Kew Reach

The Future Tree

Inside the science of future-proof planting.

Royal Botanic Gardens Kew



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INTRODUCTION

Planting for a changing climate

The climate is changing and its effects are already being felt across our landscapes.

Rising temperatures, changing rainfall patterns, prolonged periods of drought and more frequent extreme weather events are altering the conditions on which ecosystems depend. These pressures are particularly acute in towns and cities, where the effects of heat, drought and intense rainfall can be amplified by the built environment. But the challenge extends far beyond urban areas: landscapes and ecosystems everywhere are being asked to adapt to a changing climate.

Trees have a vital role to play in mitigating the effects of, and adapting to, climate change. They can help cool our streets and public spaces, capture and store carbon, intercept rainfall, reduce surface water runoff, stabilise soils, support biodiversity and contribute to healthier, more resilient environments. As climate pressures increase, these ecosystem services will become even more important.

But there is a problem. The trees we rely on to help us adapt to climate change must themselves be able to withstand it.

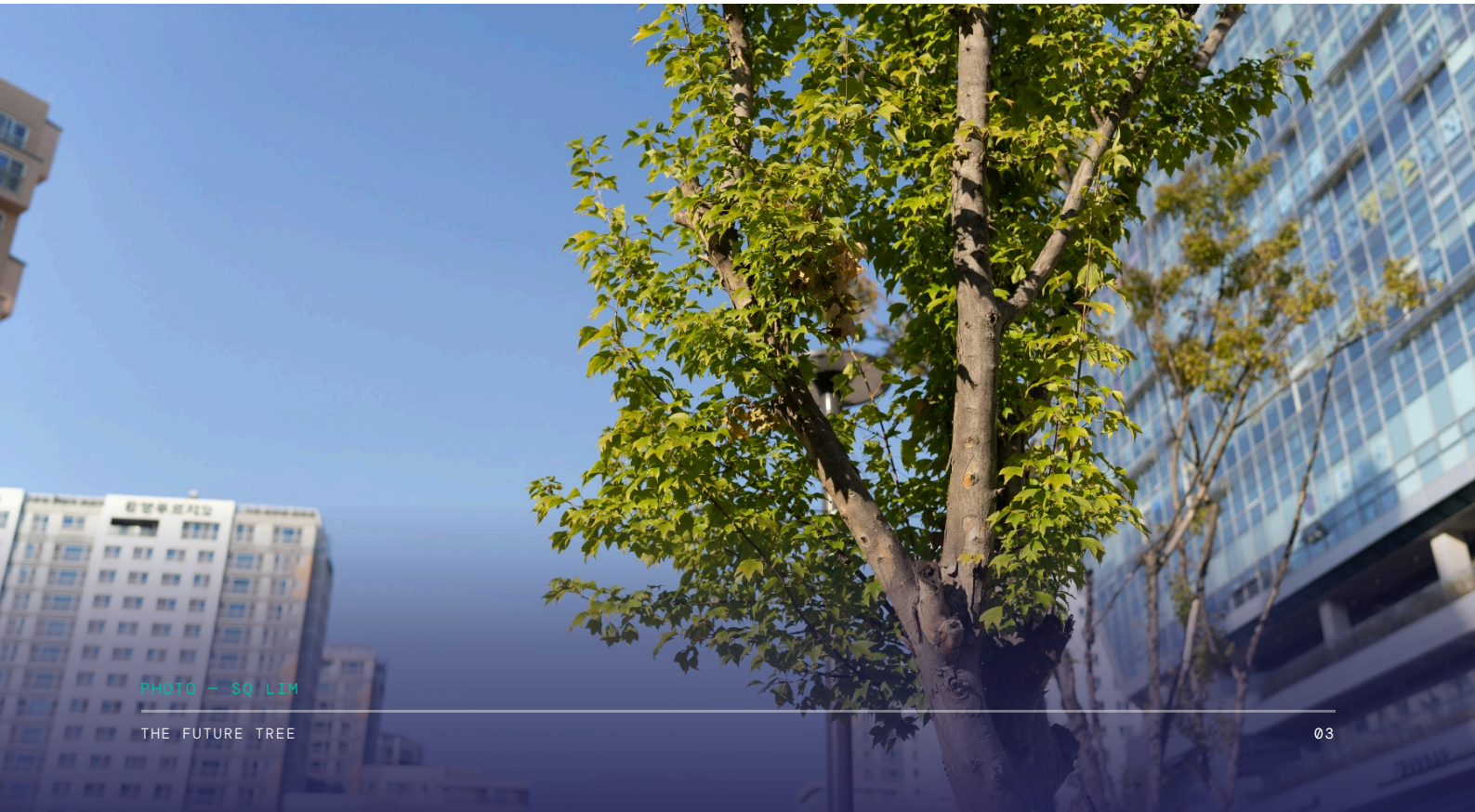


PHOTO — SO LIM

What makes a tree resilient enough to thrive in the future?

The answer is not straightforward. In reality, we need to understand both the environment trees are likely to experience and the characteristics that enable different species to cope with them.

The tree we plant today is, in effect, a tree for the future. It may take decades to reach maturity and will experience conditions we cannot yet fully predict. Plus, throughout its lifetime, it may be needed to provide the ecosystem services that we rely on.

So, what will the future tree look like?

There isn't one answer to this question. As this report will explore, it depends on the place, the climate, the species and our ability to understand how these things interact.

Drawing on research from scientists at the Royal Botanic Gardens, Kew, alongside evidence from the wider scientific literature, we consider the relationship between future climate, site conditions, and species characteristics that influence how trees respond to environmental stress. Together these strands of evidence provide a more informed basis for understanding which trees are most likely to thrive as conditions change.

This methodology has been harnessed to develop Palette: a practical way of translating complex scientific evidence into more informed planting decisions. Palette's purpose is to equip those making decisions about trees and landscapes with better evidence to build resilient, diverse ecosystems capable of meeting the challenges ahead.

In the face of an uncertain future, we must adjust our decision-making processes around planting and realise that what thrives today may not in the future.



PHOTO — VITALIJS BARILO

THE FUTURE CLIMATE

What will the future ask of our trees?

If we want to know whether a tree is resilient enough to thrive in the future, we first need to understand the environment it will be asked to grow in.

For a tree planted today, the climate it experiences at maturity will not be the climate we know today.

Across the UK, climate projections point towards a warmer future, with hotter summers and milder winters. Rainfall patterns are also expected to change, with a general tendency towards wetter winters and drier summers, although the scale of these changes will vary between regions and seasons. Periods of extreme heat, drought and intense rainfall may also become more frequent.

Climate change, rather than being simply a gradual change in temperature, is a changing combination of conditions.

Moreover, climatic conditions will not change uniformly. A tree planted in southern England will experience a different future climate from one planted in Scotland. A tree growing in a city may also experience additional heat associated with the built environment. Therefore, if we are going to assess whether a species is suited to the future, we need to understand not just how the climate will change overall, but how climate changes specifically in the place where the tree is planted.



PHOTO — LUKE TANIS

Looking to the future

Trees are long-lived organisms. A tree planted today may still be growing, providing shade, storing carbon and supporting biodiversity many decades from now. Therefore, today's planting decisions need to look beyond today's climate.

Looking towards 2050 and 2090 gives us two points in that longer timeframe: a mid-century future and conditions towards the end of the century. The purpose is not to predict the weather in a particular year. Climate projections describe longer-term patterns, typically using averages calculated over periods of several decades.

Exploring possible futures

We cannot know exactly what the future climate will look like. Instead, climate scientists use sophisticated models to explore how the climate system could respond under different future Greenhouse Gass (GHG) and socioeconomic pathways (typically referred to as SSPs). Global climate model experiments provide a way of examining these possible futures, while scenarios such as SSP3-7.0 and SSP5-8.5 allow us to consider different levels of future climate change.

There is uncertainty in all of this. Future emissions are uncertain, natural variability will continue, and different climate models represent the climate systems in different ways. Uncertainty does not mean that the future is unknowable. It means that resilient planting decisions need to account for a range of possible conditions. Incorporating this uncertainty is at the heart of Palette's scientific framework.

From global to granular

Global climate models give us the big picture. But trees do not grow in global averages. They grow in specific places.

To understand what climate could mean for a tree, climate data needs to be translated to a much finer spatial scale. High-resolution datasets such as CHESLA provide climate information at approximately 1km resolution, allowing projected temperatures and precipitation to be considered across individual locations rather than treating the UK as one uniform climate.

Making Climate Meaningful for Trees

A tree does not experience temperature and rainfall as separate variables. Its ability to grow and function depends on the balance between the water available and the amount of water being lost to the atmosphere.

This becomes particularly important as temperatures rise. Warmer conditions can increase potential evapotranspiration (the amount of water that can be transferred from the land and vegetation to the atmosphere when water is available). If this atmospheric demand increases faster than precipitation can meet it, the growing environment can become progressively drier, even when rainfall does not decline dramatically.

> A central question for trees therefore is whether there will be enough water available to meet the demands that the climate places on the tree?

One way of capturing this relationship is through the Climatic Moisture Index (CMI). CMI brings together two fundamental aspects of climate: precipitation and potential evapotranspiration. In other words, it provides an indication of whether the climate has a relative surplus or deficit of water.

A positive CMI indicates that precipitation is relatively high compared with atmospheric water demand. As CMI approaches zero and becomes negative, the balance shifts towards increasing moisture stress. This is significant because two locations with similar temperatures can present very different challenges for trees if their water availability and atmospheric demand differ.

The balance also changes through the year. From many trees, particularly deciduous species, the conditions experienced during the growing season are especially important. April to October is therefore used as the default growing-season period when assessing the climate in which trees are actively growing and transpiring. Looking at this period can reveal stresses that may be obscured by annual averages.

Therefore, understanding future tree suitability requires us to understand the balance between water supply and atmospheric demand on trees, when that balance occurs, and how it may change over the lifetime of a tree.



PHOTO — DANIIL KORBUT

THE TREE'S RESPONSE

Different trees respond differently to the same climate.

External factors only tell us half of the story. Trees growing in the same place can respond very differently to these external pressures. Species have all evolved under different environmental conditions, resulting in characteristics that influence how they grow, use water and withstand stress. Scientists name them functional traits - measurable characteristics that help explain how plants function and respond to their environment.

What happens when a tree runs short of water?

Water is fundamental to plant function. It supports photosynthesis, transports nutrients and maintains the pressure within plant cells that keeps leaves functioning.

As water becomes harder to obtain, that pressure falls. Eventually a leaf reaches a point where it can no longer maintain its normal turgor – known as the turgor loss point. This is one example of an important functional trait, one that provides a measurable indication of a plant's response to water stress. A more negative turgor loss point means a species can maintain leaf function at lower water potentials and is generally associated with greater drought tolerance.



PHOTO – CLOVIS WOOD

Research across tree species demonstrates just how much this can vary. Measurements reported by Hirons and colleagues, for example, show a substantially more negative turgor loss point for holm oak (*Quercus ilex*) than for silver birch (*Betula pendula*), reflecting very different capacities to tolerate water stress.



Holm oak (*Quercus ilex*, left) has a more negative turgor loss point than silver birch (*Betula pendula*, right), an indication of greater drought tolerance

Another important functional trait is wood density. Wood is the structural framework of a tree, but it also plays a critical role in transporting and storing water. Differences in wood density can therefore reflect different strategies for balancing growth, structure and resistance to environmental stress.

Other traits provide different insights. Leaf dry matter content (LDMC) can indicate how a species invests in durable leaf tissue and is associated with more conservative strategies for coping with environmental stress.

> These measurements give us something climate data alone does not: evidence of how the tree itself may cope when conditions become difficult.

Wood density, leaf traits, physiological measurements and evidence from where species naturally occur each tell us something different about a tree but cannot on their own define resilience. To understand which trees are most likely to thrive in a changing climate, we need to bring these different strands of evidence together.

NO SINGLE MEASURES TELLS THE WHOLE STORY

Building a more complete picture of resilience.

No single measure can tell us whether a tree will thrive in a changing climate.

Climate projections help us understand whether future conditions are likely to fall within the range a species can tolerate and functional traits provide evidence of how that species may respond to stresses such as drought. Together, these different lines of evidence give us a much stronger assessment of species resilience.

It is also important to consider that a tree does not experience these factors in isolation. Its ability to cope depends on the interaction between its characteristics and the specific conditions in which it grows.

The physical environment matters too. Soil type, available rooting space, water availability and drainage can all influence how a tree establishes and grows. In urban settings, paved surfaces can further affect the conditions around the tree, influencing how much water reaches the soil and how heat is experienced.

Therefore, a more complete assessment of a future resilience must consider the tree, its future climate and the environment in which it will grow.



PHOTO — SERGEI KARAKULOV

BIOSECURITY, DIVERSITY AND LANDSCAPE RESILIENCE

Why biosecurity and species diversity matters.

A tree may be well suited to its future environment, but resilience does not end with the individual tree. The trees we plant form part of a wider population and, over time, a wider landscape. The resilience of that landscape depends not just on how individual species respond to environmental stress, but also on the diversity of species within it.

Biosecurity is another important consideration. The movement and establishment of pests and diseases can pose significant risks to tree populations, particularly where planting relies heavily on a narrow range of species. The losses from ask dieback and ongoing concerns around oak processionary moth are examples of the risks associated with relying too heavily on a narrow range of species, reminding us that some species may be more vulnerable to particular threats, while the introduction of new species can bring its own biosecurity considerations. Understanding these risks is therefore part of making responsible choices about the future tree population.

Different species have different characteristics, tolerances and responses to heat, drought, pests and disease. A diverse planting palette can therefore provide a range of responses to environmental change, rather than creating a heavy reliance on a small number of species. Diversity does not remove the risk of pests and diseases, but it can form part of a broader approach to managing that risk and building resilience at the landscape scale.

The future tree, then, is not one species. It is part of a diverse population of trees, each suited to its place and contributing to the resilience of the landscape as a whole. And so, the aim should be to build a more informed and diverse palette of trees capable of contributing to resilient landscapes in the future.



PHOTO — JARRETT

FROM EVIDENCE TO REAL-WORD PLANTING DECISIONS

How do we turn this scientific evidence into decisions about what to plant?

A planting decision happens in a real place, with real constraints. The conditions around the tree matter.

Is it being planted in a paved urban environment, where rooting space and water availability may be limited? Is it part of a Sustainable Drainage System (SuDS), where tolerance to periodic waterlogging is important? Is it exposed to coastal conditions, shade or prolonged drought? The physical demands of the site can fundamentally change what makes a species suitable.

It is here that decades of established expertise from RGB Kew on tree and site selection provides another important layer of evidence for Palette. Furthermore, the Tree Species Selection for Green Infrastructure (TDAG) guidance considers characteristics such as drought tolerance, shade tolerance, waterlogging, crown form and growth habit alongside different planting contexts.

These considerations help move us from understanding a species in isolation to asking how it is likely to perform in a particular place and for a particular purpose. Trees can provide shade and cooling, intercept rainfall, support biodiversity, store carbon and contribute to the character and quality of a place. The best planting decisions therefore need to consider not only whether a tree can cope with future conditions, but what it can contribute in return.

Ultimately, we need to turn that evidence into choices that work in the real world.

PALETTE: FROM THE SCIENCE TO DECISIONS

Putting the science into practice

We now have a much clearer picture of what makes a tree resilient.

It is not simply a question of temperature tolerance, drought resistance or where a species grows today. Future climate, water availability, species characteristics, site conditions, ecosystem functions, diversity and biosecurity can all influence whether a tree is likely to thrive.

The challenge is that these different forms of evidence come from different scientific disciplines, datasets and sources. Bringing them together in a way that can support a real planting decision is not straightforward. This is exactly what Palette was designed for.

Developed by Kew Reach alongside the masterminds of resilience research at the Royal Botanic Gardens, Kew, Palette brings these strands of evidence together to help users explore which tree species may be suitable for different locations and future conditions.

It combines projections of future climate with evidence about species' natural climatic ranges and functional traits. It then places this information alongside practical considerations about the planting environment, ecosystem services, and biosecurity.

The result is not a prediction of exactly what will happen to a tree decades from now. Instead, Palette provides a way to interrogate the available evidence and compare species against the conditions they will possibly encounter.

A user can start with a place and explore the species that may be suited to its future climate and site conditions. They can then filter results according to the ecosystems services required of the tree.

The platform brings the underlying evidence into a form that can support conversations between landscape professionals, planners, arboriculturists and others making decisions about trees.

> Palette was not designed as a replacement for professional judgement. Rather, it is a way of making a complex and evolving evidence base more accessible, transparent and traceable at the point where decisions are made.



PHOTO — MARTIN MAGNEMYR

CONCLUSION

Planting for the future

There is no one answer to the question, what makes a tree resilient enough to thrive in the future?

A tree's future depends on the climate it will experience, the availability of water, the characteristics that enable it to respond to environmental stress and the conditions of the place in which it grows. Its suitability also needs to be considered alongside the functions we want trees to provide; the diversity of the wider planting population and the biosecurity risks we need to manage. None of these factors exist in isolation. The science explored in this report provides a way of bringing them together.

The future tree isn't a particular species or a single ideal tree. It is a tree selected with a better understanding of the climate it will encounter, the characteristics that will help it cope, the place in which it will grow and the role it will need to play. This is important because the trees we plant today will live in the future climate, not the climate we know today.

We cannot know exactly what conditions they will encounter. Nor can any model or assessment remove the uncertainty inherent in making decisions about a changing world. But uncertainty does not mean we have to make those decisions without evidence.

> The future tree is not a single species waiting to be discovered. It is the tree we choose today with a better understanding of the world it will grow into.

Instead of simply choosing trees that have performed well in the past, we can begin to ask which trees have the characteristics, climate suitability and site fit to contribute to the landscapes we will need in the future. And how we can create diverse, resilient populations capable of adapting as conditions change.

That is the purpose behind this work. Not to predict the future with certainty, but to build the strongest possible evidence for the decisions we make today.

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Data and technical sources

CHELSA Climate Data	High-resolution global climate data used to represent present and future climatic conditions.
GBIF - Global Biodiversity Information Facility	Global species occurrence data used to understand the observed climatic ranges of tree species.
TRY Plant Trait Database	Global database of plant functional traits, supporting the assessment of characteristics associated with plant performance and environmental stress.
TreeGOER	Database of observed environmental ranges for tree species, used to support understanding of species–climate relationships.
LEDA Traitbase	Database of plant functional and life-history traits used as a source of trait information.
Tree Species Selection for Green Infrastructure (TDAG)	Technical guidance on tree selection, environmental tolerances and suitability for different planting contexts.
GHS-SMOD - Global Human Settlement Layer	Settlement and urbanisation data used to inform consideration of urban heat effects.

Climate and wider evidence

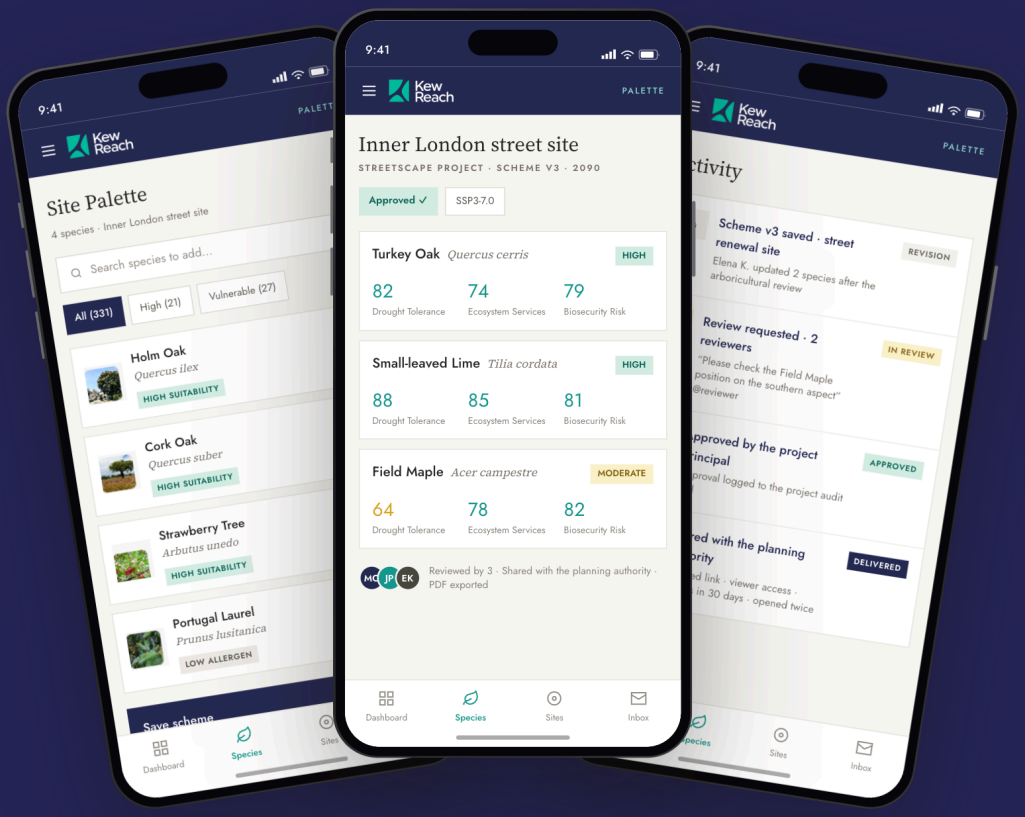
The report also draws on established climate science and projections from the CMIP6 framework, including scenarios such as SSP3-7.0 and SSP5-8.5, to represent a range of possible future climate conditions.



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