Contents

1. Listening to cities
   From noisy environments to positive soundscapes

2. Wildfires under climate change
   A burning issue

3. Phenology
   Climate change is shifting the rhythm of nature

1. Surround sound: our acoustic environment 8
2. Sound effects 9
3. Turning down the volume 11
4. Healthy decisions for positive soundscapes 12
References 13

1. Waves of extreme wildfires 24
2. Human influences on wildfires 26
3. Changing climate, changing fire weather 28
4. Wildfire management improvements in the face of further climate changes 30
References 31

1. Timing is everything for ecosystem harmony 42
2. Disruption in ecosystem harmony 43
3. Evolving toward new synchronies 45
4. Bridges to new harmonies 46
References 47

This report is designed to be read on screens. Some pages may not print with a legible font size on a standard A4.
Foreword

Humanity has altered the planet in many detrimental ways, from the warming of our climate to the ever-diminishing wildernesses on land and in the sea. But in such a complex system as the Earth, science must always keep searching – for both solutions to problems already identified and new threats coming our way.

UNEP’s Frontiers Report does this by identifying and exploring areas of emerging or ongoing environmental concern. The 2022 edition delves into three issues: noise pollution in cities, the growing threat of wildfires and shifts in seasonal events – such as flowering, migration and hibernation, an area of study known as phenology.

As cities grow, noise pollution is identified as a top environmental risk. High levels of noise impair human health and well-being – by disrupting sleep or drowning out the beneficial and positive acoustic communications of many animal species that live in these areas. But solutions are at hand, from electrified transport to green spaces – which must all be included in city planning with a view to reducing noise pollution.

Meanwhile, recent years have seen devastating wildfires across the world, from Australia to Peru. The trends towards more dangerous fire-weather conditions are likely to increase, due to rising concentrations of atmospheric greenhouse gases and the attendant escalation of wildfire risk factors. The next decade will be critical in building greater resilience and adaptive capacity to wildfires – including on the wildland-urban interface. In particular, further research should address vulnerable groups’ exposure to hazards before, during and after extreme wildfires and action taken to increase efforts to prevent and prepare for wildfires.

Although wildfires are a striking impact of climate change, phenological shifts are equally worrying. Plants and animals often use temperature, the arrival of rains and daylength as cues for the next stage in a seasonal cycle. Yet climate change is accelerating too quickly for many plant and animal species to adapt, causing disruption to the functioning of ecosystems. Rehabilitating habitats, building wildlife corridors to enhance habitat connectivity, shifting boundaries of protected areas and conserving biodiversity in productive landscapes can help as immediate interventions. However, without strong efforts to reduce greenhouse gas emissions, these conservation measures will only delay the collapse of essential ecosystem services.

This report helps us understand that learning from ecosystems and how to live within them in harmony are objectives that we all need to adopt. We cannot have a healthy society without a healthy environment. And we need good science to inform responsible policies that back a healthy environment, which the Frontiers Report provides.

Inger Andersen
Executive Director
United Nations Environment Programme
Acknowledgements

Listening to cities: From noisy environments to positive soundscapes

Author
Francesco Aletta, Bartlett School of Environment, Energy and Resources, University College London, London, United Kingdom

Reviewers
Angel Dzhambov, Faculty of Public Health, Medical University of Plovdiv, Plovdiv, Bulgaria
Cecelia Anderson, United Nations Human Settlement Programme (UN-Habitat), Nairobi, Kenya
Dominique Potvin, Faculty of Science, Health, Education and Engineering, University of the Sunshine Coast, Moreton Bay, Australia
Guillermo Rey-Gozalo, Department of Applied Physics, University of Extremadura, Badajoz, Spain
Hui Ma, School of Architecture, Tianjin University, Tianjin, China
Jin Yong Jeon, Department of Architectural Engineering, Hanyang University, Seoul, Republic of Korea
Jose Chong, UN-Habitat, Nairobi, Kenya
Paulo Henrique Trombeta Zannin, Department of Mechanical Engineering, Federal University of Paraná, Paraná, Brazil
Sohel Rana, UN-Habitat, Nairobi, Kenya

Wildfires under climate change: A burning issue

Authors
Andrew Dowdy, University of Melbourne, Melbourne, Australia
Luke Purcell, AFAC National Resource Sharing Centre, Melbourne, Australia
Sarah Bouter, Griffith University, Brisbane, Australia
Livia Carvalho Moura, Institute for Society, Population and Nature, Brasilia, Brazil

Reviewers
Cristina Del Rocio Monitel-Molina, Department of Geography, Complutense University of Madrid, Madrid, Spain
Juan Pablo Argañaraz, Gulich Institute (CONAE-UNC), CONICET, Córdoba, Argentina
Matthew P. Thompson, Rocky Mountain Research Station, U.S. Forest Service, Colorado, USA
Sheldon Strydom, Department of Geography and Environmental Sciences, School of Geo and Spatial Science, North-West University, Mafikeng, South Africa

Phenology: Climate change is shifting the rhythm of nature

Author
Marcel E. Visser, Department of Animal Ecology, Netherlands Institute of Ecology (NIOO-KNAW), Wageningen, The Netherlands

Reviewers
Elsa Cleland, Division of Biological Sciences, University of California San Diego, USA
Gary Tabor, Center for Large Landscape Conservation, Montana, USA
Geetha Ramaswami, Nature Conservation Foundation, Bangalore, India
Jan van Gils, Royal Netherlands Institute for Sea Research, ‘t Horntje, The Netherlands
Kelly Ortega-Cisneros, Department of Biological Sciences, University of Cape Town, South Africa
Leonor Patricia Cerdeira Morellato, Department of Botany, São Paulo State University, São Paulo, Brazil
Rebecca Asch, Department of Biology, East Carolina University, USA
Shoko Sakai, Center for Ecological Research, Kyoto University, Japan
Yann Vitasse, Swiss Federal Research Institute WSL, Birmensdorf, Switzerland

UN Environment Programme Frontiers 2022 Report

Production team
Production heads: Edoardo Zandri and Maarten Kappelle, UNEP, Nairobi, Kenya
Chief editor: Pinya Sarasas, UNEP, Nairobi, Kenya
Technical support: Allan Lelei and Rachel Kosse, UNEP, Nairobi, Kenya
Science editor: Catherine McMullen, Canada
Illustrations, design and layout
Carlos Reyes, Reyes Work, Barcelona, Spain
Listening to cities

From noisy environments to positive soundscapes

Author

Francesco Aletta, Bartlett School of Environment, Energy and Resources, University College London, London, United Kingdom

Contributors and Reviewers

Angel Dzhambov, Faculty of Public Health, Medical University of Plovdiv, Plovdiv, Bulgaria

Cecelia Anderson, United Nations Human Settlements Programme (UN-Habitat), Nairobi, Kenya

Dominique Potvin, Faculty of Science, Health, Education and Engineering, University of the Sunshine Coast, Moreton Bay, Australia

Guillermo Rey-Gozalo, Department of Applied Physics, University of Extremadura, Badajoz, Spain

Hui Ma, School of Architecture, Tianjin University, Tianjin, China

Jin Yong Jeon, Department of Architectural Engineering, Hanyang University, Seoul, Republic of Korea

Jose Chong, UN-Habitat, Nairobi, Kenya

Paulo Henrique Trombetta Zannin, Department of Mechanical Engineering, Federal University of Paraná, Paraná, Brazil

Sohel Rana, UN-Habitat, Nairobi, Kenya
Sounds are complex physical phenomena originating in the vibration from a source that propagate energy into a medium as an acoustic wave. Sounds happen continuously and are everywhere: there is no such thing as ‘silence’ on the planet. As physical phenomena, sounds are neither positive nor negative. They acquire meaning and produce an effect only when considered from the perspective of a listener. When sounds are unwanted, they become noise. When noise is too loud and persist too long, they become noise pollution.

Today, noise pollution is a major environmental problem, cited as a top environmental risk to health across all age and social groups and an addition to the public health burden. Prolonged exposure to high levels of noise impairs human health and well-being, which is a growing concern for both the public and policymakers. Across the European Union, at least 20 per cent of citizens are currently exposed to road traffic noise levels that are considered harmful to health. This estimate is an average, with urban areas showing a far higher percentage. Noise pollution comes from conventional sources, such as roads, railways, airports, and industry; however, high noise levels may also come from domestic or leisure activities. Traffic and other urban noises affect not only human well-being, but also disturb and endanger the survival of species crucial to the urban environment.

Decibels (dB) is the units of measure for indicating the intensity or loudness of a sound that help predict thresholds when a noise starts to annoy people or when sleep disturbance emerges. While the loudness of noise is important, the frequency, in terms of high or low pitch, and temporal patterns of sounds also determine the physical and psychological effects it has on the listener.

Physically, proximity to very loud ambient sounds, such as a gunshot over 140 dB, could capture the ear’s tympanic membrane, causing immediate hearing loss. Listening to music with earphones at the maximum volume — ranging between 90 and 100 dB at the earache — could start to cause hearing damage after only 15 minutes per day. Regular exposure to over 85 dB for a 8-hour day or longer can cause permanent hearing damage. Long-term exposures even at relatively lower noise levels that are common in urban areas, can also damage both physical and mental health.

Noise quality cannot be judged only by its physical properties, however. The definition of noise as unwanted sound implies a psychological concept. While it is necessary to reduce noise levels when they are physically harmful to people, it may not be a sufficiently broad evaluation. It is becoming more relevant to consider soundscape that contribute to people’s physical as well as psychological well-being, especially in the urban environment.

The sounds of Big Ben in London or the calls to prayer from the Masjid al-Haram in Makkah, for example, are evocative experiences. In its broader understanding, acoustic comfort should not be seen merely as the absence of noise, but rather as a situation where environmental sounds offer ample opportunities for people to thrive and look after both their physical and mental well-being.

### What is a soundscape?

The International Organization for Standardization (ISO) defines a soundscape as “[t]he acoustic environment as perceived or experienced and/or understood by a person or people, in context.” In other words, soundscape encompasses the way people perceive, experience, and respond to the full range of sounds in a place at a given time. As an emerging discipline, soundscape studies try to look at or people, in context”.

Perceived as near-complete silence

<table>
<thead>
<tr>
<th>Sound Event</th>
<th>Decibel Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic or gunfire within 1 m</td>
<td>140 dB</td>
</tr>
<tr>
<td>Loudspeaker or machine gun at 10 m</td>
<td>130 dB</td>
</tr>
<tr>
<td>Taking off in 30 m away</td>
<td>120 dB</td>
</tr>
<tr>
<td>Loud motorcycle or leaf blower</td>
<td>110 dB</td>
</tr>
<tr>
<td>Ambulance sirens 30 m away</td>
<td>100 dB</td>
</tr>
<tr>
<td>Lawnmower or leaf blower</td>
<td>90 dB</td>
</tr>
<tr>
<td>Heavy traffic noise within vehicle 1 m</td>
<td>80 dB</td>
</tr>
<tr>
<td>Vacuum cleaner 3 m away</td>
<td>75 dB</td>
</tr>
<tr>
<td>Animal (a rabbit)</td>
<td>60 dB</td>
</tr>
<tr>
<td>Rain</td>
<td>50 dB</td>
</tr>
<tr>
<td>Library</td>
<td>40 dB</td>
</tr>
<tr>
<td>Soft whisper or tick-tick clock</td>
<td>30 dB</td>
</tr>
<tr>
<td>Rusting leaves</td>
<td>20 dB</td>
</tr>
<tr>
<td>Normal breathing</td>
<td>10 dB</td>
</tr>
</tbody>
</table>

### Noise measurement

The pressure or intensity of sound is commonly expressed in decibels. Since the range of sound pressure that the human ear can detect is so large, the decibel scale is logarithmic: a scale based on powers of 10.

On the dB scale, the lowest audible sound, perceived as near-complete silence, is 0 dB. A sound 10 times greater in pressure than 0 dB is assigned a sound level of 10 dB. But this increment of 10 dB is generally perceived as a doubling of loudness by the ear. A sound 100 times more intense than 0 dB, or 10^2 times greater in pressure than 0 dB is assigned a sound level of 20 dB. But this increment of 100 dB is generally perceived as an increase of sound pressure by another factor of 10. A sound 10^4 times more intense than 0 dB is assigned a sound level of 40 dB, and so on. That is, each increase of 10 dB is equivalent to an increase of sound pressure by another factor of 10.

### Noise pollution in the urban environment

Noise pollution comes from conventional sources, such as roads, railways, airports, and industry; however, high noise levels may also come from domestic or leisure activities. Traffic and other urban noises affect not only human well-being, but also disturb and endanger the survival of species crucial to the urban environment.

Across the European Union, at least 20 per cent of citizens are currently exposed to road traffic noise levels that are considered harmful to health. This estimate is an average, with urban areas showing a far higher percentage. Noise pollution comes from conventional sources, such as roads, railways, airports, and industry; however, high noise levels may also come from domestic or leisure activities. Traffic and other urban noises affect not only human well-being, but also disturb and endanger the survival of species crucial to the urban environment.

### Decibels (dB) is the units of measure for indicating the intensity or loudness of a sound that help predict thresholds when a noise starts to annoy people or when sleep disturbance emerges. While the loudness of noise is important, the frequency, in terms of high or low pitch, and temporal patterns of sounds also determine the physical and psychological effects it has on the listener.

Physically, proximity to very loud ambient sounds, such as a gunshot over 140 dB, could capture the ear’s tympanic membrane, causing immediate hearing loss. Listening to music with earphones at the maximum volume — ranging between 90 and 100 dB at the earache — could start to cause hearing damage after only 15 minutes per day. Regular exposure to over 85 dB for a 8-hour day or longer can cause permanent hearing damage. Long-term exposures even at relatively lower noise levels that are common in urban areas, can also damage both physical and mental health.

Noise quality cannot be judged only by its physical properties, however. The definition of noise as unwanted sound implies a psychological concept. While it is necessary to reduce noise levels when they are physically harmful to people, it may not be a sufficiently broad evaluation. It is becoming more relevant to consider soundscape that contribute to people’s physical as well as psychological well-being, especially in the urban environment.

The sounds of Big Ben in London or the calls to prayer from the Masjid al-Haram in Makkah, for example, are evocative experiences. In its broader understanding, acoustic comfort should not be seen merely as the absence of noise, but rather as a situation where environmental sounds offer ample opportunities for people to thrive and look after both their physical and mental well-being.
The adverse effects of noise on public health are modifiable and are a growing global problem. They occur over a broad spectrum of populations, ranging from the mild and temporary distress to severe and chronic physical ailments. Noise-induced sleep disturbance and sleep effects were being the following day. Estimates suggest that in Europe 20 million to 8 million people suffer from chronic noise annoyance and sleep disturbances respectively. The elderly, pregnant women and shift workers are among those at risk of noise-induced sleep disturbance.

Noise-induced awakening can trigger a range of physiological and psychological stress responses because sleep is necessary for hormonal regulation and cardiovascular functioning. There is increasing evidence that traffic noise exposure is a risk factor for the development of cardiovascular and metabolic disorders such as elevated blood pressure, arterial hypertension, coronary heart disease and diabetes. A consequent estimate indicates that long-term exposure to environmental noise contributes to 48,000 new cases of ischemic heart disease and causes 12,000 premature deaths annually in Europe.

Two 15-year-long studies of long-term residents of Toronto, Canada found that exposure to road traffic noise elevated risks of acute myocardial infarction and the cumulative occurrence of diabetes mellitus by 9 per cent, and hypertension by 12 per cent. These studies have already taken into account the confounding effects of traffic-related air pollution that are associated with the same outcomes. An analysis of national health and noise data from the United Kingdom estimated that for every 10 decibels above the night-time noise level originates from various sources. The natural soundscape includes oceanic sounds, environmental and metabolic effects; cognitive impairment, effects on sleep, hearing impairment and bronchitis, admire birth outcomes, and qualities of mental health and wellbeing. The noise exposure considered in those reviews includes traffic noises, railways, aircraft, wind turbines, and leisure activities like attending sporting or concert events, listening to music through personal devices, and other non-auditory situations.

Based on these reviews, the WHO recommends certain exposure thresholds in producing or receiving signals, the inability to communicate reproductive success. The reviews reported on the existence of systematic reviews and meta-analysis. They concluded that the evidence for the inferences drawn from both clinical physiological and psychological studies of wellbeing was to assess significant environments. The WHO reported the positive influence of natural soundscape on physical and mental health. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation, as well as be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation, as well as be associated with evolutionary advantages.

The health outcomes include annoyance, sleep disturbance and more awakenings. The ecological implications of noise on human health outcomes may be severe and chronic physical adverse birth outcomes; and quality of life. The noise sources considered in these reviews include traffic noises, railways, aircraft, wind turbines, and leisure activities like attending sporting or concert events, listening to music through personal devices, and other non-auditory situations.

In contrast, some sounds bring health benefits, particularly sounds from nature. A number of systematic reviews documented empirical research from both clinical physiological and psychological studies of wellbeing. The reviews reported the positive influence of natural soundscape on physical and mental health.

The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation, as well as be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation, as well as be associated with evolutionary advantages.

The reviews reported on the existence of systematic reviews and meta-analysis. They concluded that the evidence for the inferences drawn from both clinical physiological and psychological studies of wellbeing was to assess significant environments. The WHO reported the positive influence of natural soundscape on physical and mental health. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation, as well as be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation, as well as be associated with evolutionary advantages.

The reviews reported on the existence of systematic reviews and meta-analysis. They concluded that the evidence for the inferences drawn from both clinical physiological and psychological studies of wellbeing was to assess significant environments. The WHO reported the positive influence of natural soundscape on physical and mental health. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation, as well as be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation, as well as be associated with evolutionary advantages.

The reviews reported on the existence of systematic reviews and meta-analysis. They concluded that the evidence for the inferences drawn from both clinical physiological and psychological studies of wellbeing was to assess significant environments. The WHO reported the positive influence of natural soundscape on physical and mental health. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation, as well as be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation, as well as be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation, as well as be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation, as well as be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation, as well as be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation, as well as be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation, as well as be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation, as well as be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation, as well as be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages.

The reviews reported on the existence of systematic reviews and meta-analysis. They concluded that the evidence for the inferences drawn from both clinical physiological and psychological studies of wellbeing was to assess significant environments. The WHO reported the positive influence of natural soundscape on physical and mental health. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation.

The reviews reported on the existence of systematic reviews and meta-analysis. They concluded that the evidence for the inferences drawn from both clinical physiological and psychological studies of wellbeing was to assess significant environments. The WHO reported the positive influence of natural soundscape on physical and mental health. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation.

The reviews reported on the existence of systematic reviews and meta-analysis. They concluded that the evidence for the inferences drawn from both clinical physiological and psychological studies of wellbeing was to assess significant environments. The WHO reported the positive influence of natural soundscape on physical and mental health. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation.

The reviews reported on the existence of systematic reviews and meta-analysis. They concluded that the evidence for the inferences drawn from both clinical physiological and psychological studies of wellbeing was to assess significant environments. The WHO reported the positive influence of natural soundscape on physical and mental health. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation.

The reviews reported on the existence of systematic reviews and meta-analysis. They concluded that the evidence for the inferences drawn from both clinical physiological and psychological studies of wellbeing was to assess significant environments. The WHO reported the positive influence of natural soundscape on physical and mental health. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation.

The reviews reported on the existence of systematic reviews and meta-analysis. They concluded that the evidence for the inferences drawn from both clinical physiological and psychological studies of wellbeing was to assess significant environments. The WHO reported the positive influence of natural soundscape on physical and mental health. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation.

The reviews reported on the existence of systematic reviews and meta-analysis. They concluded that the evidence for the inferences drawn from both clinical physiological and psychological studies of wellbeing was to assess significant environments. The WHO reported the positive influence of natural soundscape on physical and mental health. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation.

The reviews reported on the existence of systematic reviews and meta-analysis. They concluded that the evidence for the inferences drawn from both clinical physiological and psychological studies of wellbeing was to assess significant environments. The WHO reported the positive influence of natural soundscape on physical and mental health. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation.

The reviews reported on the existence of systematic reviews and meta-analysis. They concluded that the evidence for the inferences drawn from both clinical physiological and psychological studies of wellbeing was to assess significant environments. The WHO reported the positive influence of natural soundscape on physical and mental health. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation.

The reviews reported on the existence of systematic reviews and meta-analysis. They concluded that the evidence for the inferences drawn from both clinical physiological and psychological studies of wellbeing was to assess significant environments. The WHO reported the positive influence of natural soundscape on physical and mental health. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation.

The reviews reported on the existence of systematic reviews and meta-analysis. They concluded that the evidence for the inferences drawn from both clinical physiological and psychological studies of wellbeing was to assess significant environments. The WHO reported the positive influence of natural soundscape on physical and mental health. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation.

The reviews reported on the existence of systematic reviews and meta-analysis. They concluded that the evidence for the inferences drawn from both clinical physiological and psychological studies of wellbeing was to assess significant environments. The WHO reported the positive influence of natural soundscape on physical and mental health. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation.

The reviews reported on the existence of systematic reviews and meta-analysis. They concluded that the evidence for the inferences drawn from both clinical physiological and psychological studies of wellbeing was to assess significant environments. The WHO reported the positive influence of natural soundscape on physical and mental health. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation.

The reviews reported on the existence of systematic reviews and meta-analysis. They concluded that the evidence for the inferences drawn from both clinical physiological and psychological studies of wellbeing was to assess significant environments. The WHO reported the positive influence of natural soundscape on physical and mental health. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation.

The reviews reported on the existence of systematic reviews and meta-analysis. They concluded that the evidence for the inferences drawn from both clinical physiological and psychological studies of wellbeing was to assess significant environments. The WHO reported the positive influence of natural soundscape on physical and mental health. The importance of natural soundscape to general well-being may also be associated with evolutionary advantages. Natural soundscape may signal a safe environment, reduce anxiety and offer mental recuperation.
Sound check: How noisy are cities?

The World Health Organization has estimated that 1.1 billion people worldwide live in environments where they are exposed to noise levels of over 70 dB. Not only does noise pollution affect our sleep, stress, and mental health, but it also impacts general public health with adverse effects on cardiovascular and respiratory diseases. It is estimated that noise pollution can increase the risk of hypertension by 2%, incidence of diabetes mellitus by 8%, and elevated risks for acute myocardial infarction and stroke.

Soundscapes offer an opportunity to positively contribute to peaceful and quiet surroundings. Quiet urban areas offer acoustic relief to city inhabitants from noisy surroundings, positively contribute to mental restoration and neurophysiological recovery. The following data from various cities can help create a peaceful urban environment.

### Soundscape management: From noise mitigation to desirable soundscape

Sights and sounds

- **Pathway interventional**: Provides the ability to control noise by introducing nature, design, and vegetation to control noise.
- **Mitigation of noise**: Introduces design and vegetation to control noise.
- **Noise barriers**: Provides the ability to control noise by introducing nature, design, and vegetation to control noise.
- **Vegetated noise barriers**: Provides the ability to control noise by introducing nature, design, and vegetation to control noise.
- **Green spaces**: Provides the ability to control noise by introducing nature, design, and vegetation to control noise.
- **Quiet space**: Provides the ability to control noise by introducing nature, design, and vegetation to control noise.
- **Place-making**: Provides the ability to control noise by introducing nature, design, and vegetation to control noise.

### Noise levels

<table>
<thead>
<tr>
<th>City</th>
<th>Noise Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>New York</td>
<td>70</td>
</tr>
<tr>
<td>Morogoro, Tanzania</td>
<td>77</td>
</tr>
<tr>
<td>Abuja, Nigeria</td>
<td>88</td>
</tr>
<tr>
<td>Cape Coast, Ghana</td>
<td>77</td>
</tr>
<tr>
<td>Cairo, Egypt</td>
<td>85</td>
</tr>
<tr>
<td>San Diego, US</td>
<td>83</td>
</tr>
<tr>
<td>Nis, Serbia</td>
<td>76</td>
</tr>
<tr>
<td>Moscow</td>
<td>73</td>
</tr>
<tr>
<td>Atlanta, US</td>
<td>60</td>
</tr>
<tr>
<td>Toronto, Canada</td>
<td>60</td>
</tr>
<tr>
<td>Buenos Aires, Argentina</td>
<td>60</td>
</tr>
<tr>
<td>Paris, France</td>
<td>60</td>
</tr>
<tr>
<td>Jakarta, Indonesia</td>
<td>76</td>
</tr>
<tr>
<td>Beijing, China</td>
<td>75</td>
</tr>
<tr>
<td>Ho Chi Minh City, Viet Nam</td>
<td>75</td>
</tr>
<tr>
<td>Karachi, Pakistan</td>
<td>75</td>
</tr>
<tr>
<td>Chennai, India</td>
<td>55</td>
</tr>
<tr>
<td>Mumbai, India</td>
<td>55</td>
</tr>
<tr>
<td>Rio de Janeiro, Brazil</td>
<td>60</td>
</tr>
<tr>
<td>Sao Paulo, Brazil</td>
<td>60</td>
</tr>
<tr>
<td>Sydney, Australia</td>
<td>90</td>
</tr>
<tr>
<td>Tokyo, Japan</td>
<td>95</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>85</td>
</tr>
</tbody>
</table>

### Conclusion

Implementing green areas and natural spaces effectively can break the chain of noise propagation between source and receiver. Measures such as vegetation, barriers, and greener spaces can enhance noise attenuation and contribute to a desirable soundscape. Further research into the relationship between urban soundscape and health outcomes is needed.
The effects of noise on health are not uniform among individuals or across population groups. Specific individual differences can increase a person’s vulnerability. An individual’s sensitivity to noise is considered a static trait and partly genetic; it can be influenced by environmental exposure levels. Noise sensitivity manifests as a heightened degree of vigilance and physiological reactivity to sounds. Noise exposure can exacerbate stress responses and may be associated with an individual’s general ill-health. Noise sensitivity manifests as a heightened degree of vigilance and physiological reactivity to sounds. Noise exposure can exacerbate stress responses and may be associated with an individual’s general ill-health.

Age also seems to shape our reaction to sounds, with the very young and the elderly at higher risk from the effects of particular noises. Age also seems to shape our reaction to sounds, with the very young and the elderly at higher risk from the effects of particular noises. Evidence of gender differences in vulnerability to noise is mixed, where differences may be noted in the way men and women perceive and deal with stresses in general.

At the population scale, some social groups are more vulnerable than others. Poor individuals are more likely to have fewer choices, often forcing them to live near environmental stressors such as waste dumps, industrial areas, and roads with high traffic density. Poor individuals are more likely to have fewer choices, often forcing them to live near environmental stressors such as waste dumps, industrial areas, and roads with high traffic density. Subsequent long-term exposure to such environmental stressors can compromise the understanding and the physical well-being of individuals living in these communities. Studies from many major cities suggest that marginalized communities are exposed to higher environmental noise levels, with indications that noise exposure inequalities also drive disparities in health outcomes. Studies from many major cities suggest that marginalized communities are exposed to higher environmental noise levels, with indications that noise exposure inequalities also drive disparities in health outcomes. Enhancing access to urban green spaces and local quiet areas can improve soundscapes and buffer the negative impact of noise.

The WHO noise guidelines also emphasize that policy attention should not simply focus on noise with high noise levels, but also on areas with less noise.Quiet urban parks, converted canal towpaths and rail tracks, and other linear areas can provide valuable opportunities for public access to quiet areas and restoration of environmental assets that are embedded in the city fabric. Quiet urban parks, converted canal towpaths and rail tracks, and other linear areas can provide valuable opportunities for public access to quiet areas and restoration of environmental assets that are embedded in the city fabric.

Public bodies, industry and research have focused mainly on these kinds of technological developments. The alternative conventional measures, like installing noise barriers, are typically less cost-effective and only solve a problem locally, with potential negative landscape impacts as an additional drawback. Public bodies, industry and research have focused mainly on these kinds of technological developments. The alternative conventional measures, like installing noise barriers, are typically less cost-effective and only solve a problem locally, with potential negative landscape impacts as an additional drawback.

Noise abatement and mitigation measures can be classified as direct and indirect noise abatement strategies. Direct noise abatement strategies involve reducing the source of the noise, for example, by using quieter vehicles or sound-insulating materials. Indirect noise abatement strategies are more complex and may involve changing the way people interact with the environment. Indirect noise abatement strategies are more complex and may involve changing the way people interact with the environment.

The effects of noise on health are not uniform among individuals or across population groups. Specific individual differences can increase a person’s vulnerability. An individual’s sensitivity to noise is considered a static trait and partly genetic; it can be influenced by environmental exposure levels. Noise sensitivity manifests as a heightened degree of vigilance and physiological reactivity to sounds. Noise exposure can exacerbate stress responses and may be associated with an individual’s general ill-health. Evidence of gender differences in vulnerability to noise is mixed, where differences may be noted in the way men and women perceive and deal with stresses in general.

Subsequent long-term exposure to such environmental stressors can compromise the understanding and the physical well-being of individuals living in these communities. Studies from many major cities suggest that marginalized communities are exposed to higher environmental noise levels, with indications that noise exposure inequalities also drive disparities in health outcomes. Enhancing access to urban green spaces and local quiet areas can improve soundscapes and buffer the negative impact of noise. Indirect noise abatement strategies include management of road, rail and air traffic flow like installing noise barriers, and adopt building energy components for aircraft, and shifts away from internal combustion engines to quieter propulsion systems. Public bodies, industry and research have focused mainly on these kinds of technological developments. The alternative conventional measures, like installing noise barriers, are typically less cost-effective and only solve a problem locally, with potential negative landscape impacts as an additional drawback.

Noise mitigation in cities can also be achieved with indirect approaches. In the national plan to combat noise and reduce its sources, the Government of Egypt has incorporated measures with environmental co-benefits. These include encouraging the use of bicycles, and adopting building energy standards to reduce noise emission from air-conditioning systems. In Berlin, Germany, new cycle lanes on wide roads have been used as an indirect noise abatement strategy aiming at reducing the available driving space for motorized vehicles. More than 50,000 residents were originally expected to use these new lanes, resulting in a reduction in noise levels higher than 50 dB; in many city roads with two lanes per direction and volumes of transit up to 30,000 daily units were narrowed to single-lane roads, reducing space for bicyclists and pedestrians. This moved the source of the sound emission towards the middle of the roads, away from residential settings. Overall, it achieved a reduction in noise levels to more than 50,000 residents.

In April 2016, the Ultra-Low Emission Zone came into effect in Central London and expanded in late 2021 to include an area encompassing 3.8 million people. While the scheme was mainly driven by a desire to improve air quality, encouraging the use of electric and hybrid vehicles has noise-reduction benefits as these vehicles are much quieter compared with internal combustion engine vehicles, especially at low speeds. However, the desirability of quiet vehicles may become a safety concern for pedestrians and consequently a new challenge.

Leasing of cities with complex vertical development and right road networks, Hong Kong stands out as a challenging case where land use and urban morphology are key factors affecting the spatial distribution of noise sources in the built environment. With one of the densest populations exposed to road traffic noise at levels greater than the 70 dB limit, the authorities adopted a relatively aggressive policy centered on infrastructure design and land-use planning, with limited success.

The WHO noise guidelines also emphasize that policy attention should not simply focus on noise with high noise levels, but also on areas with less noise. Quiet urban parks, converted canal towpaths and rail tracks, and other linear areas are places where people can escape city noise. Access to nearby quiet areas contributes to the health and well-being of local communities. While noise level is an important aspect, soundscape quality is also contextual and influenced by non-audio factors, including the feeling of safety, which may be a notable concern for women and for parents. Quiet areas are more generally understood as places with pleasant soundscapes or where unwanted sounds are mostly absent. Providing or protecting these spaces is a more passive, yet still valuable, way of mitigating against noise in urban areas.

Quiet areas are generally understood as places with pleasant soundscapes or where unwanted sounds are mostly absent.
Noise pollution should be considered within a broader range of environmental challenges through integrated policies, particularly for the combination of noise and air pollution.

Over the past several decades, policymakers have achieved some progress in addressing noise pollution as an environmental and public health issue. However, two major shortcomings have emerged. First is the inherent limitation of using a reactive approach—waiting until noise pollution is retroactively reducing noise levels. The second is thinking of sound only in terms of discomfort, such as transport and industrial noise, rather than investigating how to promote sounds that provide comfort. These two points need to be urgently addressed to achieve livable cities and support research-informed interventions is crucial in this process.

To overcome the first shortcoming, in any urban development strategy, environmental sounds should be considered at the earliest possible stage of planning and design to prevent them from becoming an afterthought—one that could involve significant expense. According to data from Europe, more than 50 per cent of all urban noise focus on the source, which is often ineffective but will not necessarily provide soundscape quality. “A very limited percentage of measures dealing with environmental sounds resort to land use or urban planning, while growing evidence from researchers indicates that this approach leads to the most sustainable paths.”12,13 Therefore, it is crucial that experts in environmental acoustics and urban soundscapes are involved in urban development processes and that they communicate with local stakeholders.

Furthermore, noise pollution should be considered within a broader range of environmental challenges through integrated policies, particularly for the combination of noise and air pollution. Many countries surveyed by the European Environment Agency report successful policies that provide co-benefits, including traffic-calming measures, green vehicle fleets, energy-efficient buildings, tree and shrub plantings to create and link green corridors, and incorporating downcycled materials into engineered noise control solutions.14

To address the second shortcoming, there needs to be an extension of the scope of policymaking through a shift from only managing environmental sounds when they cause noise pollution to considering environmental sounds as opportunities for promoting healthy living environments for all age, gender and cultural groups. The Government of Wales aspires to preserve or cultivate acoustic environments.

While lockdown soundscapes thrived, while keeping noise pollution within acceptable bounds, new approaches need to account for people’s perception rather than just their exposure; this will complement and augment the dB measure for characterizing soundscapes. Although desirable for some contexts like urban parks or residential areas, simple silence or quiet cannot be the standard for assessing the quality of every urban space. We need our cities to be aurally diverse and inclusive, to support different social and cultural activities, local commuting, and incorporate a broader range of co-benefits, including traffic calming measures, green vehicle fleets, energy-efficient buildings, tree and shrub plantings to create and link green corridors, and incorporating downcycled materials into engineered noise control solutions.15

We need our cities to be aurally diverse and inclusive, to support mixed uses; this is something silence alone cannot deliver.

The long-term implications of the COVID-19 crisis are still unclear and current global research should provide further insights. The unexpected silence from human sound sources triggered a debate among academic communities and the public on how modern cities could sound and whether we are doing enough to achieve positive soundscapes.

Although there is consensus that the limitations imposed by lockdown measures and lower noise levels in many cities, the maximum observed reductions for traffic noise were still typically in the region of only 5–10 dB. While this would be perceptually noticeable in most situations, it is not always enough to bring noise pollution to safe levels according to WHO recommendations. Hence, cities need to improve their soundscapes, using different strategies for planning and infrastructural changes would develop healthier acoustic environments.


UN ENVIRONMENT PROGRAMME FRONTIERS 2022 REPORT


Montreal, Canada


New York, USA


San Diego, USA


Toronto, Canada

16. Bai et al. 2020

17. Shin et al. 2020


LATIN AMERICA

Bogota, Colombia - Puerto Vallarta, Mexico


29. Dorado-Correa et al. (2016)

Santiago, Chile


Talca, Chile


EUROPE

Barcelona, Spain

2. European Environment Agency (2020)


Belgrade, Serbia


London, United Kingdom


Sound check: How noisy are cities?

AFRICA

Abuja, Nigeria - Algiers, Algeria - Cape Coast Metropolis, Ghana - Ibadan, Nigeria - Morogoro, Tanzania - Nairobi, Kenya


Cairo, Egypt


NORTH AMERICA

Atlanta, USA, Los Angeles, USA


Montreal, Canada

Graphic references


29. Dorado-Correa et al. (2016)

Santiago, Chile


Talca, Chile


EUROPE

Barcelona, Spain

2. European Environment Agency (2020)


Belgrade, Serbia


London, United Kingdom

UN ENVIRONMENT PROGRAMME FRONTIERS 2022 REPORT


Tokat, Turkey


WEST ASIA

Alvaz, Iran


Beirut, Lebanon - Damascus, Syria - Tabriz, Iran


Erbil, Iraq


Hebron


Irbid, Jordan


SOUTH ASIA

Asansol, India


Colombo, Sri Lanka


Delhi, India


Nasim…Road…Region…39-45.pdf

Dhaka, Bangladesh


Faisalabad, Pakistan - Islamabad, Pakistan - Karachi, Pakistan


Jaipur, India


Kathmandu, Nepal


Kolkata, India

Moradabad, India

Rajshahi, Bangladesh

Tangail, Bangladesh

EAST ASIA, SOUTH EAST ASIA AND THE PACIFIC

Hong Kong, China

Hanoi, Viet Nam - Ho Chi Minh City, Viet Nam

Hue, Viet Nam


Jakarta, Indonesia

Manila, The Philippines

Melbourne, Australia

Soundscape management:
From noise mitigation to desirable soundscape

Sight and sound

Green solutions

Soundscape


Tree belts
Green roofs

Electric vehicles

Pathway intervention

Mitigation at source

Noise barriers

Vegetated noise barriers

Ecosystem services


Green space


Quiet space


Place-making
Wildfires under climate change

A burning issue
1. Waves of extreme wildfires

Recent years have seen devastating wildfires in many regions of the world, following heatwaves and droughts. Much news coverage focuses on Northern hemisphere wildfires destroying towns, such as during the extraordinary 2020 fire season in the western United States. The extensive 2021 evacuations from the Greek island of Euboea brought haunting images of what researchers suggest will become more frequent events in Mediterranean countries.

Catastrophic wildfires rage in the global South as well. In 2019/2020, Australia experienced the unprecedented Black Summer fires, with news stories and shocking images broadcast internationally. Despite being a country shaped by fire in many ways, the sheer scale and intensity of the Black Summer fires brought into focus how global warming is adding to wildfire risk. The fires burned over 24 million hectares, thousands of homes were destroyed and 33 people lost their lives. The 2019-2020 massive fires destroyed critical habitats for hundreds of species, including those already threatened with extinction.

In Latin America, the rapid and widespread deforestation of savannahs and tropical rainforests, compounded by droughts and the limitations of existing fire management policies, has led to disastrous wildfires in recent decades. In 2019, more than 6 million hectares burned in the Chiquitania, Cerrado and Amazon regions in Bolivia, Brazil, Colombia, Paraguay and Peru, mostly within protected areas of native vegetation. During the dry season of 2020, another long and destructive wave of wildfires swept through the area, across Africa, fires are visible in satellite imagery throughout the year, adding up to vast burned areas in observation and monitoring records.

Over continents and biomes, there are similarities among these extreme wildfire events in the form of underlying risk factors, hazards and consequences for society and the environment. Long-term effects on physical and mental health are not limited to those fighting wildfires, evacuated, or suffering great loss. Smoke and particulate matter from wildfires deliver significant consequences for human health in downwind settlements, sometimes thousands of kilometres from the source. Research suggests that the most vulnerable – women, children, elderly, disabled and the poor – suffer the worst ongoing damage from their wildfire exposure, echoing the acknowledged understanding of this same result as the common outcome from most disasters.

The observed trends towards more dangerous fire weather conditions for wildfires are projected to continue increasing, due to mounting concentrations of atmospheric greenhouse gases, with escalating risk factors.

“The observed trends towards more dangerous weather conditions for wildfires are projected to continue increasing, due to mounting concentrations of atmospheric greenhouse gases, with escalating risk factors.”

On 11 July 2012, more than 18,500 hectares of boreal forests were burning across central and eastern Siberia, Russia. Uncontrolled wildfires were ignited from Kuyga in the west to Sakhalin in the east. This satellite image shows fires raging near the Aldan River in Yakutia on 19 July 2012.

Source: NASA Earth Observatory
Burned areas in the last two decades

This chart illustrates global burned area patterns from 2000 to March 2021, using the remote sensing data set from NASA’s Moderate Resolution Imaging Spectroradiometer (MODIS).

From 2002 to 2015, approximately 423 million hectares of the Earth’s land surface burned annually, the majority (67%) on the African continent. A related analysis estimated that from 2003 to 2016 over 13 million individual fires occurred globally, each lasting 4–5 days. On average, each ignition burned an area of 440 hectares globally, while in Australia individual fires burned up to 1,790 hectares.

The data includes all types of burned areas detected, including cropland, pasture, and natural vegetation regardless of the ignition source, fire type, or reason for burning.

The Brazilian savannah, or Cerrado, covers about 23% of total land area, the second largest biome after the Amazon rainforest (48%). Fires in the Cerrado have increased in frequency and concentration in the dry season and now tend to burn every 2–3 years, such as in 2004, 2007, 2010, 2012, 2015, and 2017.

70–90% of the total burned area of Russia is in Siberia, with the majority of Siberian wildfires occurring in larch-dominated forests. In southern Siberia, the 2003 extreme fires in the permafrost-underlain larch forests were influenced by low surface moisture and lack of precipitation in the previous year, and elevated temperatures in early 2003.

9–10% of Angola’s land surface burns every year, with the largest proportion of forest and a small proportion of natural and local vegetation. The practice of felling forest to create land for grass development has promoted more intense fires in the dry season.

The unusual fire events in Bolivia in 2004 have been linked to the impact of drought and forest loss.

According to research on long-term trends, the 2005 wildfires in Paraguay have been associated with a rise in deforestation. The record number of forest fires in Mexico in 2011 were most likely associated with prolonged drought periods due to less winter rain in the previous year.

The extensive burned areas in the boreal forests of the Northwest Territories of Canada in 2014 and the United States’ Alaska in 2015 are attributed to a record number of climate-driven lightning ignitions.

The conversion of native forests to areas of highly flammable vegetation, together with a sustained megadrought in central Chile, facilitated large fires during the 2016/2017 fire season.

* South Sudan gained independence from Sudan on 9 July 2011. The burned area data prior to the date have been mapped to the present border demarcations of both countries.
2. Human influences on wildfires

Wildfires are a natural feature of the Earth system, necessary for the functioning of many ecosystems. Interactions between vegetation and climate over extended periods establish a particular pattern of wildfire recurrence in a defined ecosystem, known as its fire regime. Deviations from the prevailing fire regime – the timing, frequency, size and intensity of wildfires – can drive significant ecological changes in both fire-dependent ecosystems that need fires to thrive and fire-sensitive ecosystems where fires bring more negative than positive effects.

Humans directly and indirectly alter fire regimes by modifying landscapes and their vegetation, by starting fires as a land management practice where natural fires rarely occur, by suppressing and preventing fires to protect human communities, and by changing the climate. Land clearing, deforestation, agricultural expansion, resource extraction and urban and rural development are all major land-use changes that can interfere with natural fire regimes.

Fire-sensitive tropical rainforests seldom burn naturally, because fire ignitions are rarely sustained in such a humid environment with moist vegetation. Now wildfires have become more common in some regions where they were not expected to occur, including due to climate change as well as other factors such as land-use change and deforestation. In the Amazon rainforest fires are set by humans: native vegetation is cut down, the more valuable timber is selected and removed, and the remains are left to dry until the debris is deliberately set alight to open space for farms and grazing land. Forest fragmentation and the eventual breakdown into savannah and grassland create favourable conditions for future wildfires, resulting in the permanent loss of tropical forest ecosystems.

Growing urbanization, as cities expand into wildland, is another important form of land-use change and landscape transformation. Recent decades saw a rapid expansion of cities towards forest areas in many regions. This wildland-urban interface is the area where wildfire risks are most pronounced.

Inappropriate fire management policies, including aggressive fire suppression, and the low recognition of traditional fire management practices and indigenous knowledge, can generate a cascade of challenges. In some other cases, attempts to eliminate fire from ecosystems, including fire-dependent ones, can lead to build-up of fuel loads and an associated increase in ignition risks. Fire management policies such as these can result in fire regime shifts with large and frequent wildfires becoming prevalent.

In recent decades, a growing recognition of the need for a systematic and whole-of-landscape approach that is integrated with the cultural and ecological significance of indigenous land management is helping to promote ecological health and prevent larger, more destructive uncontrolled fires in ecosystems. For example, fire management initiatives in Australian savannahs have measured and monitored the effects of prescribed burning that incorporates indigenous wildfire management techniques, with positive results. This approach has provided inspiring examples for other countries, including in Brazil’s Cerrado and Botswana’s savannah ecosystems.
Wildfires in the Anthropocene

Fire ecology

What is a wildfire?

In a wildfire, fire spreads through vegetation, fuel, and weather conditions. A wildfire can start naturally or be caused by human activity. Wildfires have become more common due to climate change and land use changes.

Vegetation and management

Vegetation can vary depending on the ecosystem and climate. Vegetation management involves controlling wildfires and preventing fuel build-up.

Altered fire regimes

Human activities have altered fire regimes in many parts of the world. Fire regimes can be characterized by periods of rapid spread and intense behavior. Different types of wildfires exhibit distinct behaviors.

Fire regimes are changing

Fire regimes are changing due to climate change, land use changes, and human activities. The map shows active fires of all types observed from 1 January to 20 September 2021. The image was created by merging still frames extracted from NASA's time-lapse video of active fires. For best viewing, see the timelapse.

Source:

Adapted from Bowman et al. (2010–2020).
3. Changing climate, changing fire weather

Globally, many types of extreme weather events are now more intense and occurring more frequently than in the past due to anthropogenic climate change. Hotter temperatures, coupled with more droughts, lead to longer fire seasons and more likelihood of dangerous fire weather conditions. 28,29

Long-term warming trends show that most years are now hotter than those observed before 1950 in 41 out of the world’s 45 regions. 30 Hotter temperatures, coupled with more droughts, lead to longer fire seasons and more likelihood of dangerous fire weather conditions. 30,31

Research focusing on western North America shows that heatwaves and multi-year droughts are not only fostering more wildfires, but the wildfires are increasing in severity and burning larger areas. 32,33 In South America, severe and prolonged droughts and higher air temperatures are associated with increased fire incidence and severity in humid tropical areas and seasonally flooded wetlands, including areas where wildfires were unprecedented. 34-36 In the temperate climate region of Australia, rainfall in the period leading to the fire season has declined by over 10 per cent since the late 1990s. 37 Based on over 100 years of data, 2019 was Australia’s hottest and driest year on record. 38-41

In Chile, New Zealand and parts of Africa, research has also shown the influence of climate change in increased drought conditions and forest fire activity. 42-45 In Southern Europe and around the Mediterranean Sea, climate change is likewise driving more dangerous fire weather conditions as the entire Basin transitions into a more arid system. 46,47,48

Lightning is an important natural ignition source for wildfires and frequency of lightning strikes in some parts of the world are projected to increase with a changing climate. 49-51 In recent years climate-driven lightning ignitions account for the majority of burned areas in the North American boreal forests. 52 An increased frequency of dry lightning – a type of lightning that occurs with little or no precipitation – has also been documented in some parts of southeast Australia in recent decades, while some areas experienced a decline. 53-55 Of the total area burned by wildfires, a significant proportion can be attributed to lightning ignitions, because they can occur variably over time and space and they spread in remote regions that are difficult to reach with response capabilities. 56

Another phenomenon that has become more frequently reported in Australia and North America in recent decades is the fire-generated thunderstorm. 57-60 A characteristic of more extreme fire events, these thunderstorms form in wildfire smoke plumes, generating what are known as pyrocumulonimbus clouds. The frequency of weather conditions associated with the occurrence of fire-generated thunderstorms is increasing over time in parts of southern Australia, with these increases projected to continue. 61-64 Fire-generated thunderstorms can contribute to more dangerous conditions for fires on the ground, including more erratic wind speeds and changes in direction, as well as generating lightning that can ignite new fires far beyond the fire front. 65-66 They illustrate the risk of dangerous feedback loops between the fire and atmospheric processes.

Available biomass fuel is a key factor driving fire intensity under the uncertain influence of climate change. Fuel loads may increase due to the CO2 fertilization effect when higher carbon dioxide concentrations at ground level encourage certain plant types to thrive. 67-68 While the bulk of organic material could increase, lower relative humidity would turn the greater bulk into dry fuels for wildfires. Fuel load has also increased due to the practice of wildfire exclusion in some cases. 69-70 Better comprehension of fire-dependent ecosystems, and fire ecology as a whole, is fostering the shift toward integrated fire management including the use of controlled and prescribed burning at appropriate times and under the correct conditions to reduce fuel loads. 71,72

While climate change is already influencing wildfires, wildland fires may likewise be influencing climate change. 73-75 The loss of the Amazon rainforest and thawing of Arctic permafrost are considered two possible tipping elements that could potentially accelerate climate change. 76-79 Recent research has indicated deforestation in the Amazon is shifting the region from a carbon sink to a carbon source and permafrost thaw is accelerating in the Siberian Arctic, with fires as contributing factors in both cases. 80,81
Lightning ignition

Lightning is an important natural ignition source for wildfires. Lightning strikes are projected to increase in frequency in some parts of the world as climate changes. Lightning ignition is the predominant driver of massive wildfires in the boreal forests of North America and northern Siberia.60

Fire-generated thunderstorms

Extremely intense fires can trigger the development of smoke-infused thunderstorms that can cause more dangerous fire behaviour as well as ignite new fires through lightning.

Impacts of extreme wildfires on the Earth’s system

Atmospheric pollution

Large, intense wildfires release enormous amounts of air pollutants, such as black carbon, particulate matter, and greenhouse gases. These pollutants may be transported over long distances and deposited over remote landscapes, including glaciers.

Water pollution

Following severe wildfires, elevated sediment levels in rivers increase turbidity, alter water temperature, and affect fish populations. Post-wildfire erosion increases the risk of soil erosion and landslides, which can transport sediments into water bodies, affecting water quality and aquatic species.

Biochemical loss

More frequent and more intense wildfires can alter the nutrient cycles of ecosystems, affecting soil fertility and plant productivity. These changes can affect the ability of ecosystems to sequester carbon and store nutrients, affecting the balance of carbon and nutrients in ecosystems.

Species under threat of altered fire regimes

Percentage of species threatened by altered fire regimes including fire exclusion per habitat

- Savannah: 28.0%
- Grassland: 26.3%
- Rocky areas: 26.0%
- Shrubland: 25.7%
- Forest: 18.7%
- Wetlands: 10.9%
- Desert: 7.6%

Source: Kelly et al. (2020). See page 40 for a complete reference.
Wildfire management improvements in the face of further climate changes

While developed country practices have often emphasized fire exclusion, many developing countries lack capacity to manage fires, beyond exclusion approaches, recognition of indigenous practices that maintain or restore ecosystems, such as savannahs and grasslands, where fuel loads build up and property. Effective fire management is important in fire-dependent ecosystems, such as savannahs and grasslands, where fuel loads build up and property. Effective fire management is important in fire-dependent ecosystems, such as savannahs and grasslands, where fuel loads build up and property. Effective fire management is important in fire-dependent ecosystems, such as savannahs and grasslands, where fuel loads build up and property. Effective fire management is important in fire-dependent ecosystems, such as savannahs and grasslands, where fuel loads build up and property.

Community-owned solutions in Latin America

Building resilience: new tools and approaches

Long-term changes in climatologically driven events and the increased frequency and intensity of natural disasters are posing a greater challenge to existing approaches to disaster risk reduction. The increased frequency and intensity of natural disasters are posing a greater challenge to existing approaches to disaster risk reduction. The increased frequency and intensity of natural disasters are posing a greater challenge to existing approaches to disaster risk reduction. The increased frequency and intensity of natural disasters are posing a greater challenge to existing approaches to disaster risk reduction.

The threats will only increase as anthropogenic climate change intensifies, and taking a systems approach to managing climate change is needed.

Australia has manyResponses required the risk management approaches and decision-making over a broad range of timescales. Climate change related impacts include changes in climate and weather, changes in the frequency and intensity of extreme events, changes in the timing and duration of seasons, changes in the availability and quality of water, and changes in the occurrence and severity of droughts. Climate change related impacts include changes in climate and weather, changes in the frequency and intensity of extreme events, changes in the timing and duration of seasons, changes in the availability and quality of water, and changes in the occurrence and severity of droughts. Climate change related impacts include changes in climate and weather, changes in the frequency and intensity of extreme events, changes in the timing and duration of seasons, changes in the availability and quality of water, and changes in the occurrence and severity of droughts.

The threats will only increase as anthropogenic climate change intensifies, and taking a systems approach to managing climate change is needed.

Australia has manyResponses required the risk management approaches and decision-making over a broad range of timescales. Climate change related impacts include changes in climate and weather, changes in the frequency and intensity of extreme events, changes in the timing and duration of seasons, changes in the availability and quality of water, and changes in the occurrence and severity of droughts. Climate change related impacts include changes in climate and weather, changes in the frequency and intensity of extreme events, changes in the timing and duration of seasons, changes in the availability and quality of water, and changes in the occurrence and severity of droughts.

The threats will only increase as anthropogenic climate change intensifies, and taking a systems approach to managing climate change is needed. The threats will only increase as anthropogenic climate change intensifies, and taking a systems approach to managing climate change is needed. The threats will only increase as anthropogenic climate change intensifies, and taking a systems approach to managing climate change is needed.

Australia has manyResponses required the risk management approaches and decision-making over a broad range of timescales. Climate change related impacts include changes in climate and weather, changes in the frequency and intensity of extreme events, changes in the timing and duration of seasons, changes in the availability and quality of water, and changes in the occurrence and severity of droughts. Climate change related impacts include changes in climate and weather, changes in the frequency and intensity of extreme events, changes in the timing and duration of seasons, changes in the availability and quality of water, and changes in the occurrence and severity of droughts. Climate change related impacts include changes in climate and weather, changes in the frequency and intensity of extreme events, changes in the timing and duration of seasons, changes in the availability and quality of water, and changes in the occurrence and severity of droughts.

The threats will only increase as anthropogenic climate change intensifies, and taking a systems approach to managing climate change is needed. The threats will only increase as anthropogenic climate change intensifies, and taking a systems approach to managing climate change is needed. The threats will only increase as anthropogenic climate change intensifies, and taking a systems approach to managing climate change is needed. The threats will only increase as anthropogenic climate change intensifies, and taking a systems approach to managing climate change is needed. The threats will only increase as anthropogenic climate change intensifies, and taking a systems approach to managing climate change is needed.

Australia has manyResponses required the risk management approaches and decision-making over a broad range of timescales. Climate change related impacts include changes in climate and weather, changes in the frequency and intensity of extreme events, changes in the timing and duration of seasons, changes in the availability and quality of water, and changes in the occurrence and severity of droughts. Climate change related impacts include changes in climate and weather, changes in the frequency and intensity of extreme events, changes in the timing and duration of seasons, changes in the availability and quality of water, and changes in the occurrence and severity of droughts. Climate change related impacts include changes in climate and weather, changes in the frequency and intensity of extreme events, changes in the timing and duration of seasons, changes in the availability and quality of water, and changes in the occurrence and severity of droughts. Climate change related impacts include changes in climate and weather, changes in the frequency and intensity of extreme events, changes in the timing and duration of seasons, changes in the availability and quality of water, and changes in the occurrence and severity of droughts. Climate change related impacts include changes in climate and weather, changes in the frequency and intensity of extreme events, changes in the timing and duration of seasons, changes in the availability and quality of water, and changes in the occurrence and severity of droughts. Climate change related impacts include changes in climate and weather, changes in the frequency and intensity of extreme events, changes in the timing and duration of seasons, changes in the availability and quality of water, and changes in the occurrence and severity of droughts. Climate change related impacts include changes in climate and weather, changes in the frequency and intensity of extreme events, changes in the timing and duration of seasons, changes in the availability and quality of water, and changes in the occurrence and severity of droughts. Climate change related impacts include changes in climate and weather, changes in the frequency and intensity of extreme events, changes in the timing and duration of seasons, changes in the availability and quality of water, and changes in the occurrence and severity of droughts. Climate change related impacts include changes in climate and weather, changes in the frequency and intensity of extreme events, changes in the timing and duration of seasons, changes in the availability and quality of water, and changes in the occurrence and severity of droughts.

The threats will only increase as anthropogenic climate change intensifies, and taking a systems approach to managing climate change is needed. The threats will only increase as anthropogenic climate change intensifies, and taking a systems approach to managing climate change is needed. The threats will only increase as anthropogenic climate change intensifies, and taking a systems approach to managing climate change is needed. The threats will only increase as anthropogenic climate change intensifies, and taking a systems approach to managing climate change is needed. The threats will only increase as anthropogenic climate change intensifies, and taking a systems approach to managing climate change is needed. The threats will only increase as anthropogenic climate change intensifies, and taking a systems approach to managing climate change is needed.
References


Graphic references

Areas burned by fires in the last two decades

Angola

Australia

Bolivia

Brazil


Canada

Chile

Mexico

Paraguay

Russia 2003

Wildfires in the Anthropocene

What is a wildfire?

Wildfire and ecosystems

Fusco et al. (2019).

Fire and invasive species
44. Fusco et al. (2019)


Where fires burn
15. Andela et al. (2019)


Changing fire regimes in selected biomes and Land-use change
35. Bowman et al. (2011)


37. Bond and Keane (2017)


40. Bond and Keane (2017)


Fire regimes are changing

Changing fire regimes in selected biomes and Land-use change
35. Bowman et al. (2011)


37. Bond and Keane (2017)


40. Bond and Keane (2017)


Fire-dependent plants


Climate change: Fire weather is becoming more extreme

42. Bowman et al. (2020)


Lightning ignition
42. Bowman et al. (2020)


Fire-generated thunderstorms

Impacts of extreme wildfires on the Earth’s system

Atmospheric pollution

Changed albedo
42. Bowman et al. (2020)


Carbon sink turns into carbon source
42. Bowman et al. (2020)

Water pollution

Ocean fertilization

Biodiversity loss


42. Bowman et al. (2020)


Erosion


Lightning ignition
42. Bowman et al. (2020)


Fire-generated thunderstorms

Impacts of extreme wildfires on the Earth’s system

Atmospheric pollution

Changed albedo
42. Bowman et al. (2020)


Carbon sink turns into carbon source
42. Bowman et al. (2020)

Water pollution


Erosion

Ocean fertilization

Biodiversity loss


42. Bowman et al. (2020)


Water pollution

Species under threat of altered fire regimes

Phenology
Climate change is shifting the rhythm of nature
Timing is everything for ecosystem harmony

Phenology in the tropics

A key feature of tropical climates is the lack of distinct seasonal temperature variations. In contrast, changes in rainfall and the switch between dry and wet seasons define clearer phases within annual cycles of the tropics. The frequency and intensity of rainfall, or its absence, is a crucial driver of phenological changes in tropical plants, as well as sunlight, humidity, and the subtle temperature changes. Given the high species diversity in tropical ecosystems, phenological responses to these drivers are various and complex, within species and communities.

Rainfall patterns in tropical regions are highly influenced by the ENSO (El Niño/Southern Oscillation), characterized by alternating warm and cool phases of sea surface temperature in the equatorial Pacific Ocean. These anomalies occur every 2-7 years and last typically for 9-12 months. Tropical plant communities respond to ENSO events, such as El Niño-induced mass flowering or ENSO events, such as El Niño-induced mass flowering or drought-affected fruiting.

More frequent and more intense extreme weather events, delivered by climate change, are likely to further disrupt the timing of leafing, flowering and fruit production. Such phenological changes will have cascading effects on dependent herbivores, nectarivores and frugivores, as well as other functional groups within the ecosystems. Long-term observations of phenological change in the tropics are still scarce, and predicting the magnitude of phenological shifts and mismatches remains a challenge.

Understanding phenology in tropical regions is more complicated than in regions that have clear annual seasonal cycles, due to less variation in temperature and daylight. Tropical species show diverse phenological strategies, individuals within a population may not synchronize, and cycles can be shorter than 12 months. Different factors, including rain, drought, moisture availability and abundant exposure to sunlight, can trigger the next life-cycle stage in tropical regions.

A major concern with phenological changes in response to climate change is that not all interdependent species in a particular ecosystem shift in the same direction or at the same rate. The reason for varying shifts is that each important factor is sensitive to different environmental drivers, and shows different levels of sensitivity to a single environmental driver. Within food chains, plants may shift their development stage quickly than animals that feed on them, leading to phenological mismatches. Detailed studies on species life-cycle stages across a wide range of plant and animal species have detected significant phenological mismatches. These mismatches between predator and food source within a food web will affect individual growth, reproduction and survival rates, with eventual repercussions for whole populations and ecosystems.

The blooming of cherry blossom (Prunus serrulata) marks the arrival of springtime and is central to Japanese culture. Celebration of cherry blossom has been traced back to 8th century CE. Today, cherry blossom is in Kyoto have been historically recorded in old diaries and chronicles. Researchers have assembled a phenological data series of full-blooming dates of cherry blossom from these documents, dating back as early as 812 AD. Over 1,200 years, the full-blooming dates started as early as late March and as late as early May.

Blossoming has advanced progressively to earlier dates since 1920s, which also coincided with rising temperature based on meteorological observations, with Seattle recording significant annual temperature rise of urban heat already eliminated.
Shifts in phenology due to climate change have been detected at a variety of scales: reproduce, flowering, leaf-out, onset of larval development, life stages of adult plants, insects, fish, amphibians, birds and mammals, for which few data have been accumulated on the long-term through observations in both hemispheres. Researchers have also tracked an increasing probability of phenological mismatches across multiple species and groups tracked in recent assessments. A synthesis of those databases indicate that the phenological shifts are occurring in synchrony.

Identifying shifts, tracking trends

In the early 2000s, researchers published a few pioneering broad assessments of phenological shifts: (a) terrestrial systems in the northern hemisphere and (b) marine systems in the southern hemisphere. Phenological responses in crops to seasonal variations have been assessed for phenological trends. The visualization of those databases indicates that the phenological shifts are occurring in synchrony.

A long-standing, well-known example of phenological mismatch is between the great tit (Parus major) and its caterpillar food. This small passerine bird is found across Asia and Europe and produces unusually large populations in different environments. In Belgium and the Czech Republic, the great tit population expanded, and the provision of ecosystem services on which human systems depend. For example, fruit trees that bloom early and then experience late-season frosts will be challenging food production in the face of climate change. For example, fruit trees that bloom early and then experience late-season frosts will be challenging food production in the face of climate change. In the early 2000s, researchers published a few pioneering broad assessments of phenological shifts: (a) terrestrial systems in the northern hemisphere and (b) marine systems in the southern hemisphere. Phenological responses in crops to seasonal variations have been assessed for phenological trends. The visualization of those databases indicates that the phenological shifts are occurring in synchrony.

Hungry birds and early caterpillars

A long-standing, well-known example of phenological mismatch is between the great tit (Parus major) and its caterpillar food. This small passerine bird is found across Asia and Europe and produces unusually large populations in different environments. In Belgium and the Czech Republic, the great tit population expanded, and the provision of ecosystem services on which human systems depend. For example, fruit trees that bloom early and then experience late-season frosts will be challenging food production in the face of climate change. For example, fruit trees that bloom early and then experience late-season frosts will be challenging food production in the face of climate change. In the early 2000s, researchers published a few pioneering broad assessments of phenological shifts: (a) terrestrial systems in the northern hemisphere and (b) marine systems in the southern hemisphere. Phenological responses in crops to seasonal variations have been assessed for phenological trends. The visualization of those databases indicates that the phenological shifts are occurring in synchrony.

Studies on birds provide ample evidence of mismatch affecting successful breeding. Species such as parasitic flycatchers and passerines that breed early have higher nestling survival rates, as a cue to time their breeding so the nestlings may deliver caterpillars at the rate of almost one 18 days it takes for their full development. Adults of nourishment for fast-growing nestlings in the Netherlands has advanced its egg-laying in response to warming trends, but the shift is ongoing work.

Phenology shifts are occurring in synchrony.

Asynchronous changes in the phenology of a broad range of interacting species and groups tracked in recent assessments. See page 57 for complete references.
Migration is a behavioural adaptation to seasonality. Incredibly, the white stork is a long-lived migratory bird that correctly time their arrival for abundant prey. This behavior may reduce migration due to temperature changes and less winter sea feeding sites along the Baltic Sea. Accelerating the journey, they tend to skip stopover places as they have begun migrating earlier to avoid increased hatchling mortality. Although phenotypic plasticity—the ability to adapt in response to environmental changes—is widespread among European migratory birds over 5 decades, this has contributed to population declines in some migrants, particularly those that have increased in the tropics.

Long-distance migrants are particularly vulnerable to phenological change caused by climate warming effects, which are not uniform across regions. North America's monarch butterfly has been particularly hard hit, as late-season migration by 6 days/decade due to warmer-than-normal temperatures. In the past 27 years, fin and humpback whales have shortened daylength and lower temperatures in autumn usually prompt migration by 6 days/decade due to warmer-than-normal temperatures. This has contributed to population declines in some migrants, particularly those with increased in the tropics.

Migration is a behavioural adaptation to seasonality. Incredibly, the white stork is a long-lived migratory bird that correctly time their arrival for abundant prey. This behavior may reduce migration due to temperature changes and less winter sea feeding sites along the Baltic Sea. Accelerating the journey, they tend to skip stopover places as they have begun migrating earlier to avoid increased hatchling mortality. Although phenotypic plasticity—the ability to adapt in response to environmental changes—is widespread among European migratory birds over 5 decades, this has contributed to population declines in some migrants, particularly those that have increased in the tropics.

Long-distance migrants are particularly vulnerable to phenological change caused by climate warming effects, which are not uniform across regions. North America's monarch butterfly has been particularly hard hit, as late-season migration by 6 days/decade due to warmer-than-normal temperatures. In the past 27 years, fin and humpback whales have shortened daylength and lower temperatures in autumn usually prompt migration by 6 days/decade due to warmer-than-normal temperatures. This has contributed to population declines in some migrants, particularly those that have increased in the tropics.

Migration is a behavioural adaptation to seasonality. Incredibly, the white stork is a long-lived migratory bird that correctly time their arrival for abundant prey. This behavior may reduce migration due to temperature changes and less winter sea feeding sites along the Baltic Sea. Accelerating the journey, they tend to skip stopover places as they have begun migrating earlier to avoid increased hatchling mortality. Although phenotypic plasticity—the ability to adapt in response to environmental changes—is widespread among European migratory birds over 5 decades, this has contributed to population declines in some migrants, particularly those that have increased in the tropics.

Long-distance migrants are particularly vulnerable to phenological change caused by climate warming effects, which are not uniform across regions. North America's monarch butterfly has been particularly hard hit, as late-season migration by 6 days/decade due to warmer-than-normal temperatures. In the past 27 years, fin and humpback whales have shortened daylength and lower temperatures in autumn usually prompt migration by 6 days/decade due to warmer-than-normal temperatures. This has contributed to population declines in some migrants, particularly those that have increased in the tropics.

Migration is a behavioural adaptation to seasonality. Incredibly, the white stork is a long-lived migratory bird that correctly time their arrival for abundant prey. This behavior may reduce migration due to temperature changes and less winter sea feeding sites along the Baltic Sea. Accelerating the journey, they tend to skip stopover places as they have begun migrating earlier to avoid increased hatchling mortality. Although phenotypic plasticity—the ability to adapt in response to environmental changes—is widespread among European migratory birds over 5 decades, this has contributed to population declines in some migrants, particularly those that have increased in the tropics.

Migration is a behavioural adaptation to seasonality. Incredibly, the white stork is a long-lived migratory bird that correctly time their arrival for abundant prey. This behavior may reduce migration due to temperature changes and less winter sea feeding sites along the Baltic Sea. Accelerating the journey, they tend to skip stopover places as they have begun migrating earlier to avoid increased hatchling mortality. Although phenotypic plasticity—the ability to adapt in response to environmental changes—is widespread among European migratory birds over 5 decades, this has contributed to population declines in some migrants, particularly those that have increased in the tropics.

Migration is a behavioural adaptation to seasonality. Incredibly, the white stork is a long-lived migratory bird that correctly time their arrival for abundant prey. This behavior may reduce migration due to temperature changes and less winter sea feeding sites along the Baltic Sea. Accelerating the journey, they tend to skip stopover places as they have begun migrating earlier to avoid increased hatchling mortality. Although phenotypic plasticity—the ability to adapt in response to environmental changes—is widespread among European migratory birds over 5 decades, this has contributed to population declines in some migrants, particularly those that have increased in the tropics.
Out of reach

The red knot (Calidris canutus) is a medium-sized shorebird in the sandpiper family. The global population is in decline and considered Near Threatened. The 6 subspecies of red knot migrate remarkably long distances from the high Arctic breeding grounds to wintering grounds across different continents.

A subspecies, Calidris canutus canutus, breeds in central and northern Siberia, and migrates to winter areas along the coast of Mauritania, notably Bab Goda National Park. At the start of the journey, they mate and lay eggs. Juvenile red knots feed on insects that seasonally become more abundant near thawing marshes, as they migrate towards their wintering grounds. As the snow starts to melt, they mate and lay eggs. This knock-on effect leads to increased mortality for the red knots in later life stages.

In the last 3 decades, snowmelt duration in the high Arctic has progressively advanced by 0.5 days/year, resulting in the early emergence and abundance of insects. This change in phenology causes a mismatch of consequences for the red knots in later life stages. Since the birds have not adjusted their breeding phenology, offspring miss the peak emergence and abundance of insects. This mismatch in phenology causes a series of knock-on effects that partake halfway across the globe.

Phenological microevolution, the process of natural selection where genetic changes shift the timing of species to better fit the changed climate, most likely played an important role in species and ecosystem adaptation to past warming periods. Still, as the rate of warming is much faster now—perhaps by as much as a factor of 100—such microevolution may be able to keep up with the rapid environmental changes we are experiencing. Species also require genetic changes to adapt to changes in habitat characteristics, such as growth of longer grasses, like insects, than trees. Few generations over decades. These are the kinds of changes where genetic change, as a response to climate change, can be recognized as microevolution, mainly in insects and some birds. Genetic changes and happening at a much slower rate than the climate is changing.

In practice, conservation and ecosystem management measures could be taken to encourage favourable conditions for microevolution. One measure is to support and nurture the genetic diversity of populations, as the microevolutionary potential for increased connectivity and resilience becomes better. Increasing ecological connectivity through habitat corridors would enable greater collaboration and movement of natural genetic material within a particular ecosystem, promoting genetic diversity and increasing the chances of successful adaptation.
Phenological monitoring and citizen science

In the last few decades, governments and non-governmental organizations have initiated a number of projects and activities to track the development of plants and animals across the globe. These initiatives have become an important teaching tool for farmers, gardeners, and nature-lovers, and are also used to identify and track climate changes and adaptive responses from living collections that underpin governmental objectives to reduce global warming to limits set by the Paris Agreement. The 2012 intense marine heatwave warmed the surface waters off the northern coast of KwaZulu-Natal, South Africa. In response, sardines increased their run further north, and the occurrence of sardines shifted by more than one month in some regions. The phenomenon attracts many opportunistic bird species, and also has a significant impact on local economies and tourism.

The Sardine Run

Farming and phenology

Crop management practices, including selection of plants across different latitudes, longitudes and hemispheres, are a key component of the global food system. The phenotype and performance of crops depend on climate, soil, water, and other factors. Phenology, which is the study of the timing of events in the life cycle of a plant or animal, is an important aspect of crop management. The timing of flowering, fruiting, and other phenological events can affect the productivity of crops and the success of planting and harvesting. Phenology can also be affected by climate change, which can shift the phenological stages of a variety of crops. For example, crops such as wheat, rice, and maize are vulnerable to heatwaves that can affect their productivity. To counteract climate-induced phenological changes, farmers can adapt their planting and harvesting practices to coincide with the optimal phenological stages of their crops. For example, the sardine run, which occurs off the coast of South Africa, is closely tied to the phenology of sardine spawning. If the shifting trends continue, the sardine run may no longer extend as far north, or the run may collapse in the long term.

Adaptation practices focus on implementing sustainable production and management, including organic fertilizer use, combining legumes, and adopting new techniques and new seeds. By studying the phenology and adaptive changes of keystone species, such as sardines, and conserving biodiversity in productive landscapes, we can build resilience and adaptability throughout ecosystems. With modern communication tools, understanding of phenological stages all around the world, for communities and whole ecosystems, climate change is accelerating. Time and opportunity to achieve new harmonies will be needed.


100. The Zoological Society of London (ZSL) (2010). *Climate change impacts on migratory species - The path ahead.* https://www.zsl.org/topics/ecological-connectivity


171. Teske, P.R., Emami-Khoyi, A., Golla, T., Sandoval-Castillo, J., Lamont, T., Chiazzari, B. et al. (2021). The sardine run in southeastern Africa is a mass migration into an ecological trap. *Science Advances* 7(38), eabf4514. https://doi.org/10.1126/sciadv.abf4514
Graphic references

Identifying shifts, tracking trends

Plants


Insects


Ungulates


Fishes


Birds


**Bats**


**Marine species**

31. Poloczanska et al. (2013)

32. Poloczanska et al. (2016)