Co-Creation of a Prototypical Climate Service Product to Support Climate Change Adaptation in the City Forest of Karlsruhe

Markus Groth, Stephanie Bauer, Katharina Bülow, Diana Rechid, Bettina Steuri, Florian Knutzen

(Dr. Markus Groth, Climate Service Center Germany (GERICS) – Helmholtz-Zentrum Hereon, Geesthacht, Germany, markus.groth@hereon.de)
Dr. Katharina Bülow, Climate Service Center Germany (GERICS) – Helmholtz-Zentrum Hereon, Geesthacht, Germany)
(Stephanie Bauer, Forstamt, City of Karlsruhe, Germany)
(Bettina Steuri, Climate Service Center Germany (GERICS) – Helmholtz-Zentrum Hereon, Geesthacht, Germany)
(Dr. Florian Knutzen, Climate Service Center Germany (GERICS) – Helmholtz-Zentrum Hereon, Geesthacht, Germany)
(Dr. Diana Rechid, Climate Service Center Germany (GERICS) – Helmholtz-Zentrum Hereon, Geesthacht, Germany)

1 ABSTRACT

Climate change presents severe challenges to forests, impacting ecosystems, biodiversity, and overall forest health. To address these challenges, the German forestry sector is exploring various adaptation strategies, including promoting the cultivation of more climate-resilient tree species, implementing sustainable forest management practices, and developing early warning systems for pest outbreaks and extreme weather events. Additionally, efforts are underway to enhance public awareness and engagement, fostering a collaborative approach to both mitigate climate change as well as to adapt to the impacts of climate change.

Our research adopts an integrative approach, based on transdisciplinary processes and co-creation, to understand the needs of forest practitioners and develop a user specific climate service product. Focusing on climate extremes such as drought, heat, and heavy rain, we investigate diverse perceptions among authorities, scientists, and forest users. Drawing insights from the research project ClimXtreme, we engaged in a collaborative case study with foresters from the City Forest Karlsruhe. The transdisciplinary research aims to address specific climate information needs, inform society about climate change impacts and adaptation strategies, and facilitate communication with various forest users.

The resulting climate service product – an easy understandable and scientifically sound brochure of twelve pages – covers a range of topics from climate change scenarios to specialized climate indices for forestry as well as practical adaptation measures initiated by the City Forestry office of Karlsruhe. To support the usability and to enhance the societal and scientific impacts based on our case-study, a multi-level approach has been chosen. Thus, in addition to the published brochure, all data and methods used are comprehensively explained and additional indices, analyses, methods, data, and literature have been made freely accessible online.

The outcome of our efforts emphasizes the important role of co-creation to enhance inter- and transdisciplinary capacities for climate change adaptation in a city forest. By fostering dialogues with key practice partners and co-creating climate information, particularly tailored for a city forestry office in south-western Germany, our efforts inform society about climate change impacts and adaptation strategies and facilitate communication with diverse forest users and visitors (e.g. cyclists, joggers, walkers, riders). This integrated approach ensures a meaningful contribution to climate resilience in the German forestry sector and beyond.

Keywords: climate extremes, climate change adaptation, forestry sector and city forests, integrative research, stakeholders

2 INTRODUCTION

Climate extremes pose significant challenges to the German forestry sector, impacting ecosystems, biodiversity, and overall forest health (Knutzen et al. 2025a). Extreme weather events such as droughts, heat waves, and heavy rainfall are expected to occur more frequently and/or with increased intensity (Cardell et al. 2020). In fact, heat waves and many rainfall events have already been made much more likely due to human interference with the climate system (IPCC 2021). Additionally, droughts have become more likely as recently shown by Bevacqua et al. (2024) for Germany. Extended periods of drought fundamentally increase the stress level of trees, making them more vulnerable to pests and diseases (Frank 2020), while heat waves further add to this stress, reducing growth and raising mortality (Haberstroh et al. 2022). Heavy precipitation is also known to affect forest soil and infrastructure (Schauwecker et al. 2019). Moreover, rising temperatures may disadvantage native species and favor non-native or invasive species, shifting forest composition (Martinez del Castillo et al. 2022). Warmer conditions could also expand the spread of pests,

like bark beetles, which can kill off vast forest areas in a single season (Hlásny et al. 2021). While forest fires are less common in Germany, climate change may increase wildfire risks, adding challenges for management and firefighting (Fekete & Nehren 2023; Grünig et al. 2023). The economic impacts of climate extremes are significant, as forestry relies on sustainable wood production, and climate-induced challenges demand effective adaptation strategies to ensure long-term viability and profitability in forest enterprises (Rosenkranz et al. 2023). Additionally, occupational safety is a growing concern, with increased tree mortality creating more hazardous conditions for workers (FAO, ILO, UN, 2023).

To address the challenges, efforts are also needed to enhance public awareness and engagement, fostering a collaborative environment to mitigate and adapt to the impacts of climate change. Central to these efforts is the aim to sustainably balance economic, protective, and recreational functions, ensuring that the provision of forest services is tailored to the specific characteristics and priorities of each region. Since the implementation of an adapted forest management is reliant on the commitment of forest practitioners, it is essential to understand their perceptions of the various climate related challenges and impacts on the forests they manage as well as what strategies they consider suitable to achieve the desired adaptation targets.

In this paper we describe a collaborative approach with stakeholders from the City Forest Karlsruhe to assess and quantify perceptions of practitioners by employing a transdisciplinary research approach. 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, the sandy Hardt plains and the Kinzig-Murg-Rinne, the hilly loess landscapes of Kraichgau and Pfinzgau, and the foothills of the Black Forest. 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 wellbeing 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.

Hence, the City Forest is a vital part of Karlsruhe’s green lung and also 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. The City Forest Office is working hard to preserve, restore, and strengthen the resilience of the diverse forest ecosystems in Karlsruhe.

Against this background, the paper presents the joint development of a prototypical climate service product to support climate change adaptation in the City Forest of Karlsruhe, with a strong focus on explaining the need for adaptation as well as possible adaptation measures to society. The paper is structured as follows. Chapter three describes the methodological background as well as the interaction with stakeholders from the Karlsruhe Forestry Office. The main content of the brochure “Karlsruhe City Forest in a changing climate – The forest today and in the future“ is highlighted in chapter four. A summarizing conclusion is presented in chapter five.

3 METHODOLOGICAL BACKGROUND AND STAKEHOLDER INTERACTION

3.1 Methodology

One main aim of the research project CS4eXtremes was to identify the practical needs for climate change information in order to provide forest users with the best possible support in dealing with new adaptation challenges. Considering inter- and transdisciplinary work, we follow suggestions that have been developed with particular focus on the intersection between scientists and practitioners or stakeholders (Bammer et al. 2020). They are often referred to as integrative research. The two main concepts within this framework are the concept of transdisciplinarity and the approach of co-creation(Schuck-Zöller et al. 2023).

Transdisciplinarity is seen as a bridge between science and action (Renn 2021; Lang et al. 2012). In addition to classical features of interdisciplinary cooperation, the linking of research to relevant contexts and a focus on complex and socially controversial problems promotes a deliberative methodology to combine scientific knowledge with the experience and contextual knowledge of affected groups and people. Co-creation focuses on transdisciplinarity as a merger of scientific and practical knowledge, whereby dialogues should occur on an equal footing in a learning process involving scientists and practitioners (Renn 2021). In this

case, scientific knowledge and practical expert knowledge are complementary. Both forms of knowledge are essential for a common understanding of the challenges and possible solutions.

Our dialogue-based approach acts as a merger of scientific and practical knowledge, which has shown to work in a forest management context (Ciccarino et al. 2023). The relevance of stakeholder participation is growing as also demonstrated by Jacobsson et al. (2020) for southern Sweden, where forests are also under an increasing pressure which bears the risk of conflicts between stakeholder groups with different interests. As part of the overall research project, we focused on interviews with forest practitioners as a well established method of transdisciplinary work with stakeholders (Kujala et al., 2022; Steger et al. 2021;OECD 2020), which is true from the perspective of academics as well as practitioners in the forest sector (Jakobsen et al. 2021).

In sum, interviews with 28 forest practitioners have been carried out (Knutzen et al. 2025b, submitted). Furthermore, two workshops have been conducted, reflecting on the science-practice dialogue as part of the tdAcademy initiative (Schäfer et al. 2024).

3.2 Interaction with stakeholders from the Karlsruhe Forestry Office

As a result of the second workshop as part of the overall research project and the conducted interviews, further discussions were carried out with key stakeholders to explore opportunities for the joint development of climate service products. The needs of the Karlsruhe Forestry Office have been identified as particularly urgent due to the severe pressure from climate extremes, combined with public demands for action. Additionally, urban forests are particularly important due to their impact on densely populated areas, providing essential ecosystem services such as recreation, local climate regulation, and serving as "green lungs" that improve air quality and well-being in surrounding settlements. Forests in the Karlsruhe/Upper Rhine Graben region are under considerable stress from climate extremes, particularly due to spring and summer droughts and the cumulative effects of successive dry years. These factors have had, and continue to have, a drastic impact on forest vitality.

Central task for the coming years are a targeted replanting of damaged and regeneration-needing areas. Unlike past forest damage events, regeneration in the context of climate change presents unique challenges. The objective is to establish stable, site-appropriate, and climate-adaptive mixed forests that enhance biodiversity, maintain a characteristic forest microclimate, continue carbon sequestration through tree growth, and fulfil expected social functions. As part of the research project, near-natural forest conservation in the Karlsruhe municipal forest has been supported by providing and processing climate change information. This forest-specific climate data aids in planning adaptation measures, such as determining optimal replanting times and selecting suitable tree species.

Collaboration with the Karlsruhe Forestry Office was maintained throughout the project. The Forestry Office specifically requested an information sheet to inform society about the effects of the changing climate on Karlsruhe's City Forest and to outline how it can be adapted and further developed. Therefore, the "GERICS Climate Outlook for Karlsruhe" (Pfeifer et al. 2021) has been presented as part of a workshop and afterwards served as a scientific basis to take into account possible future climate developments based on regional climate simulations. In all its efforts, the forestry office was committed to preserving the forest and shaping it into a climate-resilient, diverse, and adaptable ecosystem. This represents a significant challenge not only for the forest's flora and fauna but also for visitors.

The primary goal of the jointly developed information brochure (Bülow et al. 2024) described in the next chapter, is to inform about the impacts of climate change on Karlsruhe. Raising awareness is crucial, as some areas have suffered such severe damage that they are no longer accessible for recreational use. During interviews, workshops, and reflection sessions, specific climate indicators relevant to forestry were identified in partnership with the Karlsruhe Forestry Office. These indicators will assist foresters and other stakeholders in planning effective adaptation measures, ensuring the preservation and restoration of a healthy, resilient forest despite escalating climate challenges. In addition to forestry-specific indices, basic information on future climate developments were required, including for example annual and seasonal temperature, precipitation, the number of dry days, and the annual number of frost and summer days.

4 MAIN CONTENT OF THE BROCHURE "KARLSRUHE CITY FOREST IN A CHANGING CLIMATE – THE FOREST TODAY AND IN THE FUTURE"

The goal of this jointly developed climate service product is to inform about the effects of the changing climate on Karlsruhe's City Forest, about projected future changes of climate variables which drive impacts on forests and to outline how the forest can be adapted and further developed. The brochure includes (1) a title page and imprint, (2) an introduction to the brochure itself and the City Forest Karlsruhe, (3) a map of local forestry areas and specific impacts of climate change, (4) information about climate parameters and their future changes under different global warming levels, and (5) examples of adaptation measures as well as (6) a tiny survey.

Besides a map highlighting examples of the effects of climate change in forest districts in the city of Karlsruhe, one key element of the brochure is the provision of state-of-the-art information on climate indicators relevant to the urban forest and their possible future changes, based on the use of climate models as essential tools to simulate these potential scenarios (Bülow et al. 2024).To address the uncertainties in climate modelling and the range of possible futures, numerous climate simulations of various models are considered. This results in a range of potential climate changes. To assess the reliability of these outcomes, the climate indicators are supplemented with expert evaluations. When a majority of climate models indicate a statistically significant increase or decrease for an indicator, the change is classified as robust. 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. When models show both increases and decreases in roughly equal proportions, the change is considered unclear.

The analysis includes climate indicators and their projected 30 year mean changes compared to the period from 1971to 2000, and for scenarios where the future global mean temperature increases by 1.5 °C, 2 °C, 3 °C, and 4 °C compared to pre-industrial levels. Also the average observed value over the years 1971 to 2000 has been included. The climate changes were calculated using a variety of models, with results ranging between the specified minimum and maximum, with a special focus an the median value, which is the point where half of the models fall below and half above. Based upon this information, six selected climate indicators – (1) late frost, (2) precipitation, (3) wind, (4) heat, (5) heat wave, and (6) drought period – and their impacts on the Karlsruhe City Forest have been highlighted in detail.

Regarding for example late frost – the number of days between April and June when the daily minimum temperature drops below 0 °C– which after bud burst poses risks to fresh greenery and young blossoms, can slow down tree growth and, in extreme cases, lead to the death of young plants. Climate simulations indicate that fewer days with late frostier expected in the future, but it can still occur, and the risk of damage from late frost will remain.

Focussing on heat stress, the results regarding future heat waves – at least three consecutive days with maximum temperatures above30°C – show a robust increase, whereby heat waves 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 heat waves are crucial factors. Climate simulations suggest that both the number and length of heat waves in the Karlsruhe region are increasing. As a result, the City Forest will also increasingly suffer from heat stress and its associated impacts in the future.

Regarding the need to adapt to the unavoidable impacts of climate change, the creation of stable, site-appropriate, and long-term adaptable mixed forests is key, as the brochure highlights in a chapter on specific adaptation measures. Within this chapter the description of the local adaptation measures is divided into (1) the overall goal of achieving long-term adaptable, stable and site-appropriate mixed forest, (2) selected measures for maintaining the vitality of the forest through near-natural forest management as well as (3) risk management including adaptation and the further development of existing strategies.

Furthermore, a brief evaluation of the brochure has been offered by using a QR code leading to a short online survey with six questions.

5 CONCLUSION

The Karlsruhe City Forest Office has already been working extensively towards the forest of tomorrow, whereby the overarching focus is on the ecological diversity and vitality of the forest and its individual trees. Through multiple workshops and face-to-face interviews within the overall frame of the research project

ClimXtreme, stakeholders from the City Forest Karlsruhe have also been identified as key partners for the co-creation process of a novel prototypical climate service product to support climate change adaptation in the City Forest of Karlsruhe. Thereby the practical need was highlighted, that the forestry office requires this specific brochure for purposes like (1) reducing pressure from public on forestry practitioners, (2) informing the public about the impacts of climate change and local adaptation measures, (3) addressing specific user groups, (4) facilitating the dialogue with politicians, companies, and society as well as (5) supporting foresters and other stakeholders in the forest sector to develop suitable adaptation strategies for the preservation and reforestation of a robust and healthy forest.

Taking this need for support into account, the scientist involved as well as key stakeholders progressed jointly through several stages of developing a climate service product. Although these stages are typically sequential, iterative feedback loops have proven beneficial. Thereby the co-creation process can be summarized as follows: (1) collaboratively identifying the local information needs regarding climate change and its impact on the City Forest, (2) preparing examples of how to leverage climate model results, (3) discussing the objectives for the brochure, (4) presenting the first draft of the brochure to the City Forest Office for review and gathering feedback on elements like climate indicator descriptions, (5) using the feedback to refine the brochure to better meet the practitioner needs, and vi) presenting a second draft of the flyer to the City Forest Office. This prototype process was continued until all participants were satisfied with the outcome, after which the final version was printed and utilized by the City Forest Office Karlsruhe.

Printed versions of the brochure have been distributed for example in the town hall, strategic places in the forest (e.g. visitor centres, forest entrances and meeting points), at local companies and organisations as well as at events in or about the City Forest. Digital versions of the brochure have been provided online and promoted by articles in local newspapers as well as press releases and social media channels. In addition to the published brochure, all data and methods used are comprehensively explained and additional indices, analyses, methods, data, and literature have been made freely accessible online.[1]

The outcome of this case-study and prototype development, emphasizes the important role of co-creation to enhance inter- and transdisciplinary capacities for climate change adaptation in a city forest. By fostering dialogues with key stakeholders and co-creating practice-specific climate information, particularly tailored for a city forestry, we inform society about climate change impacts and adaptation strategies and facilitate communication with diverse forest users and visitors (e.g. cyclists, joggers, walkers, riders). This integrated approach ensures a meaningful contribution to climate resilience in the German forestry sector and beyond.

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