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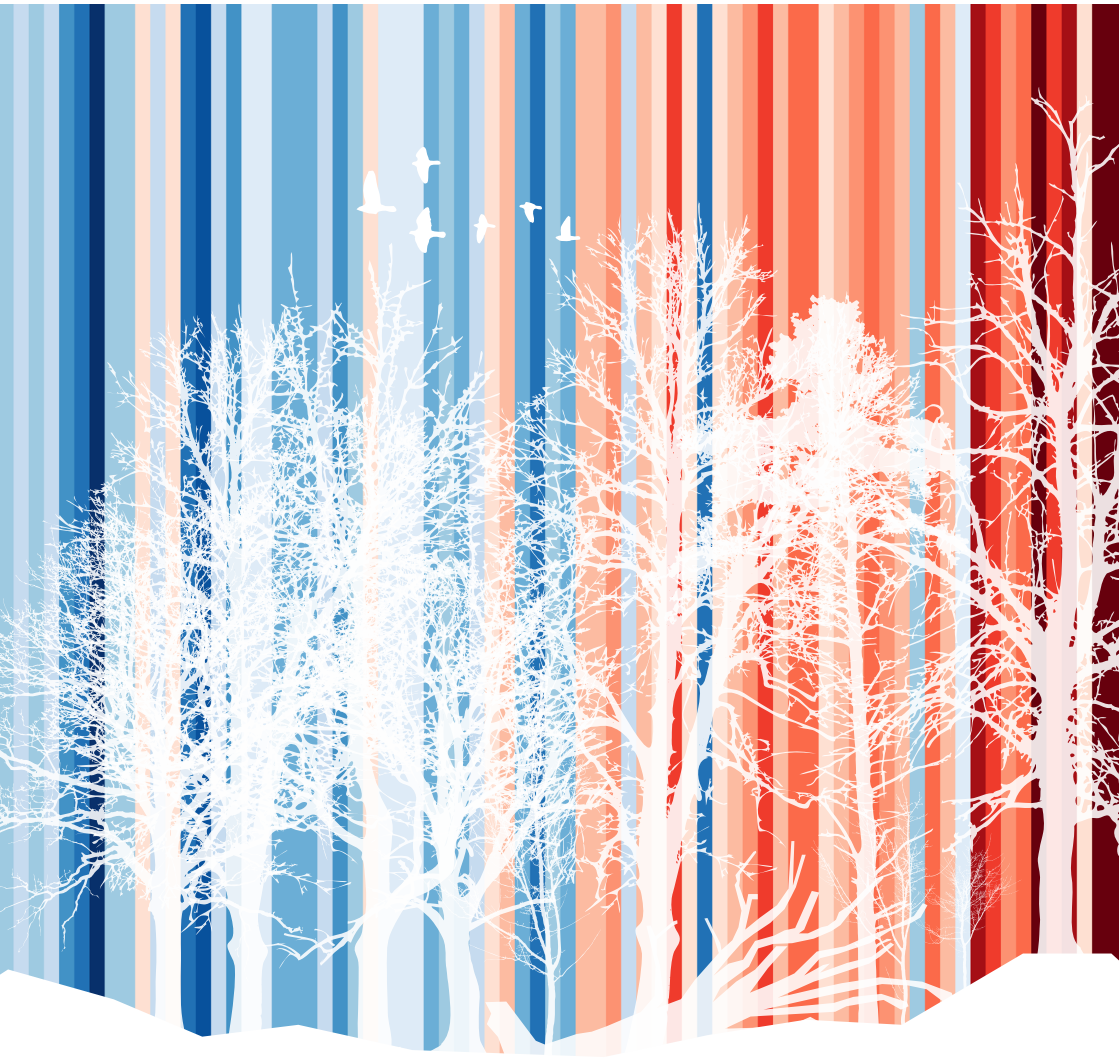
Karlsruhe City Forest in a changing climate

The forest today and in the future



DEAR FOREST VISITORS

The City Forest is a vital part of Karlsruhe's green lung – it provides a place for people to relax and serves as a habitat for animals, plants, and fungi. However, the impacts of climate change are already noticeable here: prolonged heat and drought during the past summers have caused lasting damage. This is especially visible in the Oberreut forest, where certain tree species, such as European beech, are showing clear signs of stress.

In Figure 1, you can see near surface air temperatures for the Karlsruhe district. The red bars indicate that temperatures have increased particularly strong over the last two decades. In the lower part of the figure, precipitation amounts are shown, highlighting particularly dry years like 2003, 2015, and 2018-2020, which were notably lower than the 1971-2000 average.

Future climate changes and increasing weather extremes are expected, requiring urgent measures to protect the forest. These changes will inevitably alter the familiar landscape. The City Forest Office is working hard to preserve, restore, and strengthen the resilience of the diverse forest ecosystems in Karlsruhe.

The goal of this brochure is to inform you about the effects of the changing climate on Karlsruhe's City Forest and to outline how it can be adapted and further developed. On the following pages, you will find information on the following topics:

1. The Karlsruhe City Forest
2. Impacts of climate change
3. Key climate indicators and their future changes
4. Adaptation measures

1. THE KARLSRUHE CITY FOREST

The City Forest has played an important role in Karlsruhe's history. In 1715, the city was founded by Margrave Karl Wilhelm in a clearing in the Hardtwald forest. Despite significant deforestation during over 300 years of urban development, Karlsruhe remains a forest-rich city, with 26 percent of its area covered by forest.

The Karlsruhe City Forest is diverse and rich in species. It spans approximately 2,250 hectares and includes four distinct natural regions: the water-influenced Rhine meadows to the west, the sandy Hardt plains and the Kinzig-Murg-Rinne, the hilly

loess landscapes of Kraichgau and Pfinzgau in the northeast, and the foothills of the Black Forest in the southeast. Broadleaf species dominate the landscape, accounting for about 90 percent of the trees. Around 30 tree species make up the ecologically valuable mixed deciduous forests in various combinations.

The trees in the City Forest have a positive impact on Karlsruhe's climate and the well-being of its inhabitants. They improve local air quality by filtering pollutants, store water, and protect against erosion and flooding. Additionally, they produce oxygen, provide cooling shade, and capture carbon dioxide from the atmosphere.

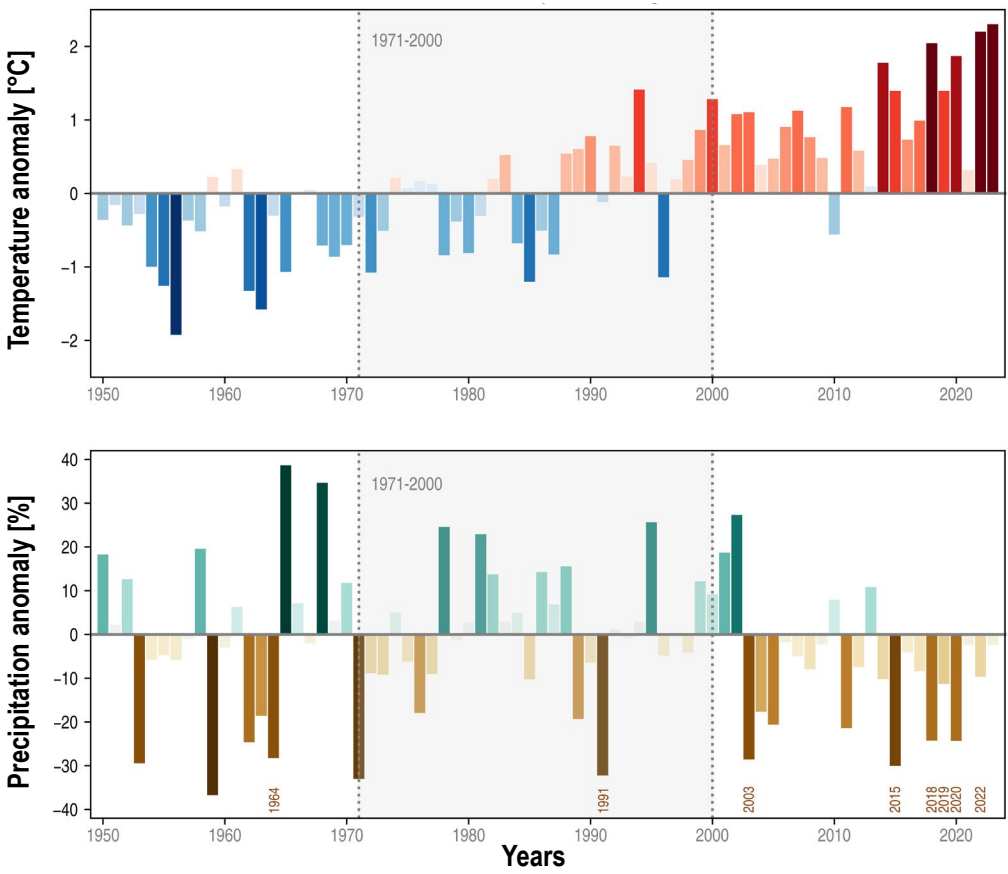


Figure 1 | Annual mean deviations of observed temperature and precipitation from 1950 to 2023 compared to the average of the years 1971 to 2000 in the Karlsruhe district. The temperature deviations from the upper part of the figure have also been used to create the climate stripes on the cover image.

Own representation based on the graphic concept by Ed Hawkins; data analysis using the E-OBS dataset from the EU-FP6 project UERRA, Copernicus Climate Change Service, and the ECA&D project.

2. IMPACTS OF CLIMATE CHANGE

Figure 2 | The forest districts of the city of Karlsruhe are highlighted in green (West, Center, East), while settlements and transportation routes are shown in gray. The speech bubbles list examples of the effects of climate change in different forest areas.

Own illustration and texts; map base: City of Karlsruhe | Liegenschaftsamt 2024 3305.

3. CLIMATE INDICATORS AND THEIR FUTURE CHANGES

Scientific research allows us to explore how climate indicators relevant to the urban forest may evolve under different future climate conditions. Climate models serve as essential tools to simulate these potential scenarios.

To address the uncertainties in climate modeling and the range of possible future evolutions, numerous climate simulations are run using various models. This results in a range of potential climate changes. To assess the reliability of these outcomes, the climate indicators shown in Table 1 are supplemented with expert evaluations. These are represented by different shades of gray in the table: „The darker the gray, the clearer the projected climate change."

When a majority of climate models indicate a statistically significant increase or decrease for an indicator, the change is classified as „robust" (dark gray). If most models suggest a clear direction of change, but the changes themselves are not significant, this is marked as a „trend towards increase or decrease" (gray). When models show both increases and decreases in roughly equal proportions, the change is considered unclear (light gray/ambiguous). Below the median of all climate simulations, a range of possible developments is shown, indicating minimum and maximum potential changes.

On the following two pages, six key climate indicators from Table 1 are explained in detail. The text color for each indicator corresponds to the colors of the matching text boxes in the forest silhouette (see Figure 3). The explanation outlines how these indicators might shift in the future and what implications this holds for the Karlsruhe City Forest. Each colored text box follows a consistent structure:

1. Name of the climate indicator
2. Definition of the climate indicator
3. Impact of the climate indicator on the City Forest
4. Potential effects of future climate changes

The data basis, details about the climate models used, and further information on the methods can be found on our GitHub page via this link (https://bit.ly/3WH3awO) or by scanning the adjacent QR code.

	1971-2000	Change 1.5 °C	Change 2 °C	Change 3 °C	Change 4 °C
Frost days [days]	66.8	-14.4	-21.0	-31.5	-38.3
Min : Max		-27.1 : -1.0	-32.6 : -6.8	-51.8 : -16.8	-62.1 : -20.8
Late frost days [days]	3.1	-0.8	-1.0	-1.7	-1.9
Min : Max		-4.0 : 0.1	-4.8 : 0.2	-8.1 : -0.3	-9.7 : -0.3
Annual precipitation [mm/day]	2.2	+0.1	+0.1	+0.2	+0.1
Min : Max		-0.2 : 0.3	-0.1 : 0.4	-0.1 : 0.7	-0.2 : 0.8
Spring precipitatiom [mm/day]	2.1	+0.2	+0.2	+0.2	+0.4
Min : Max		-0.3 : 0.5	-0.1 : 0.5	-0.1 : 0.7	-0.1 : 0.8
Summer precipitation [mm/day]	2.3	0	0	-0.1	-0.3
Min : Max		-0.4 : 0.5	-0.4 : 0.6	-0.5 : 1.0	-0.8 : 1.2
Heat days (Tmax > 30°C) [days]	11.5	+4.2	+5.3	+13.3	+23.0
Min : Max		0.3 : 18.1	0.9 : 24.5	1.5 : 41.1	8.2 : 56.8
Temperature max. > 35°C [days]	0.6	+1.0	+1.3	+3.4	+7.5
Min : Max		0 : 6.3	-0.1 : 9.4	0 : 18.7	0.4 : 28.2
max. Heatwave [days]	3.5	+1.5	+1.8	+4.4	+6.8
Min : Max		0.1 : 5.5	-0.1 : 8.1	0.6 : 18.4	2.9 : 20.4
Heatwaves [number]	1.4	+0.5	+0.6	+1.5	+2.5
Min : Max		-0.1 : 2.2	0 : 3.0	0.1 : 4.0	1.0 : 5.3
Annual dry days [days]	231.9	+0.8	-1.1	+2.3	+5.7
Min : Max		-8.6 : 14.8	-10.5 : 13.7	-19.5 : 11.6	-14.9 : 16.8
Dry days in spring [days]	57.8	-1.2	-1.1	-0.5	-2.1
Min : Max		-5.2 : 4.1	-4.6 : 3.5	-6.2 : 3.9	-6.1 : 2.5
Dry days in summer [days]	59.8	+1.3	+1.3	+3.3	+6.1
Min : Max		-2.6 : 5.9	-4.2 : 6.4	-6.2 : 8.4	-6.7 : 12.7
Annual max. dry period [days]	22.2	+0.1	0	+0.8	+1.8
Min : Max		-2.4 : 4.2	-2.3 : 4.8	-3.1 : 8.7	-2.0 : 22.6
Annual dry periods [number]	17.1	+0.3	+0.1	+0.4	+0.8
Min : Max		-1.2 : 1.9	-1.4 : 1.6	-2.2 : 1.5	-1.8 : 2.8

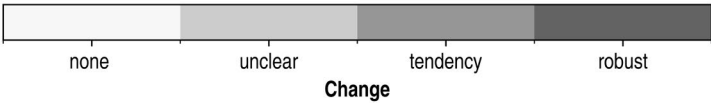


Table 1 | Analysis for the Karlsruhe district: climate indicators and their projected mean changes compared to the period from 1971 to 2000, and for scenarios where the global mean temperature increases by 1.5°C, 2°C, 3°C, and 4°C compared to pre-industrial levels. The first column shows the average observed value over the years 1971 to 2000. The climate changes were calculated using a variety of models, with results ranging between the specified minimum and maximum (min-max). Above this range is the value (median), which is the point where half of the models fall below and half above.

Own representation and analysis using data from the EURO-CORDEX initiative (see QR code on the left).

LATE FROST
robust decreas

Number of days between April and June when the daily minimum temperature drops below 0°C.

Late frost after bud burst poses risks to fresh greenery and young blossoms. This can slow down tree growth and, in extreme cases, lead to the death of young plants. Climate simulations indicate that fewer days with late frost are expected in the future, but it can still occur, and the risk of damage from late frost will remain.

PRECIPITATION

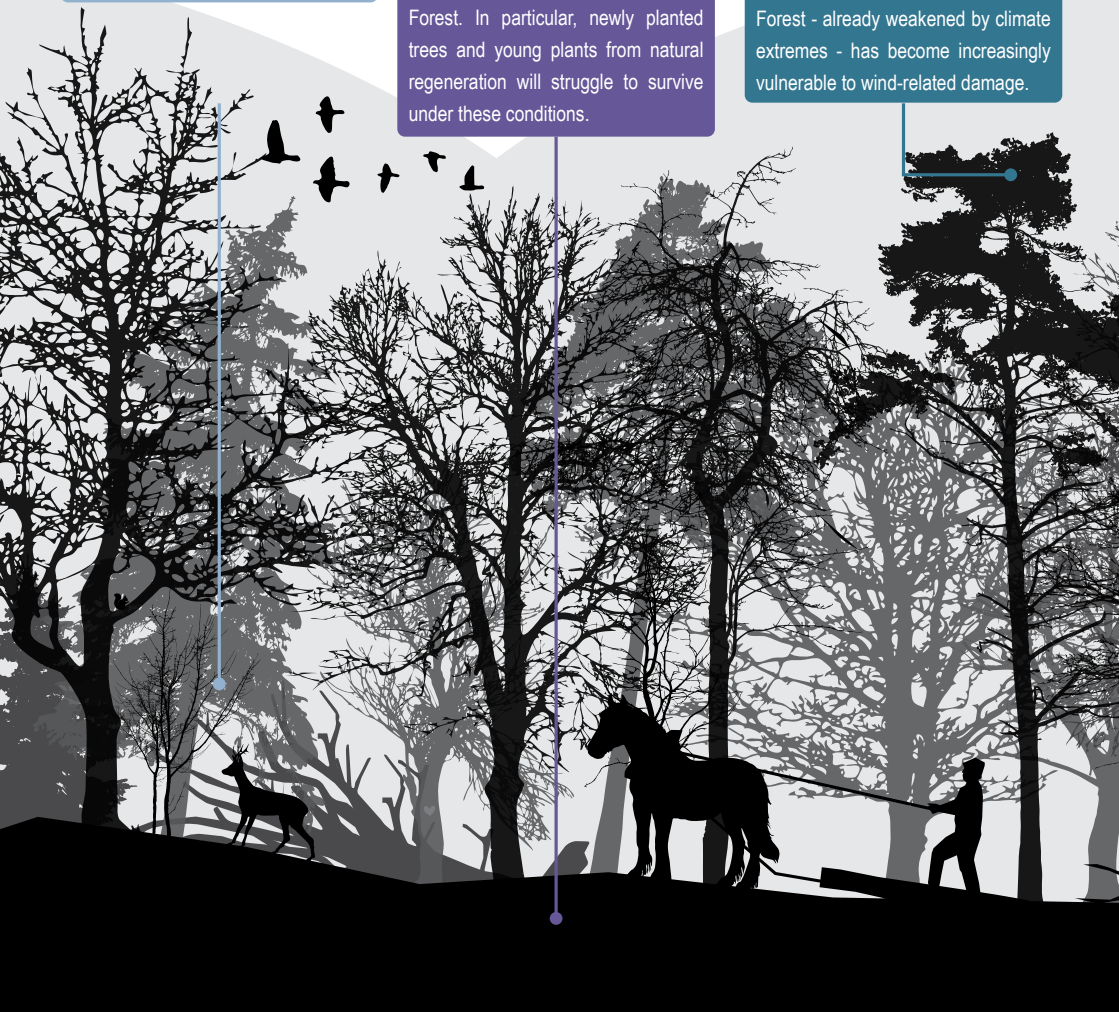
Average daily precipitation in millimeters.

The vitality of the trees—and thus the appearance of the City Forest—depends heavily on water availability. Climate simulations indicate that annual precipitation will tend to increase. However, only minor changes in summer precipitation are expected. The number of dry days is likely to increase, which will continue to cause drought stress in the City Forest. In particular, newly planted trees and young plants from natural regeneration will struggle to survive under these conditions.

WIND

Average daily wind speed in meters per second.

Even at low wind speeds, falling branches pose a safety risk for forest visitors. Strong winds, however, also threaten the vitality and stability of the forest. Windthrow and breaking stems increase trees‘ vulnerability to pests and also compromise safety on pathways. While climate simulations do not indicate a clear increase in wind speed for Karlsruhe, the City Forest - already weakened by climate extremes - has become increasingly vulnerable to wind-related damage.



HEAT
robust increase

Number of hot days per year with a daily maximum temperature > 30°C or > 35°C.

While higher temperatures can promote tree growth, they can also cause heat damage, such as sunburn on beech stems. Climate simulations indicate a continuous increase in hot days for Karlsruhe, with more days exceeding 35°C. This negatively affects the positive impact of the City Forest on air quality and the population, as temperatures approaching 40°C significantly limit the functionality of trees.

HEAT WAVE
robust increase

At least three consecutive days with maximum temperatures above 30°C.

Heatwaves affect the health of the City Forest, particularly in spring and summer. In autumn, however, trees can better cope with heat stress through leaf shedding. The frequency and duration of heatwaves are crucial factors. Climate simulations suggest that both the number and length of heatwaves in the Karlsruhe region are increasing. As a result, the City Forest will increasingly suffer from heat stress and its associated impacts in the future.

DROUGHT PERIOD

At least five consecutive days with less than one millimeter of precipitation each day.

Drought reduces the vitality of trees, increasing their susceptibility to pests and storm damage. Prolonged drought also raises the risk of forest fires. Climate simulations indicate a tendency for dry periods to increase on average in Karlsruhe in the future. Consequently, the City Forest will continue to suffer from water shortages, which could lead to the local extinction of certain tree species.

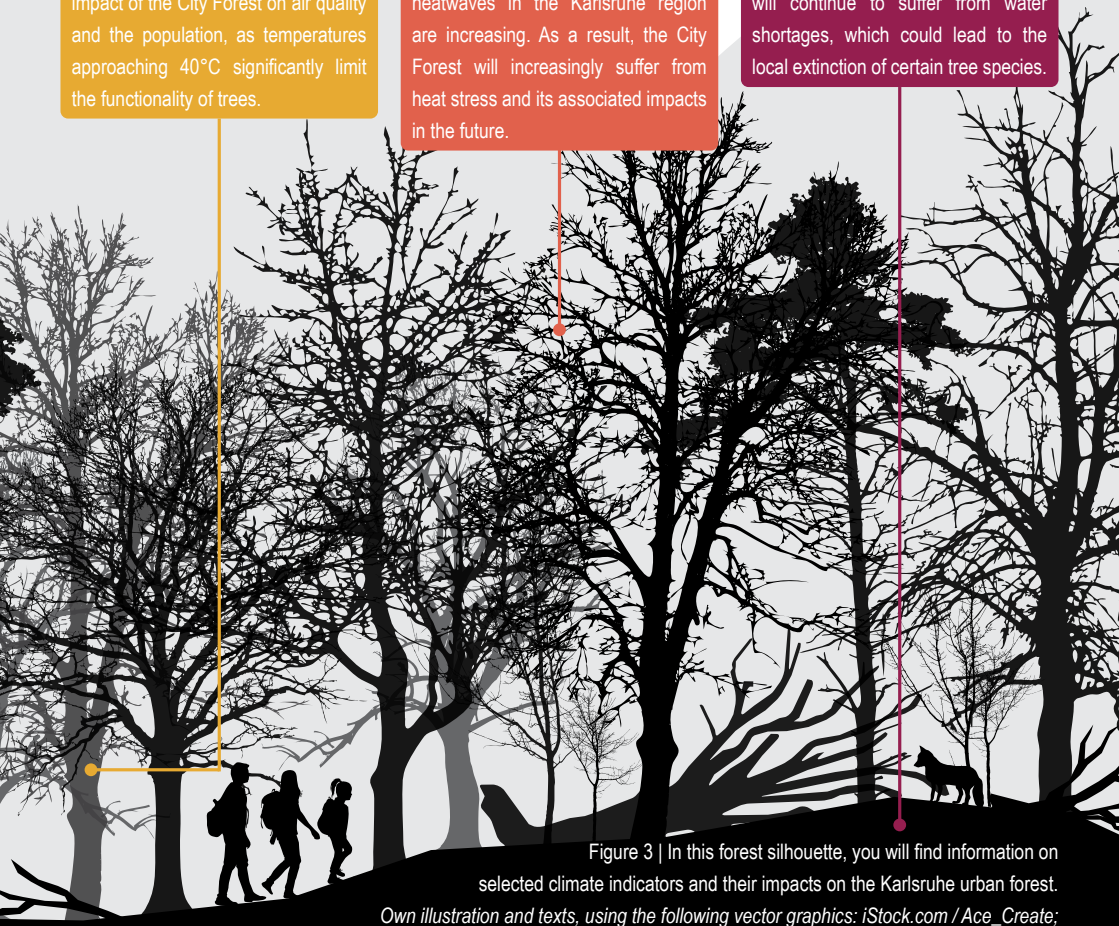


Figure 3 | In this forest silhouette, you will find information on selected climate indicators and their impacts on the Karlsruhe urban forest.
Own illustration and texts, using the following vector graphics: iStock.com / Ace_Create; iStock.com / Nosyrevy; iStock.com / syntika; iStock.com / Terriana; Pixabay.com / Gordon Johnson

4. ADAPTATION MEASURES

The goal of adapting to the unavoidable impacts of climate change is to create stable, site-appropriate, and long-term adaptable mixed forests. These forests should preserve local biodiversity, provide recreational space for residents, have a positive local climatic effect, ensure long-term carbon storage through wood growth, and offer future generations opportunities for forest use.

Preserving the forest as a habitat for species and promoting natural forest development are top priorities. Conservation, maintenance, and development measures require a small-scale and thoughtful approach that considers both heat, drought, and water needs, as well as the specific habitat requirements of individual species. The team at the Karlsruhe City Forest Office, with its specialized staff, is already working towards the future forest of tomorrow. The overarching focus is on the ecological diversity and vitality of the forest and its individual trees. Through early and targeted silvicultural measures, individual trees are given more space to develop. This increases root area and water absorption capacity, reduces competition with neighboring trees, and allows trees to develop large, healthy canopies. With the soil protection concept and careful logging practices, the forest soil, as well as particularly sensitive and wet areas, are protected. For example, trees are felled manually by forestry workers rather than by heavy harvesting machinery. Where feasible and sensible, horses assist with timber skidding.

Natural regeneration from young, climate-resilient trees is preferred over planting, though this becomes increasingly difficult with rising temperatures and longer dry periods in spring, reducing the survival rates of young plants. Where suitable seed trees are lacking, alternative native tree species and other climate-resilient species are introduced into the stands. The recommended planting time has been shifted from spring to autumn/winter to allow young trees to establish during the wet months.

Risk management is continuously adjusted and refined to account for changing climatic conditions. This includes regular updates to the public on current forest damage situations, development of plans for storm events, and fire prevention measures. The risks associated with forest visits and the use of forest paths have notably changed due to climate change. Visitors are generally responsible for their own safety and should expect increasing hazards from falling branches and uprooted trees. Trees near recreational facilities, buildings, and public transportation routes are regularly inspected. If

hazards are identified, removal or pruning is done for ecological reasons. In addition to ensuring public safety, timber removal primarily helps to develop and sustain forest stands, promote the growth of climate-resilient mixed tree species that might otherwise be outcompeted, and support species and habitat conservation.

WHAT CAN I DO?

1. I accept forestry measures, as they help sustain the City Forest.
2. I act responsibly in nature and remain aware of changes.
3. By practicing my own climate-friendly habits, I also contribute to the health of our City Forest.

Every small action makes a difference! Together, we can ensure a vital future for our City Forest.

BRIEF SURVEY ABOUT THE BROCHURE

Do you have any praise or criticism for us? We would like to hear your thoughts on our brochure. Please take part in an anonymous short survey* with six questions by using the QR code below or by following this link (https://bit.ly/3QAzj5g). Your feedback will be taken into account as we prepare the second edition of the brochure. **Thank you for your valuable contribution.**

**Participation takes approximately 54 seconds. The survey is anonymous, and results cannot be linked to individual participants.*

For questions about this brochure, you can contact us by email (gerics-wald@hereon.de). We will be happy to get back to you. Our privacy policy can be found here: https://bit.ly/4aglwrC

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Research for Sustainability

ADDITIONAL INFORMATION, LITERATURE, AND LINKS ON THE TOPIC:
www.gerics.de/wald

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Karlsruhe

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