already divided and intervened by building roads and excessive urbanization. In addition, it has been observed that air quality has improved as people do not go out and the traffic density'. 'Yes, for example improved air quality'. 'Yes, sure; for instance, dolphins have appeared throughout to coast so closely in broad daylight, seas and some river bed have been cleaned. Some endangered species have also been appeared closely in rural area'. HE: Yes, more people went outside. People thought that there were more birds. The truth is that the cities were less noisy and people had more time to listen to birds. It's clear now that green spaces in cities are important for the health of people;*
- *Due to the closure of society, monitoring became more complicated, for example. Part of the monitoring of the European mink was not carried out;*
- *In the beginning of the lock down, when no sports and other collective activities were allowed, many more people were hiking, running and mountain biking in nature. Now it is back to normal. Looked more like "there is nothing else to do" and the appreciation of the possibility to be active in nature dissolved again;*
- *'Just my personal observation. Unfortunately I didn't seriously research anything in this period'. 'I think that he appreciation of nature has changed during the lockdown in positive way'. 'No. Just feelings that the animals are more visible in the nature when lot of tourists are not mowing around'. 'Yes, people turned to the local community, visiting regional protected areas, traffic of vehicles decreased, recording sightings of certain of certain animal species, greater awareness of nature and undisturbed continuity'. 'Nothing specific except increased visits to protected areas';*
- *There are much more visitors allover in the landscape. Therefor we have much more people running through the forest, disturbing breeding birds and plants, at the coastline, disturbing breeding birds, and at freshwater lake ans rivers, disturbing plants and birds.*

No order or request:

- *Till now I cannot say for any indication;*
- *A survey in The […] Nature Protection Agency has shown the amount of bookings of shelters on state owned nature areas and forests has increased by 12.000 stays: https://naturstyrelsen.dk/nyheder/2020/september/vi-er-vilde-med-at-sove-i-naturen/;*
- *Yes. People again find out, how important and also beautiful is to spend time in nature.*

Further comments (Q 4.16)

Eleven respondents offered the comments listed below:

- *Analyses of photos and posts of thematic groups (e.g. about hiking) or individuals in social media could provide information too. In addition, there are many satellite-tracking (birds, animals, some reptiles) projects in Europe, so the movements of animals could be compared to those of previous years;*
- *it is too soon to get the complete picture about the covid19 impact on wildlife because epidemic situation is still not under control;*
- *It's data on humans that is really interesting. Statistics of e-bikes or drones sales could help understand the disturbances. We need also to understand the sociology of the people who went outdoors. Who are those people that did camping n the wild for the first time this spring?;*

- *People or traffic movements in the periods of lockdown and before lockdown;*
- *Data on species occurrence, range shift, movements into urban areas, occurrence of marine species near beaches and coast, etc.;*
- *I think that COV 19 has had a positive effect in the context of nature protection and that it is necessary to present trends and show that with small changes can successfully adapt to new circumstances. Better state of the environment contributes to a positive attitude towards new circumstances. COV 19 is a challenge to which we can all adapt by adopting old/new values;*
- *Not specific on wildlife. But I would like to highlight the importance to evaluate and monitor the impact on visitor experiences and management challenges. An increased number of visitors can contribute to for e.g. increased littering, crowded parking lots, crowded trails, increased number of violations of regulations, etc. How does an experience get affected by this?. And what are the management challenges due to a large increase of visitors?;*
- *I am not sure that these surveys and research is of value, as they were not properly planned or financed;*
- *We need to build on the collection of existing basic data; if this is missing, it is difficult to collect additional data - also in relation to the impacts of COVID-19;*
- *It will be useful to take into account the issues listed below during the studies on data collection:*
  1. *Economic Impacts from loss of nature-tourism;*
  2. *Direct and indirect impacts on protected areas;*
  3. *Direct impacts on ecosystem services.*
- *GPS tracking logs from mobile phones, traffic-flow measurements on land and at sea, high-resolution satellite images can be used as equipment for data collection.*

Permissio to contact for more detail or follow up (Q 4.17; Figure A2.7)

	Answers	Ratio
Yes	20	74.07%
No	7	25.93%
No Answer	0	0%

Figure A2.7 *Availability for further information or follow-up.*

Seven respondent answered 'no' to this question; the Bulgarian respondent may have made a mistake here, as he/she replied 'yes' to next question (Q 4.18).

References or links provided by the respondents (Q 4.18):
- This is a key reference in Nature: https://www.nature.com/articles/s41559-020-1237-z;
- Another useful reference here: https://www.sciencemag.org/news/2020/08/pandemic-stilled-human-activity-what-did-anthropause-mean-wildlife;
- https://www.cam.ac.uk/research/news/study-identifies-275-ways-to-reduce-spread-of-coronavirus-following-lockdown;
- https://www.sciencedirect.com/science/article/pii/S016953471930299X?via%3Dihub.

Annex 3 List of experts

Name	Affiliation	Country
Mora Aronsson	Swedish University of Agricultural Sciences	Sweden
Francesca Cagnacci	Movement and Conservation Ecology Research Line Research and Innovation Centre Fondazione Edmund Mach	Italy
Carlos Sunyer	TERRA Ecogest Environmental Consultancy	Spain
Dime Melovski	Macedonian Ecological Society	North Macedonia
Lubos Halada	Slovak Academy of Sciences	Slovakia
Matthias-Claudio Loretto	Max Planck Institute of Animal Behavior	Germany
Oliver Schweiger	UFZ	Germany
Patrick Jansen	Wageningen University	Netherlands
Jiska van Dijk	NINA	Norway
Christian Rutz	Centre for Biological Diversity, School of Biology University of St Andrews International Bio-Logging Society	Scotland, UK
Paula A. Harrison	UK Centre for Ecology & Hydrology Lancaster Environment Centre	England, UK
Roland Kays	NC State University, Dept. Forestry & Environmental Resources NC Museum of Natural Sciences	USA
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