The role of forests in global climate adaptation

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Abstract:

Forests play a crucial role in regulating the global climate. Yet, forests also influence the local climate conditions through biophysical processes that directly impact human wellbeing. With growing policy emphasis on these climate adaptation effects, we review the scale dependent impacts of forests on climate conditions and their implications for human wellbeing. Generally, existing forests buffer local temperatures, with warming effects in cold regions and cooling effects in hot regions. At a global scale, trees are more conducive to cooling in regions where dense forests would naturally exist. Additionally, forests generally reduce water runoff, which can reduce flooding in wet areas, but it can also limit water availability downstream, especially in drier regions. Together, these findings suggest that climate positive tree effects tend to be most frequent in regions where forests naturally occur, and highlight the growing consensus around the importance of natural forests for climate adaptation.

Main Text:

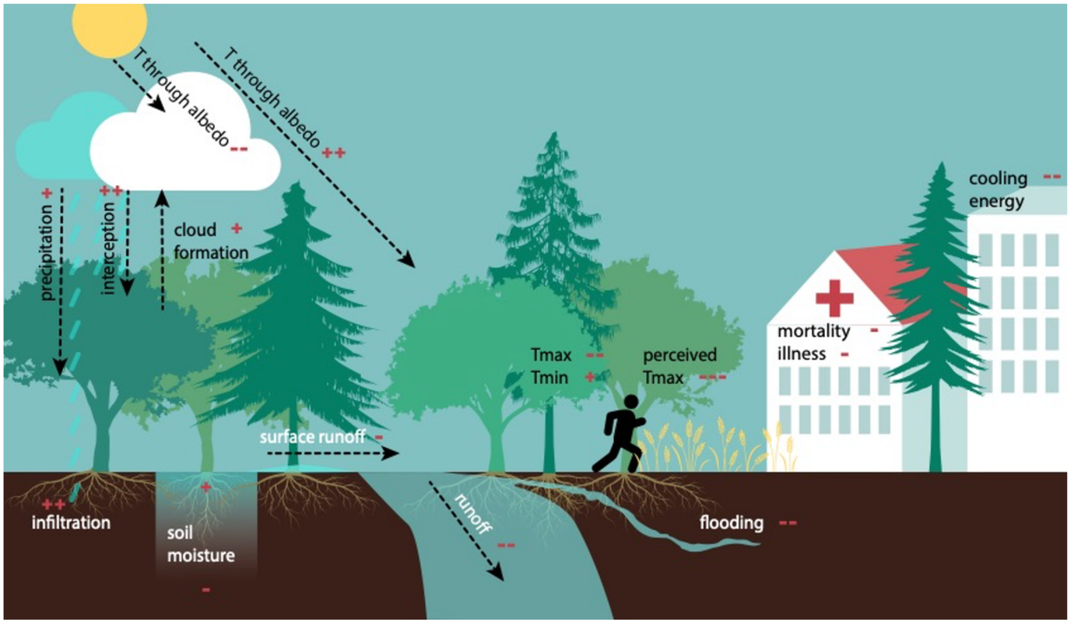
Forests play a critical role in influencing the global climate system. Over the last decade, a considerable body of research has focused on the carbon storage potential of forests (*1–4*), and their role in global-scale climate mitigation (*3*, *5*). However, tree cover also influences local climate conditions through a range of biophysical forcing processes that can increase or decrease local temperature and moisture (Fig. 1). These local climate effects of trees (*6*) could have important implications for the health and wellbeing of local people.

Given that extreme heat is a rapidly growing climate-related cause of mortality across the globe (*7*), the impacts of forests on local climate are a growing research priority. However, the impacts of forest cover on the local climate conditions are highly variable across different spatial scales and locations. Some studies have highlighted the local cooling provided by forests in certain regions (*8–10*), while others have emphasized that forests cause warming elsewhere (*11–14*). In recent years, an emerging body of global-scale research has begun to reveal consistent trends, as forests generally have a warming influence in high-latitude regions, and a cooling influence in lower-latitude regions (*15–18*). Yet, until now, we lack a comprehensive synthesis of these effects across different spatial scales.

In addition to the impacts on temperature, a growing body of research has shown the direct impacts of forests in regulating water dynamics - another climate adaptation critical for human wellbeing. In general, tree cover generally slows precipitation from reaching the ground, causing a greater proportion of water to evaporate. Trees also improve infiltration into the soil and reduce surface runoff as water is transpired (*19*, *20*). Although these effects can improve local water availability and reduce flooding, they can also lower water availability for downstream communities in different regions around the world. A thorough understanding of these processes is critical to ensure that the promotion of forest cover does not come at the expense of habitats and livelihoods. Until now, the scale-dependency of these biophysical mechanisms operating above and below the canopy (*18*), still present key sources of uncertainty for understanding the climate impacts of forests across the globe.

In this review we provide a synthesis of recent empirical research exploring the effects of trees on temperature and water regimes across local and global scales. Next, we review the secondary implications of these temperature and water dynamics for human well-being, in particular human health, food security, and related economic impacts across the globe. Although we cannot provide a comprehensive review of all papers on this topic, we instead focus on identifying the emerging areas of consensus around the biophysical impacts of forests, and identifying key research areas where further research is needed to refine our understand of the climate adaptation impacts of forests across the globe.

A



B

Category	Description	Forest Influence	Number	Source/ scale	Citation
Temperature	Subcanopy daily max. (average)	↓	-4.1 °C	global	De Frenne *et al.*, 2019
	Subcanopy daily min. (average)	↑	+1.1 °C	global	De Frenne *et al.*, 2019
	Subcanopy Human perceived max. (extreme)	↓	-15 °C	Europe	Gillerot *et al.*, 2022
C storage	Net annual carbon flux of forests	↑	-7.6 ± 49 $GtCO_2e\ yr^{-1}$	global	Harris *et al.*, 2021
Water	Canopy Interception of precipitation	↑	21.8%	global	Yue *et al.*, 2021
	Infiltration	↑	+ (83% of cases)	global	Filoso *et al.*, 2017
	Annual water yield	↓	- (79% of cases)	global	Filoso *et al.*, 2017
	Baseflow	↓	- (73% of cases)	global	Filoso *et al.*, 2017
	Flooding	↓	- (82% of cases)	global	Filoso *et al.*, 2017
Energy	Cooling energy usage	↓	- 2-90%	North America	Ko, 2018
	Heating energy	↓	- 1-20%	North America	Ko, 2018

Fig.1: Biophysical processes influenced by forests and their impacts on human wellbeing. (**A**) Illustration of processes. Red + refer to an increase in effect size when forests are present compared to non-forest, red – denote a decrease in effect size in the presence of forest. (**B**) Quantitative estimates of effect sizes.

Effects of tree cover on temperature

Forests influence temperatures from local to global scales through a variety of mechanisms. These biophysical processes and climate effects of forests operate differently below vs above the canopy. In addition, local effects may differ from the net influence on a planetary scale so that forest cover in the same location may result in both local cooling and global warming. Despite these complexities, there are many places where forests can support local and global cooling synergistically (*15*, *16*, *21*). The effects of trees on temperatures largely depend on a combination of evapotranspiration, radiation and albedo effects, as well as their carbon storage potential on a global level.

Local scale temperature effects

Trees reduce daily maximum temperatures primarily by blocking direct solar radiation, i.e., creating shade, and via evapotranspiration (during evaporation, water absorbs heat energy to change from liquid to vapor, and during transpiration, plants release water vapor from their leaves, both processes resulting in a net cooling effect) (*18*, *22*). Conversely, tree canopies also capture outgoing long-wave radiation from the soil, leading to higher below-canopy temperatures at night compared to reference conditions outside forests (*23*). As a result, local temperatures in forests are usually buffered: on average across 98 global sites, seasonally averaged maximum temperatures near the ground were 4.1 °C lower and minimum temperatures were 1.1 °C higher inside forests than in reference conditions (*16*). In urban environments, global syntheses suggest that trees locally cool air temperatures on sunny days by an average of ~1.5 to 2 °C (*23*, *24*). Moreover, trees cause stronger cooling the higher the ambient temperature: With every degree of macroclimatic warming, the temperature difference within versus outside forests increases by c. 0.32 °C (*16*). As a result, the mean maximum temperature buffering in tropical forests (-6.1 °C) is higher than in temperate (-2.7 °C) and boreal (-2.4 °C) forests (*16*) (Fig. 2A). Additionally, cooling in the same location is stronger under higher temperatures (*18*). Even more physiologically relevant to humans than absolute temperatures are human-perceived temperatures, which consider factors like wind speed, humidity, and radiation. Human-perceived temperatures can be up to 15°C lower inside than outside forests on extremely hot summer days (*9*).

Below-canopy temperature buffering is predominantly determined by forest canopy structure and composition (*18*, *25–28*). The cooling effect of trees generally increases with increasing canopy density, cover, and leaf area. Thus, promoting trees with high shade-casting ability (if appropriate for the location) is an effective management option to increase local cooling, mitigate urban heat, and enhance human thermal comfort (*9*, *23*, *24*, *28–30*). For instance, high shade casting species like beech (*Fagus sylvatica*) can provide 1°C more cooling than tree species with a lower shade casting ability like ash (*Fraxinus excelsior*), even with the same overall canopy closure (*27*). In addition to species identity, species diversity likely influences local cooling ability, with studies indicating that mixed-species stands provide stronger temperature offsets than monocultures (*31*).

Local-scale effects of tree cover on temperature are not confined to below-canopy regions. Surface temperatures, measured on top of the canopy and relevant for tree physiology, also show a buffering pattern: cooling when temperatures are high, and warming when they are low (*15*). This buffering leads to a global pattern of warming near the poles and cooling near the equator, mostly due to lower forest albedo compared to other land uses at high latitudes versus a smaller albedo effect and high evapotranspirative cooling close to the equator (*32*). The result is net forest warming above a latitude of 45°N and cooling below 35°N (including the full southern hemisphere). In between 35°N and 45°N forests typically show daytime cooling and night-time warming with daily net effects close to 0 (*15*). Local temperatures both below and above the canopy are determined by interactions with the macroclimate, landscape characteristics (e.g. forest fragmentation or the distance to the forest edge and large water bodies), as well as local site characteristics related to the topography and soil (*18*, *25–28*, *33*).

Macro scale temperature effects

In contrast to local scales, where forests mostly lead to net cooling, at macro scales the temperature effect of forests can range from warming to cooling (*21*, *34*). Key mechanisms by which trees influence global temperatures include carbon capture, the albedo effect, evapotranspiration, cloud formation, and turbulent fluxes –movements of air transporting heat and moisture.

The relative importance of each factor varies considerably with latitude and background climate. During photosynthesis, trees capture carbon from the atmosphere and store it as biomass (Fig. 2B). Forests are major contributors to carbon removal by terrestrial ecosystems and were (between 2001 and 2019) a net carbon sink of $-7.6 \pm 49\,\mathrm{GtCO_2e\,yr^{-1}}$ (*35*). The link between atmospheric carbon and global climate suggests that complete deforestation of the tropics, spanning from 10°N to 10°S, could lead to a global temperature increase of about 0.8°C, mainly due to the resultant CO_2 emissions (*36*). The specific carbon storage potential depends on climatic factors, but also stand characteristics (*37*). While rising levels of atmospheric CO_2 may promote plant growth (*38*) and thus carbon capture, climate change-induced factors like increased heat, drought, and fire risks threaten the potential of ecosystems to capture and store carbon (*39*). While young trees accumulate carbon most quickly, the highest carbon stocks are typically found in diverse, undisturbed mature forests, especially tropical broadleaf forests (*3*).

Forests tend to be darker than other land surfaces, such as grasslands or snowscapes. This lower albedo leads to relatively more heat being retained within the broader Earth system (*11–14*, *34*, *40–43*). In some locations, this albedo change causes warming that can partially or even completely counteract the cooling benefit of increased carbon storage in trees (*21*). A recent analysis of the net climate impact of increasing tree cover found that albedo increases would entirely offset maximum carbon storage across 72%, 71%, and 60% of the temperate savannah, tundra, and Mediterranean forest biomes respectively, if maximal possible tree cover were established there. In contrast, albedo entirely offsets carbon storage in only 3% of the total area of tropical and subtropical moist broadleaf forests. Moreover, locations where forests cause overall cooling exist in all biomes (*21*). The magnitude of the albedo offset also depends on forest composition, with conifers generally being darker than broadleaved and deciduous trees. While the albedo effect of darker forests is relatively well quantified, it is not the only aspect of forests' influence on the planetary albedo. The effect of forest albedo on surface temperatures is strongly dependent on available moisture; moreover, surface albedo contributes only a small portion of the planetary albedo (*44*). Much of the surface warming from reduced albedo (e.g. through increased forest cover) is not realized in regions with ample soil moisture, where the increase in absorbed energy leads to increased evapotranspiration (*45*). This leads to cooler below and above canopy air temperatures, though heat is eventually released elsewhere when the water vapor condenses.

While forests themselves are darker than many other vegetated land surfaces, forests can also indirectly modulate planetary albedo (which impacts the global energy budget and thus global temperatures) by modulating cloud formation. Patchy forests in the tropics can support cloud formation by affecting the air flow (atmospheric convection) above them (*46*). Those forests that do support cloud cover effectively counteract their low surface albedo by supporting bright clouds that reflect solar radiation and reduce the amount of solar radiation reaching the forest. While the tropics have the most extensive documentation of forest-cloud interactions, there is observational evidence for forests supporting low cloud cover in many subtropical and mid-latitude regions (*47*). Generally, places that naturally support dense forest cover are usually places where the offsetting effect of albedo is relatively small, and the net climate impact of forests is to cool the global and local climate (Fig. 3).

In addition to albedo effects, forests also have chemical effects impacting the macroclimate. Trees produce volatile organic compounds which regulate secondary organic aerosols. These are themselves highly reflective, resulting in biophysical cooling, and they also enhance cloud formation, leading to more cooling (*36*). However, the volatile organic compounds produced by trees also increase the concentrations of methane and ozone, which can diminish their positive climate impacts (*48*). A recent study concluded that under a business-as-usual emissions scenario, such chemistry-albedo feedbacks might negate approximately 23% of the carbon removal benefits of forests by the end of the century (*48*). Crucially, this research also indicates that these trade-off effects are reduced under a scenario where future CO_2 emissions are significantly curtailed (SSP1-2.6 scenario): In such a scenario, just 14% of forest carbon sequestration would be offset due to chemistry-albedo feedbacks. This underscores the interplay between emissions reductions and nature restoration, emphasizing that effective climate action is essential not only to preserve the natural environment but also to sustain its beneficial impacts on the climate (*3*, *48*).

Effects of tree cover on water regimes

Trees influence hydrologic processes across different spatial and temporal scales. In their canopies, trees transpire water, which can stimulate cloud formation and influence precipitation patterns, and they intercept rainfall. Precipitation flows down along the stems and to root structures, which allow more water to infiltrate the soil relative to shallow-rooted vegetation or bare soil, and trees then draw upon this water to grow. All these processes interact with each other, and net impacts vary between local, downstream, and downwind regions, and usually have to be assessed individually for specific scenarios.

Local scale moisture

Forest ecosystems alter the local water cycle by intercepting precipitation, enhancing infiltration, shading the forest floor, and transpiring subsurface moisture back to the atmosphere. Their net effects vary with climate, canopy structure, and soil characteristics, but forest cover frequently results in net decreases in surface runoff and flooding, and net increases in shallow soil moisture relative to other forms of vegetation. Tree canopies intercept 4-73% of annual precipitation, depending on species, stand density, canopy structure, and local precipitation patterns (*49–51*)(Fig. 2C). Interception losses account for ~6% of global continental precipitation (including precipitation falling outside of forests) (*20*) and are typically higher for small events and in broadleaf forests (*19*, *51*). Sub-canopy vegetation and forest-floor litter intercept an additional ~20% of incoming precipitation (*52*, *53*), reducing moisture inputs to the soil surface but also increasing evaporative cooling.

The collective effects of this interception, together with evapotranspiration and enhanced infiltration of water into the soil, make trees important in stormwater management (*54–56*). Forests increase soil infiltration because the growth and eventual decay of roots generate interconnected macropores in the soil structure (*54*, *56*, *57*). Forest-floor litter also inhibits evaporation from shallow soil layers and enhances soil porosity. Thus, tree cover enables greater infiltration into and percolation through the soil (*54*, *56*, *57*), facilitating water redistribution across soil strata, diminishing stormflow, and enhancing groundwater recharge (*58*, *59*). Much of what infiltrates is eventually taken up by tree roots and transpired back to the atmosphere (by trees or the forest understory), so the net effect on water budgets can be difficult to predict *a priori*. Nonetheless, syntheses of case studies show that deforestation generally increases streamflow (*58*, *59*) (at least until vegetation cover grows back), and that forest restoration generally increases infiltration (83% of 18 cases) and reduces flooding (82% of 43 cases) (*59*). However, forest restoration may be unable to restore natural infiltration rates if soils are severely degraded (*59*). Conversely, extensive reforestation initiatives in arid and semiarid zones can potentially push local water resources to their limits by reducing average streamflow (*60*).

The shading effects of forest canopies reduce soil evaporation and facilitate water retention (*61*, *62*). Trees also funnel water and nutrient inputs into the soils surrounding tree stems (*63*, *64*). The redistribution and retention of water and nutrients, combined with abundant fresh carbon inputs, create islands of fertility around trees, forming hotspots of plant and microbial diversity (*65*). These islands of fertility are critical for soil microbial communities (*66*), especially in drier climates (*67*). However, their benefits vary with landscape position (*65*) and may come at the cost of desiccation of deeper soil layers and reduced groundwater recharge (*68*), if increases in infiltration and water retention due to tree cover are outweighed by increases in interception and transpiration.

Macro scale moisture

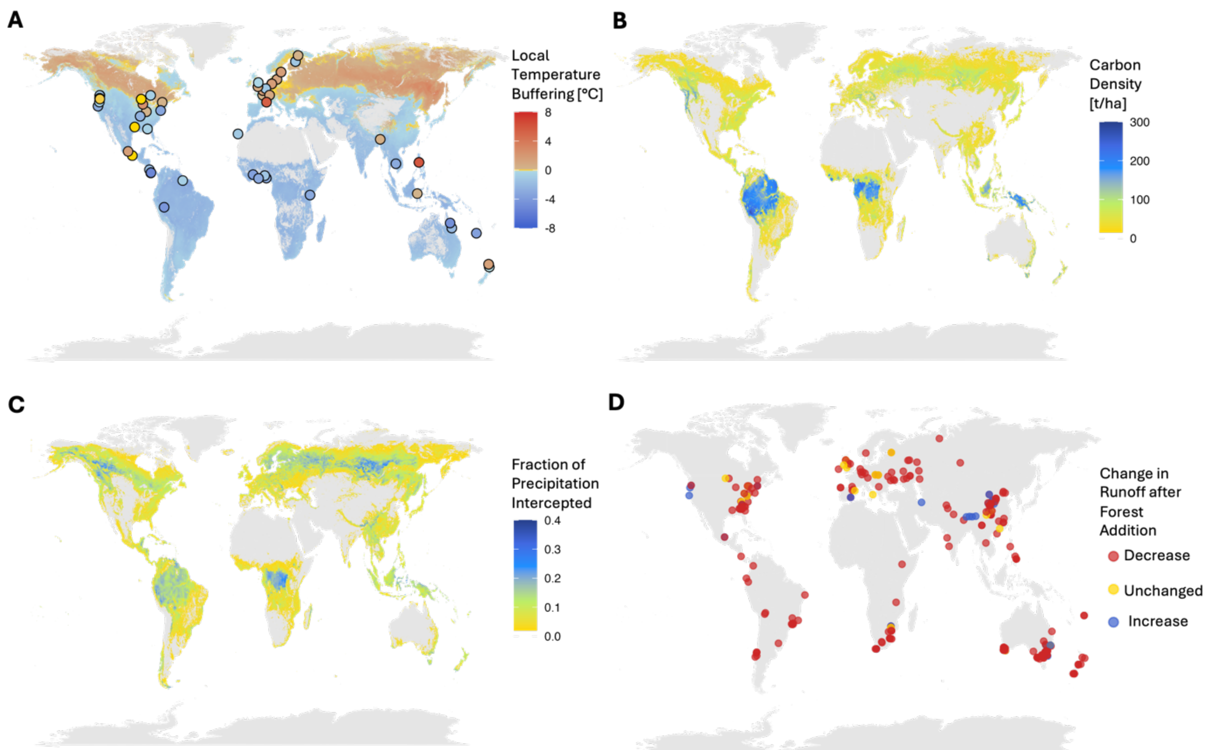
Changes in forests and climate are altering water availability globally (*69*, *70*). Evidence on the hydrology of forested catchments comes from both planted forests (native and non-native species) and native forests (that regenerated after a natural disturbance) of various ages, drawing from watershed studies with up to 90-year records.

Extensive natural forests can be major contributors to regional water availability. Amazonian deforestation under a business-as-usual scenario (based on rates before 2004), for example, is estimated to lead to an 8.1% (± 1.4%) reduction in precipitation across the Amazon basin by 2050 (*71*). At the same time, new forests globally are dominated by managed plantations (*72*, *73*). Intensively managed forest plantations, especially of non-native species such as *Eucalyptus,* can greatly reduce runoff compared to native or old-growth forest (*59*, *74*). Rapid expansion of forest plantations has been associated with reduced streamflow globally (*75*), including in South America (*76–79*), southern Africa (*80*), and China (*81*). Runoff ratios (streamflow as a fraction of precipitation) typically are in the range of 40 to 60% in native forests but may be less than 10% in intensively managed non-native *Eucalyptus* plantations under dry conditions (*75*, *76*, *78*, *82*). Additionally, plantations of native species and naturally regenerating native forests can reduce streamflow compared to older native forests (*82*). Native forests and old-growth forests produce more biomass per unit water transpired than planted forests and are less sensitive to climate fluctuations (*83*, *84*).

The magnitude of streamflow reductions from forest plantations varies with climate (*85*, *86*)(Fig 2D). In afforestation of grasslands, the driest sites (< 1000 mm annual precipitation) had the greatest proportional decreases in observed runoff (-62%± 10% on average for dry sites vs. -44% ± 3% for all sites), suggesting that the effects of afforestation on water yield will be more severe in drier regions (*74*). For afforested shrublands, reductions were also larger at drier sites. Proportional declines were larger for low flows, in dry seasons, and in dry years (*74*, *85*, *86*). Afforestation in drier locations—even if such habitats support trees—is likely to lead to severe declines in both total runoff and low flows, altering downstream habitats and human communities. This emphasizes the importance of accounting for the amount of tree cover a location could naturally support (in reference conditions with minimal human interference), as well as considering implications for downstream locations, in restoration projects.

In addition to impacts on runoff, forests also are an effective way of stabilizing slopes to reduce erosion and landslides (e.g. (*87*, *88*)). However, roads and soil disturbance, which can accompany intensive plantation forestry, can greatly increase landslides and sediment production during extreme rainfall events, especially in steep landscapes (e.g. (*89*, *90*)). In coastal regions, mangrove forests in particular are also an efficient and economic protection against floods and erosion (*91*).

Enhanced evapotranspiration from forests, including intensively managed plantations, contributes to downwind precipitation locally, regionally, and globally (*92*, *93*)(Fig. 2E). Global climate models indicate that a tripling of the total global area of restored forest (to 900 million hectares) could increase water availability (precipitation that is not lost through evaporation and available for consumption) by up to 6% in some regions and reduce it by up to 38% in others (*94*) and that enhanced vegetation (measured as an increase in leaf area index) may increase local and downwind water availability for ~45% of the land surface but may decrease it elsewhere, primarily in water-limited or high-elevation regions (*95*), which may be prone to self-propagating drought (*96*).



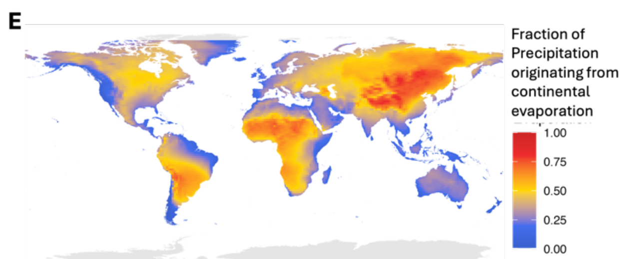


Fig. 2: Global patterns of biophysical impacts of forests. (**A**) Local forest – non-forest temperature [°C], background: satellite-sensed surface temperature, annual forest vs. non-forest offset from day- and night-time averages (data from ref (*15*) and extrapolated to global scale (data from ref (*185*), < 10% extrapolation); note that there is seasonal variation in local cooling and warming effects; points: ground-measured subcanopy temperature offsets (data from ref(*16*)) (**B**) Current above ground tree Carbon density [t ha^{-1}] (data from ref (*3*)) (**C**) Fraction of annual rainfall lost to interception (data from ref (*20*)) (**D**) Changes in water yield following restoration or forest cover expansion (data from ref(*59*)) (**E**) Fraction of precipitation resulting from continental evaporation (data from ref (*93*)).

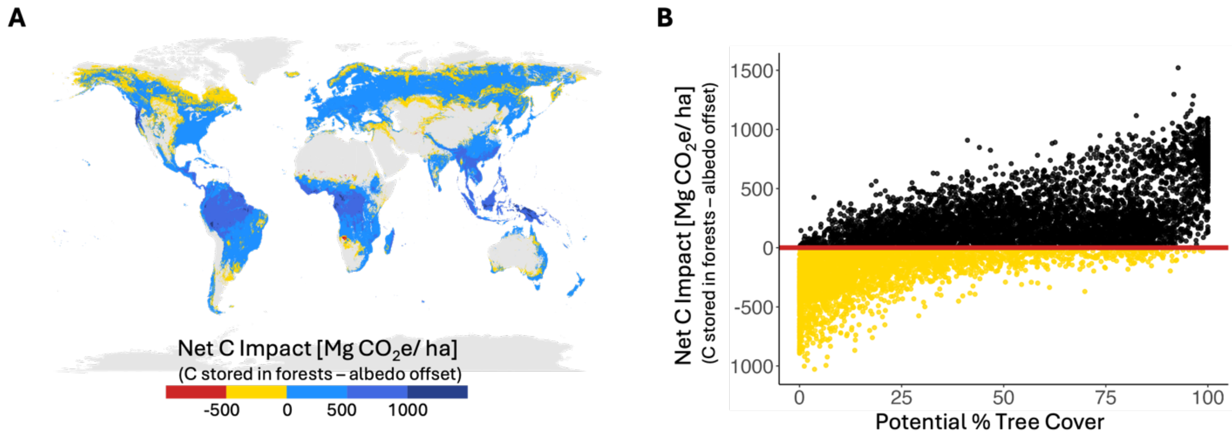


Fig. 3: Net climate impact by potential tree cover. (**A**) Net climate impact of regions with at least 30% tree cover potential. (**B**) Net climate impact of tree cover in a location based on the % of tree cover the location could naturally support. Net climate impact is estimated in carbon equivalents by estimating the carbon storage potential of restoring tree cover and accounting for albedo change based on ref (*21*). The carbon equivalents refer only to the additional carbon that could be accumulated by restoring tree cover, not the one already present. The albedo change is estimated for a transition of the observed or most likely open land cover class (open shrublands, grasslands, croplands, and cropland/natural vegetation mosaics) to the observed or most likely forest type and radiative forcing converted to carbon equivalents. In order to estimate a net impact, this is compared to maximum potential carbon storage above and belowground in woody plant biomass (but excluding soil organic matter). Potential % tree cover is based on ref (*2*), estimating the % for potential tree canopy cover based on environmental conditions and observed tree cover in protected regions.

Tree cover-climate implications for human well-being

While extreme cold currently claims more lives globally (*97*), extreme heat is a rising cause of climate-related mortality and injury (*7*). High temperatures are already associated with 490,000 deaths annually (*97*), and climate change under a high-emissions scenario (RCP 8.5) is expected to add over 70 deaths per 100,000 people per year globally by 2100 (interquartile range [6, 101]), even under scenarios of income growth and climate adaptation efforts (*98*). Both temperature and moisture effects threaten food security, as incidents of droughts and floods increasingly devastate yields and livelihoods (*99–101*). Models based on young unacclimatized workers in laboratory settings suggest that in half of the world's cropland, heat has already lowered the physical working capacity of manual agricultural workers by 14% of the full potential during growing seasons (*102*). Global warming has increased global economic inequality (*103*) and extreme heat has already caused \$5 trillion - \$29.3 trillion losses in global GDP between 1992 to 2013 (*104*). The biophysical impact of tree cover influences many of these stressors relevant to human wellbeing. In the following sections, we will focus on these temperature- and moisture- based impacts, though forests also influence human wellbeing by many other pathways.

Human Health

Tree cover influences ambient daytime temperatures, flooding, and water quality, and thus human health. The heat effects of large-scale deforestation can extend several kilometres from the deforested site, affecting many people (*105*, *106*). Mitigating heat exposure is important because it is associated with various heat-related illnesses, including fatal heat stroke, kidney injury, impaired cognition, traumatic injuries, and reduced work productivity (*107–112*). Maintaining dense, closed canopy forest cover is associated with reduced occurrence of strong to extreme daytime heat stress (*9*, *113*). By contrast, tropical forest loss and degradation over the last 15 years have decreased safe thermal working conditions for nearly three million outdoor workers who are disproportionately exposed to heat (*114*). A local model-based case study of forest loss heat impacts estimated that deforestation has accounted for 7.3–8.5% of all-cause mortality (*115*). The cooling services provided by trees are also highly beneficial to urban areas (*116*). It has been estimated that urban tree canopy saves around 1,200 lives per year in the United States that would otherwise be lost due to heat-related mortality (*117*), and a study of 93 European cities suggested an increase in tree canopy to 30% would decrease temperatures by 0.4 degrees Celsius and prevent 2,600 deaths annually (*118*).

Tree cover regulates the hydrologic cycle in ways that can be beneficial or detrimental to human health (*119*). Floods, a major natural hazard, kill tens of thousands annually (*120*) and are projected to increase under climate change (*121*, *122*). In addition, they are associated with the spread of diseases (*123*). Thus, forests' capacity to reduce floods is highly beneficial to health and wellbeing. However, as forested regions are associated with lower runoff, water usage by trees can compete with human water requirements in some locations, potentially affecting human health. Additionally, health is impacted by water quality. Especially in places where water is used with little or no treatment, erosion and nutrient pollution pose a health challenge (*124*), and both can be reduced by tree cover (*125*, *126*). A recent review in Europe suggests that the role of forests in maintaining water quality and quantity accounts for an economic benefit of 923 US$/ha/year) (*127*).

Forests also indirectly affect human health beyond impacts on local hydroclimate. They can modulate air quality (*128*), and increased deforestation and fragmentation are related to transmission of vector-and host-borne diseases (*129–131*). Tropical forests are vital for nutrition and food security (*132*, *133*) and provide medicinal plants (*134–136*) for many communities. Additionally, time spent in forests and other green spaces is associated with lower all-cause mortality through various mechanisms, including increased physical activity, lower incidence of hypertension (*137*), and improved mental health (*138*, *139*). The potential health benefits forests may be greater for more vulnerable populations (*7*).

Food Security

Due to the variety of biophysical mechanisms by which tree cover influences its surroundings, the impact of forests on agriculture and food security typically differs between the local place of tree cover, downstream, and downwind regions. In addition, it is important to consider the potential for water scarcity to understand how the biophysical impacts of tree cover will ultimately affect food security.

The temperature buffering effect of trees allows them to reduce plant exposure to both extreme heat and cold stress (*15*, *140*, *141*). Moreover, shading protects shade-tolerant crops from irreversible damage caused by excess of sunlight exposure to plant photosystems (*142*). Temperature regulation also affects agricultural workers, whose working capacity is reduced by heat exposure (*102*).

Tree cover affects the water cycle in complex ways. As forests typically show reduced runoff compared to other landcover (*143*, *144*), they can impact water availability for downstream irrigation. While protection of existing forest cover is not expected to alter water availability, afforestation can cause detrimental shifts in hydrological regimes. Ricciardi *et al*. (*145*) showed that 15% of the intertropical areas suitable for tree planting (*2*) could start to experience water stress as a result of afforestation, in addition to the currently affected 72%. Irrigation of cultivated land would further increase the water stress to 95% of the intertropical area (*145*). To support food security, afforestation projects in water-limited regions thus have to carefully consider consequences for downstream agricultural lands. Downwind regions, on the other hand, may benefit from increased precipitation and water availability due to tree cover (*140*, *146*, *147*). However, predictions on the amount of precipitation are challenging. Thus, the overall impact depends on regional water availability.

Locally, tree cover can reduce soil water status through intercepting precipitation and transpiring moisture in which case water availability for crop growth is also lowered. Tree cover can also locally improve the soil water status through nurse plant mechanisms (*144*), facilitating crop growth below canopies. This occurs in several ways: 1) trees can move moisture to higher soil layers when soils are wet at depth and dry at the surface, favouring shallow-rooted crops (*148*); 2) in certain micrometeorological settings, forest canopies may facilitate condensation (dew) and fog/cloud deposition, enhancing water availability (*149*); 3) trees can drain waterlogged soil and improve soil salinity, providing more favourable conditions for plant growth (*150*); and 4) reduced evaporation from canopy shading and enhanced infiltration can increase soil moisture compared to tree-less areas, enhancing crop growth (*151*, *152*).

Agroforestry, which combines trees and crop production, can improve microclimate and water availability (*141*, *153*). These systems can double crop yields, enhance soil fertility, and improve water quality (*152*). Silvopasture systems, which combine trees with grazing livestock, also benefit from these biophysical mechanisms and provide increased fodder options from tree by-products (*154*).

Forests also contribute to food security in ways beyond temperature or water regulation, for example by providing habitat for pollinators (*135*, *155*, *156*) and by providing local communities with fuelwood for food preparation (*157*, *158*). The presence of tree canopies enhances phosphorus and nitrogen deposition, heightening nutrient availability (*159*, *160*).

Economy

The biophysical effects of forests have a variety of economic implications, for example through human productivity, energy demand, and agriculture. The exact impact of trees' temperature modulation is contingent on contextual factors. A sizable literature documents that higher temperatures reduce worker productivity and thereby economic output (*161*). A meta-analysis suggests that temperature primarily adversely affects psychomotor and perceptual tasks (*162*), but more recent literature also documents negative effects on cognitive tasks, such as learning and school performance (*163*). These adverse effects are more pronounced in low-and middle-income countries and industries more susceptible to heat shocks, such as agriculture, construction, and manufacturing (*164–167*). For instance, a recent field experiment in Indonesia among outdoor workers showed an 8.2% reduced productivity in deforested settings relative to forested settings due to higher temperatures (*110*). Trees can also substantially reduce energy demand for air conditioning, primarily in the built environment, but the exact impact depends on the species and siting of trees, building type, and local climatic conditions (*168*). For instance, in North America, a review indicated that these energy savings vary from 2–90% for cooling and 1–20% for heating (*169*).

Deforestation- and climate-induced changes in water provision are also expected to affect poorer countries more than others because of the important role of agriculture and water resources in their economies (*170*). While trees can decrease annual water yields (*59*), deforestation often compromises water quality, leading to greater water treatment costs (*171*, *172*). Forest restoration, on the other hand, has been shown to reduce flooding (82% of 43 cases) (*59*). Bradshaw *et al.* (*173*) reported economic damages exceeding US$ 1 trillion associated with floods across 56 developing countries from 1990 to 2000 and these damages are only expected to grow in the future (*174*).

Water availability is also critical for closing agricultural yield gaps (*175*). While agriculture-driven deforestation significantly contributes to climate change, agriculture itself is profoundly affected by climate conditions and dependent on water availability (*176*). Despite this dependency, the global economy's response to climate-induced shifts in agriculture is projected to be modest, with an estimated average decrease of 0.34% in world GDP (*177*). However, the extent of these effects can vary widely at the country level (*177*, *178*). A study focused on the Southern Brazilian Amazon estimated that reducing deforestation could prevent up to US$ 1 billion in agricultural losses annually (*179*). While effective climate adaptation strategies may help alleviate these losses over time, the degree to which the agricultural sector can successfully adapt to changing climate conditions remains uncertain (*178*).

Forests also have economic implications that go beyond their effects on temperature and moisture regimes. These include their contribution to poverty alleviation (*180*) or the provisioning of timber and fibre products (*136*).

Conclusion

Forests are shaped by environmental conditions, but their presence also shapes the environment. In recent decades a considerable body of evidence has examined the impacts of forests on global carbon storage and climate mitigation (*3*, *5*). This has led to many initiatives to restore and protect the world's forests to aid climate mitigation. However, as the impacts of climate change are being felt more tangibly by populations on the ground, policy mechanisms are focusing increasingly on climate adaptation. Here we have summarized the emerging scientific understanding on how forests influence temperature and moisture regimes and what that means for human wellbeing.

This emerging understanding highlights the importance of protecting existing forests, particularly native old growth forests. Native old growth forests typically provide strong temperature buffering (*181*), reduce runoff less than other forest types (*59*, *74*), and largely exist in places where they have a beneficial impact in slowing global warming, such as the Amazon, Congo basin, and places in eastern Europe or the Malayan archipelago (Fig. 3A). Protection of existing forests costs less than afforestation, and, once gone, they take hundreds of years to regenerate. There is also a potential to capture additional carbon and increase local climate adaptation benefits by specific forest management and regeneration of existing forests (*3*). In addition to the temperature and moisture regulation and carbon storage examined in this review, native old growth forests can harbour large amounts of biodiversity and be spiritually and economically important.

In the case of reforestation and afforestation, goals and consequences must be considered carefully. Generally, diverse forests, as well as native species, are more effective at buffering local temperatures and use less water resources (*31*, *59*). Nonetheless, spatial considerations are important. The local temperature effect of trees enhances human wellbeing across most of the globe by buffering extreme temperatures (*15–18*). However, with respect to global warming, trees' albedo may offset the cooling achieved by carbon storage in some regions (*21*). In general, these negative effects happen in grasslands, deserts, or at high latitudes, whereas trees in most places that would naturally support forest cover have a net cooling effect on global temperatures (Fig. 3A).

By filtering water and soil, trees generally improve water quality (*125*, *182*). However, impacts relating to water quantity are highly variable. While tree cover can sometimes enhance local and downwind water availability (*92*, *144*), increased evapotranspiration and reduced runoff generally limit the amount of downstream water (*59*). This has the benefit of reducing flooding and landslides in wet regions (*59*, *183*, *184*), but can lead to water scarcity in dry regions (*145*). Careful evaluation of water resources and their use is thus necessary to ensure that the advantages of a forest do not come at the expense of water security downstream.

Forests shape their environment, with critical effects on human wellbeing. With a growing scientific consensus about the buffering effects of forests across the globe, the conservation of natural ecosystems represents a unique opportunity to enhance climate adaptation, particularly in rural regions where livelihoods and human wellbeing are most tangibly linked to the land.

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References and Notes

1. K.-H. Erb, T. Kastner, C. Plutzar, A. L. S. Bais, N. Carvalhais, T. Fetzel, S. Gingrich, H. Haberl, C. Lauk, M. Niedertscheider, J. Pongratz, M. Thurner, S. Luyssaert, Unexpectedly large impact of forest management and grazing on global vegetation biomass. *Nature* **553**, 73–76 (2018).

2. J.-F. Bastin, Y. Finegold, C. Garcia, D. Mollicone, M. Rezende, D. Routh, C. M. Zohner, T. W. Crowther, The global tree restoration potential. *Science* **365**, 76–79 (2019).

3. L. Mo, C. M. Zohner, P. B. Reich, J. Liang, S. de Miguel, G.-J. Nabuurs, S. S. Renner, J. van den Hoogen, A. Araza, M. Herold, L. Mirzagholi, H. Ma, C. Averill, O. L. Phillips, J. G. P. Gamarra, I. Hordijk, D. Routh, M. Abegg, Y. C. Adou Yao, G. Alberti, A. M. Almeyda Zambrano, B. V. Alvarado, E. Alvarez-Dávila, P. Alvarez-Loayza, L. F. Alves, I. Amaral, C. Ammer, C. Antón-Fernández, A. Araujo-Murakami, L. Arroyo, V. Avitabile, G. A. Aymard, T. R. Baker, R. Bałazy, O. Banki, J. G. Barroso, M. L. Bastian, J.-F. Bastin, L. Birigazzi, P. Birnbaum, R. Bitariho, P. Boeckx, F. Bongers, O. Bouriaud, P. H. S. Brancalion, S. Brandl, F. Q. Brearley, R. Brienen, E. N. Broadbent, H. Bruelheide, F. Bussotti, R. Cazzolla Gatti, R. G. César, G. Cesljar, R. L. Chazdon, H. Y. H. Chen, C. Chisholm, H. Cho, E. Cienciala, C. Clark, D. Clark, G. D. Colletta, D. A. Coomes, F. Cornejo Valverde, J. J. Corral-Rivas, P. M. Crim, J. R. Cumming, S. Dayanandan, A. L. de Gasper, M. Decuyper, G. Derroire, B. DeVries, I. Djordjevic, J. Dolezal, A. Dourdain, N. L. Engone Obiang, B. J. Enquist, T. J. Eyre, A. B. Fandohan, T. M. Fayle, T. R. Feldpausch, L. V. Ferreira, L. Finér, M. Fischer, C. Fletcher, L. Frizzera, D. Gianelle, H. B. Glick, D. J. Harris, A. Hector, A. Hemp, G. Hengeveld, B. Hérault, J. L. Herbohn, A. Hillers, E. N. Honorio Coronado, C. Hui, T. Ibanez, N. Imai, A. M. Jagodziński, B. Jaroszewicz, V. K. Johannsen, C. A. Joly, T. Jucker, I. Jung, V. Karminov, K. Kartawinata, E. Kearsley, D. Kenfack, D. K. Kennard, S. Kepfer-Rojas, G. Keppel, M. L. Khan, T. J. Killeen, H. S. Kim, K. Kitayama, M. Köhl, H. Korjus, F. Kraxner, D. Kucher, D. Laarmann, M. Lang, H. Lu, N. V. Lukina, B. S. Maitner, Y. Malhi, E. Marcon, B. S. Marimon, B. H. Marimon-Junior, A. R. Marshall, E. H. Martin, J. A. Meave, O. Melo-Cruz, C. Mendoza, I. Mendoza-Polo, S. Miscicki, C. Merow, A. Monteagudo Mendoza, V. S. Moreno, S. A. Mukul, P. Mundhenk, M. G. Nava-Miranda, D. Neill, V. J. Neldner, R. V. Nevenic, M. R. Ngugi, P. A. Niklaus, J. Oleksyn, P. Ontikov, E. Ortiz-Malavasi, Y. Pan, A. Paquette, A. Parada-Gutierrez, E. I. Parfenova, M. Park, M. Parren, N. Parthasarathy, P. L. Peri, S. Pfautsch, N. Picard, M. T. F. Piedade, D. Piotto, N. C. A. Pitman, A. D. Poulsen, J. R. Poulsen, H. Pretzsch, F. Ramirez Arevalo, Z. Restrepo-Correa, M. Rodeghiero, S. G. Rolim, A. Roopsind, F. Rovero, E. Rutishauser, P. Saikia, C. Salas-Eljatib, P. Saner, P. Schall, M.-J. Schelhaas, D. Schepaschenko, M. Scherer-Lorenzen, B. Schmid, J. Schöngart, E. B. Searle, V. Seben, J. M. Serra-Diaz, D. Sheil, A. Z. Shvidenko, J. E. Silva-Espejo, M. Silveira, J. Singh, P. Sist, F. Slik, B. Sonké, A. F. Souza, K. J. Stereńczak, J.-C. Svenning, M. Svoboda, B. Swanepoel, N. Targhetta, N. Tchebakova, H. ter Steege, R. Thomas, E. Tikhonova, P. M. Umunay, V. A. Usoltsev, R. Valencia, F. Valladares, F. van der Plas, T. Van Do, M. E. van Nuland, R. M. Vasquez, H. Verbeeck, H. Viana, A. C. Vibrans, S. Vieira, K. von Gadow, H.-F. Wang, J. V. Watson, G. D. A. Werner, S. K. Wiser, F. Wittmann, H. Woell, V. Wortel, R. Zagt, T. Zawiła-Niedźwiecki, C. Zhang, X. Zhao, M. Zhou, Z.-X. Zhu, I. C. Zo-Bi, G. D. Gann, T. W. Crowther, Integrated global assessment of the natural forest carbon potential. *Nature* **624**, 92–101 (2023).

4. W. S. Walker, S. R. Gorelik, S. C. Cook-Patton, A. Baccini, M. K. Farina, K. K. Solvik, P. W. Ellis, J. Sanderman, R. A. Houghton, S. M. Leavitt, C. R. Schwalm, B. W. Griscom, The global potential for increased storage of carbon on land. *Proceedings of the National Academy of Sciences* **119**, e2111312119 (2022).

5. P. Friedlingstein, M. O'Sullivan, M. W. Jones, R. M. Andrew, L. Gregor, J. Hauck, C. Le Quéré, I. T. Luijkx, A. Olsen, G. P. Peters, W. Peters, J. Pongratz, C. Schwingshackl, S. Sitch, J. G. Canadell, P. Ciais, R. B. Jackson, S. R. Alin, R. Alkama, A. Arneth, V. K. Arora, N. R. Bates, M. Becker, N. Bellouin, H. C. Bittig, L. Bopp, F. Chevallier, L. P. Chini, M. Cronin, W. Evans, S. Falk, R. A. Feely, T. Gasser, M. Gehlen, T. Gkritzalis, L. Gloege, G. Grassi, N. Gruber, Ö. Gürses, I. Harris, M. Hefner, R. A. Houghton, G. C. Hurtt, Y. Iida, T. Ilyina, A. K. Jain, A. Jersild, K. Kadono, E. Kato, D. Kennedy, K. Klein Goldewijk, J. Knauer, J. I. Korsbakken, P. Landschützer, N. Lefèvre, K. Lindsay, J. Liu, Z. Liu, G. Marland, N. Mayot, M. J. McGrath, N. Metzl, N. M. Monacci, D. R. Munro, S.-I. Nakaoka, Y. Niwa, K. O'Brien, T. Ono, P. I. Palmer, N. Pan, D. Pierrot, K. Pocock, B. Poulter, L. Resplandy, E. Robertson, C. Rödenbeck, C. Rodriguez, T. M. Rosan, J. Schwinger, R. Séférian, J. D. Shutler, I. Skjelvan, T. Steinhoff, Q. Sun, A. J. Sutton, C. Sweeney, S. Takao, T. Tanhua, P. P. Tans, X. Tian, H. Tian, B. Tilbrook, H. Tsujino, F. Tubiello, G. R. van der Werf, A. P. Walker, R. Wanninkhof, C. Whitehead, A. Willstrand Wranne, R. Wright, W. Yuan, C. Yue, X. Yue, S. Zaehle, J. Zeng, B. Zheng, Global Carbon Budget 2022. *Earth System Science Data* **14**, 4811–4900 (2022).

6. D. Ellison, C. E. Morris, B. Locatelli, D. Sheil, J. Cohen, D. Murdiyarso, V. Gutierrez, M. van Noordwijk, I. F. Creed, J. Pokorny, D. Gaveau, D. V. Spracklen, A. B. Tobella, U. Ilstedt, A. J. Teuling, S. G. Gebrehiwot, D. C. Sands, B. Muys, B. Verbist, E. Springgay, Y. Sugandi, C. A. Sullivan, Trees, forests and water: Cool insights for a hot world. *Global Environmental Change* **43**, 51–61 (2017).

7. M. Romanello, C. di Napoli, C. Green, H. Kennard, P. Lampard, D. Scamman, M. Walawender, Z. Ali, N. Ameli, S. Ayeb-Karlsson, P. J. Beggs, K. Belesova, L. B. Ford, K. Bowen, W. Cai, M. Callaghan, D. Campbell-Lendrum, J. Chambers, T. J. Cross, K. R. van Daalen, C. Dalin, N. Dasandi, S. Dasgupta, M. Davies, P. Dominguez-Salas, R. Dubrow, K. L. Ebi, M. Eckelman, P. Ekins, C. Freyberg, O. Gasparyan, G. Gordon-Strachan, H. Graham, S. H. Gunther, I. Hamilton, Y. Hang, R. Hänninen, S. Hartinger, K. He, J. Heidecke, J. J. Hess, S.-C. Hsu, L. Jamart, S. Jankin, O. Jay, I. Kelman, G. Kiesewetter, P. Kinney, D. Kniveton, R. Kouznetsov, F. Larosa, J. K. W. Lee, B. Lemke, Y. Liu, Z. Liu, M. Lott, M. L. Batista, R. Lowe, M. O. Sewe, J. Martinez-Urtaza, M. Maslin, L. McAllister, C. McMichael, Z. Mi, J. Milner, K. Minor, J. C. Minx, N. Mohajeri, N. C. Momen, M. Moradi-Lakeh, K. Morrissey, S. Munzert, K. A. Murray, T. Neville, M. Nilsson, N. Obradovich, M. B. O'Hare, C. Oliveira, T. Oreszczyn, M. Otto, F. Owfi, O. Pearman, F. Pega, A. Pershing, M. Rabbaniha, J. Rickman, E. J. Z. Robinson, J. Rocklöv, R. N. Salas, J. C. Semenza, J. D. Sherman, J. Shumake-Guillemot, G. Silbert, M. Sofiev, M. Springmann, J. D. Stowell, M. Tabatabaei, J. Taylor, R. Thompson, C. Tonne, M. Treskova, J. A. Trinanes, F. Wagner, L. Warnecke, H. Whitcombe, M. Winning, A. Wyns, M. Yglesias-González, S. Zhang, Y. Zhang, Q. Zhu, P. Gong, H. Montgomery, A. Costello, The 2023 report of the Lancet Countdown on health and climate change: the imperative for a health-centred response in a world facing irreversible harms. *The Lancet* **402**, 2346–2394 (2023).

8. D. J. Mildrexler, M. Zhao, S. W. Running, A global comparison between station air temperatures and MODIS land surface temperatures reveals the cooling role of forests. *J. Geophys. Res.* **116**, G03025 (2011).

9. L. Gillerot, D. Landuyt, R. Oh, W. Chow, D. Haluza, Q. Ponette, H. Jactel, H. Bruelheide, B. Jaroszewicz, M. Scherer-Lorenzen, P. De Frenne, B. Muys, K. Verheyen, Forest structure and composition alleviate human thermal stress. *Global Change Biology* **28**, 7340–7352 (2022).

10. L. R. V. Zeppetello, S. C. Cook-Patton, L. A. Parsons, N. H. Wolff, T. Kroeger, D. S. Battisti, J. Bettles, J. T. Spector, A. Balakumar, Y. J. Masuda, Consistent cooling benefits of silvopasture in the tropics. *Nat Commun* **13**, 708 (2022).

11. G. Bala, K. Caldeira, M. Wickett, T. J. Phillips, D. B. Lobell, C. Delire, A. Mirin, Combined climate and carbon-cycle effects of large-scale deforestation. *Proceedings of the National Academy of Sciences* **104**, 6550–6555 (2007).

12. R. A. Betts, Offset of the potential carbon sink from boreal forestation by decreases in surface albedo. *Nature* **408**, 187–190 (2000).

13. R. A. Betts, P. D. Falloon, K. K. Goldewijk, N. Ramankutty, Biogeophysical effects of land use on climate: Model simulations of radiative forcing and large-scale temperature change. *Agricultural and Forest Meteorology* **142**, 216–233 (2007).

14. E. L. Davin, N. de Noblet-Ducoudré, Climatic Impact of Global-Scale Deforestation: Radiative versus Nonradiative Processes. *Journal of Climate* **23**, 97–112 (2010).

15. Y. Li, M. Zhao, S. Motesharrei, Q. Mu, E. Kalnay, S. Li, Local cooling and warming effects of forests based on satellite observations. *Nat Commun* **6**, 6603 (2015).

16. P. De Frenne, F. Zellweger, F. Rodríguez-Sánchez, B. R. Scheffers, K. Hylander, M. Luoto, M. Vellend, K. Verheyen, J. Lenoir, Global buffering of temperatures under forest canopies. *Nat Ecol Evol* **3**, 744–749 (2019).

17. R. Alkama, A. Cescatti, Biophysical climate impacts of recent changes in global forest cover. *Science* **351**, 600–604 (2016).

18. P. De Frenne, J. Lenoir, M. Luoto, B. R. Scheffers, F. Zellweger, J. Aalto, M. B. Ashcroft, D. M. Christiansen, G. Decocq, K. De Pauw, S. Govaert, C. Greiser, E. Gril, A. Hampe, T. Jucker, D. H. Klinges, I. A. Koelemeijer, J. J. Lembrechts, R. Marrec, C. Meeussen, J. Ogée, V. Tyystjärvi, P. Vangansbeke, K. Hylander, Forest microclimates and climate change: Importance, drivers and future research agenda. *Glob Change Biol* **27**, 2279–2297 (2021).

19. D. G. Miralles, J. H. Gash, T. R. H. Holmes, R. A. M. de Jeu, A. J. Dolman, Global canopy interception from satellite observations. *Journal of Geophysical Research: Atmospheres* **115** (2010).

20. F. Zhong, S. Jiang, A. I. J. M. van Dijk, L. Ren, J. Schellekens, D. G. Miralles, Revisiting large-scale interception patterns constrained by a synthesis of global experimental data. *Hydrology and Earth System Sciences* **26**, 5647–5667 (2022).

21. N. Hasler, C. A. Williams, V. C. Denney, P. W. Ellis, S. Shrestha, D. E. Terasaki Hart, N. H. Wolff, S. Yeo, T. W. Crowther, L. K. Werden, S. C. Cook-Patton, Accounting for albedo change to identify climate-positive tree cover restoration. *Nat Commun* **15**, 2275 (2024).

22. R. McDonald, T. Kroeger, T. Boucher, W. L. Wang LongZhu, R. Salem, Planting healthy air: a global analysis of the role of urban trees in addressing particulate matter pollution and extreme heat. (2016).

23. J. Kim, A. Khouakhi, R. Corstanje, A. S. A. Johnston, Greater local cooling effects of trees across globally distributed urban green spaces. *Science of The Total Environment* **911**, 168494 (2024).

24. Y. Su, L. Liu, J. Liao, J. Wu, P. Ciais, J. Liao, X. He, X. Liu, X. Chen, W. Yuan, G. Zhou, R. Lafortezza, Phenology acts as a primary control of urban vegetation cooling and warming: A synthetic analysis of global site observations. *Agricultural and Forest Meteorology* **280**, 107765 (2020).

25. R. Geiger, R. H. Aron, P. Todhunter, *The Climate near the Ground* (Rowman & Littlefield Pub. Group, Lanham, Md., 7th ed., 2009; http://bvbr.bib-bvb.de:8991/F?func=service&doc_library=BVB01&doc_number=017306392&line_number=0001&func_code=DB_RECORDS&service_type=MEDIA).

26. J. Chen, S. C. Saunders, T. R. Crow, R. J. Naiman, K. D. Brosofske, G. D. Mroz, B. L. Brookshire, J. F. Franklin, Microclimate in Forest Ecosystem and Landscape Ecology: Variations in local climate can be used to monitor and compare the effects of different management regimes. *BioScience* **49**, 288–297 (1999).

27. F. Zellweger, D. Coomes, J. Lenoir, L. Depauw, S. L. Maes, M. Wulf, K. J. Kirby, J. Brunet, M. Kopecký, F. Máliš, W. Schmidt, S. Heinrichs, J. den Ouden, B. Jaroszewicz, G. Buyse, F. Spicher, K. Verheyen, P. De Frenne, Seasonal drivers of understorey temperature buffering in temperate deciduous forests across Europe. *Global Ecology and Biogeography* **28**, 1774–1786 (2019).

28. M. A. Rahman, L. M. F. Stratopoulos, A. Moser-Reischl, T. Zölch, K.-H. Häberle, T. Rötzer, H. Pretzsch, S. Pauleit, Traits of trees for cooling urban heat islands: A meta-analysis. *Building and Environment* **170**, 106606 (2020).

29. Z. Ren, H. Zhao, Y. Fu, L. Xiao, Y. Dong, Effects of urban street trees on human thermal comfort and physiological indices: a case study in Changchun city, China. *J. For. Res.* **33**, 911–922 (2022).

30. N. H. Wong, C. L. Tan, D. D. Kolokotsa, H. Takebayashi, Greenery as a mitigation and adaptation strategy to urban heat. *Nat Rev Earth Environ* **2**, 166–181 (2021).

31. S. Zhang, D. Landuyt, K. Verheyen, P. De Frenne, Tree species mixing can amplify microclimate offsets in young forest plantations. *Journal of Applied Ecology* **59**, 1428–1439 (2022).

32. G. B. Bonan, Forests and Climate Change: Forcings, Feedbacks, and the Climate Benefits of Forests. *Science* **320**, 1444–1449 (2008).

33. C. Greiser, L. Hederová, G. Vico, J. Wild, M. Macek, M. Kopecký, Higher soil moisture increases microclimate temperature buffering in temperate broadleaf forests. *Agricultural and Forest Meteorology* **345**, 109828 (2024).

34. C. A. Williams, H. Gu, T. Jiao, Climate impacts of U.S. forest loss span net warming to net cooling. *Science Advances* **7**, eaax8859 (2021).

35. N. L. Harris, D. A. Gibbs, A. Baccini, R. A. Birdsey, S. de Bruin, M. Farina, L. Fatoyinbo, M. C. Hansen, M. Herold, R. A. Houghton, P. V. Potapov, D. R. Suarez, R. M. Roman-Cuesta, S. S. Saatchi, C. M. Slay, S. A. Turubanova, A. Tyukavina, Global maps of twenty-first century forest carbon fluxes. *Nat. Clim. Chang.* **11**, 234–240 (2021).

36. D. Lawrence, M. Coe, W. Walker, L. Verchot, K. Vandecar, The Unseen Effects of Deforestation: Biophysical Effects on Climate. *Front. For. Glob. Change* **5** (2022).

37. Y. Li, W. Bao, F. Bongers, B. Chen, G. Chen, K. Guo, M. Jiang, J. Lai, D. Lin, C. Liu, X. Liu, Y. Liu, X. Mi, X. Tian, X. Wang, W. Xu, J. Yan, B. Yang, Y. Zheng, K. Ma, Drivers of tree carbon storage in subtropical forests. *Science of The Total Environment* **654**, 684–693 (2019).

38. Z. Zhu, S. Piao, R. B. Myneni, M. Huang, Z. Zeng, J. G. Canadell, P. Ciais, S. Sitch, P. Friedlingstein, A. Arneth, C. Cao, L. Cheng, E. Kato, C. Koven, Y. Li, X. Lian, Y. Liu, R. Liu, J. Mao, Y. Pan, S. Peng, J. Peñuelas, B. Poulter, T. A. M. Pugh, B. D. Stocker, N. Viovy, X. Wang, Y. Wang, Z. Xiao, H. Yang, S. Zaehle, N. Zeng, Greening of the Earth and its drivers. *Nature Clim Change* **6**, 791–795 (2016).

39. I. Aleixo, D. Norris, L. Hemerik, A. Barbosa, E. Prata, F. Costa, L. Poorter, Amazonian rainforest tree mortality driven by climate and functional traits. *Nat. Clim. Chang.* **9**, 384–388 (2019).

40. R. M. Bright, K. Zhao, R. B. Jackson, F. Cherubini, Quantifying surface albedo and other direct biogeophysical climate forcings of forestry activities. *Global Change Biology* **21**, 3246–3266 (2015).

41. T. Jiao, C. A. Williams, B. Ghimire, J. Masek, F. Gao, C. Schaaf, Global climate forcing from albedo change caused by large-scale deforestation and reforestation: quantification and attribution of geographic variation. *Climatic Change* **142**, 463–476 (2017).

42. V. Brovkin, S. Sitch, W. Von Bloh, M. Claussen, E. Bauer, W. Cramer, Role of land cover changes for atmospheric CO2 increase and climate change during the last 150 years. *Global Change Biology* **10**, 1253–1266 (2004).

43. J. Winckler, Q. Lejeune, C. H. Reick, J. Pongratz, Nonlocal Effects Dominate the Global Mean Surface Temperature Response to the Biogeophysical Effects of Deforestation. *Geophysical Research Letters* **46**, 745–755 (2019).

44. A. Donohoe, D. S. Battisti, Atmospheric and Surface Contributions to Planetary Albedo. *Journal of Climate* **24**, 4402–4418 (2011).

45. M. M. Laguë, G. B. Bonan, A. L. S. Swann, Separating the Impact of Individual Land Surface Properties on the Terrestrial Surface Energy Budget in both the Coupled and Uncoupled Land–Atmosphere System. *Journal of Climate* **32**, 5725–5744 (2019).

46. J. Wang, F. J. F. Chagnon, E. R. Williams, A. K. Betts, N. O. Renno, L. A. T. Machado, G. Bisht, R. Knox, R. L. Bras, Impact of deforestation in the Amazon basin on cloud climatology. *Proc. Natl. Acad. Sci. U.S.A.* **106**, 3670–3674 (2009).

47. G. Duveiller, F. Filipponi, A. Ceglar, J. Bojanowski, R. Alkama, A. Cescatti, Revealing the widespread potential of forests to increase low level cloud cover. *Nat Commun* **12**, 4337 (2021).

48. J. Weber, J. A. King, N. L. Abraham, D. P. Grosvenor, C. J. Smith, Y. M. Shin, P. Lawrence, S. Roe, D. J. Beerling, M. V. Martin, Chemistry-albedo feedbacks offset up to a third of forestation's CO2 removal benefits. *Science* **383**, 860–864 (2024).

49. J. Schellekens, L. A. Bruijnzeel, F. N. Scatena, N. J. Bink, F. Holwerda, Evaporation from a tropical rain forest, Luquillo Experimental Forest, eastern Puerto Rico. *Water Resources Research* **36**, 2183–2196 (2000).

50. D. F. Levia, E. E. Frost, Variability of throughfall volume and solute inputs in wooded ecosystems. *Progress in Physical Geography: Earth and Environment* **30**, 605–632 (2006).

51. K. Yue, P. De Frenne, D. A. Fornara, K. Van Meerbeek, W. Li, X. Peng, X. Ni, Y. Peng, F. Wu, Y. Yang, J. Peñuelas, Global patterns and drivers of rainfall partitioning by trees and shrubs. *Global Change Biology* **27**, 3350–3357 (2021).

52. A. M. J. Gerrits, H. H. G. Savenije, "Forest Floor Interception" in *Forest Hydrology and Biogeochemistry: Synthesis of Past Research and Future Directions*, D. F. Levia, D. Carlyle-Moses, T. Tanaka, Eds. (Springer Netherlands, Dordrecht, 2011; https://doi.org/10.1007/978-94-007-1363-5_22), pp. 445–454.

53. M. G. Floriancic, S. T. Allen, R. Meier, L. Truniger, J. W. Kirchner, P. Molnar, Potential for significant precipitation cycling by forest-floor litter and deadwood. *Ecohydrology* **16**, e2493 (2023).

54. A. Berland, S. A. Shiflett, W. D. Shuster, A. S. Garmestani, H. C. Goddard, D. L. Herrmann, M. E. Hopton, The role of trees in urban stormwater management. *Landscape and Urban Planning* **162**, 167–177 (2017).

55. U. Ilstedt, A. Malmer, E. Verbeeten, D. Murdiyarso, The effect of afforestation on water infiltration in the tropics: A systematic review and meta-analysis. *Forest Ecology and Management* **251**, 45–51 (2007).

56. D. Qiu, R. Xu, C. Wu, X. Mu, G. Zhao, P. Gao, Effects of vegetation restoration on soil infiltrability and preferential flow in hilly gully areas of the Loess Plateau, China. *CATENA* **221**, 106770 (2023).

57. J. Bartens, S. D. Day, J. R. Harris, J. E. Dove, T. M. Wynn, Can Urban Tree Roots Improve Infiltration through Compacted Subsoils for Stormwater Management? *Journal of Environmental Quality* **37**, 2048–2057 (2008).

58. M. Zhang, X. Wei, Deforestation, forestation, and water supply. *Science* **371**, 990–991 (2021).

59. S. Filoso, M. O. Bezerra, K. C. B. Weiss, M. A. Palmer, Impacts of forest restoration on water yield: A systematic review. *PLOS ONE* **12**, e0183210 (2017).

60. X. Feng, B. Fu, S. Piao, S. Wang, P. Ciais, Z. Zeng, Y. Lü, Y. Zeng, Y. Li, X. Jiang, B. Wu, Revegetation in China's Loess Plateau is approaching sustainable water resource limits. *Nature Clim Change* **6**, 1019–1022 (2016).

61. P. De Frenne, Novel light regimes in European forests. *Nat Ecol Evol* **8**, 196–202 (2024).

62. A. Muscolo, S. Bagnato, M. Sidari, R. Mercurio, A review of the roles of forest canopy gaps. *Journal of Forestry Research* **25**, 725–736 (2014).

63. M. S. Johnson, J. Lehmann, Double-funneling of trees: Stemflow and root-induced preferential flow. *Écoscience* **13**, 324–333 (2006).

64. A. J. Guswa, Canopy vs. Roots: Production and Destruction of Variability in Soil Moisture and Hydrologic Fluxes. *Vadose Zone Journal* **11**, vzj2011.0159 (2012).

65. J. D. Schade, S. E. Hobbie, Spatial and temporal variation in islands of fertility in the Sonoran Desert. *Biogeochemistry* **73**, 541–553 (2005).

66. S. Li, W. Chen, Z. Li, L. Bu, Z. Jin, G. Wei, Z. Li, Fertile islands lead to more conspicuous spatial heterogeneity of bacteria than soil physicochemical properties in a desert ecosystem. *CATENA* **206**, 105526 (2021).

67. J. Ding, D. J. Eldridge, The fertile island effect varies with aridity and plant patch type across an extensive continental gradient. *Plant Soil* **459**, 173–183 (2021).

68. C. Tölgyesi, P. Török, A. A. Hábenczyus, Z. Bátori, O. Valkó, B. Deák, B. Tóthmérész, L. Erdős, A. Kelemen, Underground deserts below fertility islands? Woody species desiccate lower soil layers in sandy drylands. *Ecography* **43**, 848–859 (2020).

69. R. B. Jackson, S. R. Carpenter, C. N. Dahm, D. M. McKnight, R. J. Naiman, S. L. Postel, S. W. Running, Water in a Changing World. *Ecological Applications* **11**, 1027–1045 (2001).

70. N. G. McDowell, C. D. Allen, K. Anderson-Teixeira, B. H. Aukema, B. Bond-Lamberty, L. Chini, J. S. Clark, M. Dietze, C. Grossiord, A. Hanbury-Brown, G. C. Hurtt, R. B. Jackson, D. J. Johnson, L. Kueppers, J. W. Lichstein, K. Ogle, B. Poulter, T. A. M. Pugh, R. Seidl, M. G. Turner, M. Uriarte, A. P. Walker, C. Xu, Pervasive shifts in forest dynamics in a changing world. *Science* **368**, eaaz9463 (2020).

71. D. V. Spracklen, L. Garcia-Carreras, The impact of Amazonian deforestation on Amazon basin rainfall. *Geophysical Research Letters* **42**, 9546–9552 (2015).

72. M. C. Hansen, P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, J. R. G. Townshend, High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science* **342**, 850–853 (2013).

73. J. Jones, D. Ellison, S. Ferraz, A. Lara, X. Wei, Z. Zhang, Forest restoration and hydrology. *Forest Ecology and Management* **520**, 120342 (2022).

74. K. A. Farley, E. G. Jobbágy, R. B. Jackson, Effects of afforestation on water yield: a global synthesis with implications for policy. *Global Change Biology* **11**, 1565–1576 (2005).

75. R. B. Jackson, E. G. Jobbágy, R. Avissar, S. B. Roy, D. J. Barrett, C. W. Cook, K. A. Farley, D. C. le Maitre, B. A. McCarl, B. C. Murray, Trading Water for Carbon with Biological Carbon Sequestration. *Science* **310**, 1944–1947 (2005).

76. A. Iroumé, J. Jones, J. C. Bathurst, Forest operations, tree species composition and decline in rainfall explain runoff changes in the Nacimiento experimental catchments, south central Chile. *Hydrological Processes* **35**, e14257 (2021).

77. A. Lara, J. Jones, C. Little, N. Vergara, Streamflow response to native forest restoration in former Eucalyptus plantations in south central Chile. *Hydrological Processes* **35**, e14270 (2021).

78. S. F. de B. Ferraz, C. B. Rodrigues, L. G. Garcia, C. A. Alvares, W. de P. Lima, Effects of *Eucalyptus* plantations on streamflow in Brazil: Moving beyond the water use debate. *Forest Ecology and Management* **453**, 117571 (2019).

79. L. Silveira, P. Gamazo, J. Alonso, L. Martínez, Effects of afforestation on groundwater recharge and water budgets in the western region of Uruguay. *Hydrological Processes* **30**, 3596–3608 (2016).

80. J. A. Slingsby, A. de Buys, A. D. A. Simmers, E. Prinsloo, G. G. Forsyth, J. Glenday, N. Allsopp, Jonkershoek: Africa's oldest catchment experiment - 80 years and counting. *Hydrological Processes* **35**, e14101 (2021).

81. Y. Li, S. Piao, L. Z. X. Li, A. Chen, X. Wang, P. Ciais, L. Huang, X. Lian, S. Peng, Z. Zeng, K. Wang, L. Zhou, Divergent hydrological response to large-scale afforestation and vegetation greening in China. *Science Advances* **4**, eaar4182 (2018).

82. J. A. Jones, D. A. Post, Seasonal and successional streamflow response to forest cutting and regrowth in the northwest and eastern United States. *Water Resources Research* **40** (2004).

83. Z. Yu, S. Liu, J. Wang, X. Wei, J. Schuler, P. Sun, R. Harper, N. Zegre, Natural forests exhibit higher carbon sequestration and lower water consumption than planted forests in China. *Global Change Biology* **25**, 68–77 (2019).

84. M.D. Farinacci, J. A. Jones, L. C. A. Silva, Carbon-Water Tradeoffs in Old-Growth and Young Forests of the Pacific Northwest. *AGU Advances* (In Press).

85. T. D. Perry, J. A. Jones, Summer streamflow deficits from regenerating Douglas-fir forest in the Pacific Northwest, USA. *Ecohydrology* **10**, e1790 (2017).

86. C. Segura, K. D. Bladon, J. A. Hatten, J. A. Jones, V. C. Hale, G. G. Ice, Long-term effects of forest harvesting on summer low flow deficits in the Coast Range of Oregon. *Journal of Hydrology* **585**, 124749 (2020).

87. V. Bonnesoeur, B. Locatelli, M. R. Guariguata, B. F. Ochoa-Tocachi, V. Vanacker, Z. Mao, A. Stokes, S.-L. Mathez-Stiefel, Impacts of forests and forestation on hydrological services in the Andes: A systematic review. *Forest Ecology and Management* **433**, 569–584 (2019).

88. P. Lehmann, J. von Ruette, D. Or, Deforestation Effects on Rainfall-Induced Shallow Landslides: Remote Sensing and Physically-Based Modelling. *Water Resources Research* **55**, 9962–9976 (2019).

89. B. C. Wemple, F. J. Swanson, J. A. Jones, Forest roads and geomorphic process interactions, Cascade Range, Oregon. *Earth Surface Processes and Landforms* **26**, 191–204 (2001).

90. F. J. Swanson, C. T. Dyrness, Impact of clear-cutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon. *Geology* **3**, 393–396 (1975).

91. E. M. A. Strain, T. Kompas, A. Boxshall, J. Kelvin, S. Swearer, R. L. Morris, Assessing the coastal protection services of natural mangrove forests and artificial rock revetments. *Ecosystem Services* **55**, 101429 (2022).

92. I. F. Creed, J. A. Jones, E. Archer, M. Claassen, D. Ellison, S. G. McNulty, M. van Noordwijk, B. Vira, X. Wei, K. Bishop, J. A. Blanco, M. Gush, D. Gyawali, E. Jobbágy, A. Lara, C. Little, J. Martin-Ortega, A. Mukherji, D. Murdiyarso, P. O. Pol, C. A. Sullivan, J. Xu, Managing Forests for Both Downstream and Downwind Water. *Front. For. Glob. Change* **2** (2019).

93. R. J. Van Der Ent, “A new view on the hydrological cycle over continents,” thesis, Delft University of Technology (2014).

94. A. J. Hoek van Dijke, M. Herold, K. Mallick, I. Benedict, M. Machwitz, M. Schlerf, A. Pranindita, J. J. E. Theeuwen, J.-F. Bastin, A. J. Teuling, Shifts in regional water availability due to global tree restoration. *Nat. Geosci.* **15**, 363–368 (2022).

95. J. Cui, X. Lian, C. Huntingford, L. Gimeno, T. Wang, J. Ding, M. He, H. Xu, A. Chen, P. Gentine, S. Piao, Global water availability boosted by vegetation-driven changes in atmospheric moisture transport. *Nat. Geosci.* **15**, 982–988 (2022).

96. D. L. Schumacher, J. Keune, P. Dirmeyer, D. G. Miralles, Drought self-propagation in drylands due to land–atmosphere feedbacks. *Nat. Geosci.* **15**, 262–268 (2022).

97. Q. Zhao, Y. Guo, T. Ye, A. Gasparrini, S. Tong, A. Overcenco, A. Urban, A. Schneider, A. Entezari, A. M. Vicedo-Cabrera, A. Zanobetti, A. Analitis, A. Zeka, A. Tobias, B. Nunes, B. Alahmad, B. Armstrong, B. Forsberg, S.-C. Pan, C. Íñiguez, C. Ameling, C. De La Cruz

Valencia, C. Åström, D. Houthuijs, D. V. Dung, D. Royé, E. Indermitte, E. Lavigne, F. Mayvaneh, F. Acquaotta, F. de'Donato, F. Di Ruscio, F. Sera, G. Carrasco-Escobar, H. Kan, H. Orru, H. Kim, I.-H. Holobaca, J. Kyselý, J. Madureira, J. Schwartz, J. J. K. Jaakkola, K. Katsouyanni, M. Hurtado Diaz, M. S. Ragettli, M. Hashizume, M. Pascal, M. De Sousa Zanotti Stagliorio Coélho, N. Valdés Ortega, N. Ryti, N. Scovronick, P. Michelozzi, P. Matus Correa, P. Goodman, P. H. Nascimento Saldiva, R. Abrutzky, S. Osorio, S. Rao, S. Fratianni, T. N. Dang, V. Colistro, V. Huber, W. Lee, X. Seposo, Y. Honda, Y. L. Guo, M. L. Bell, S. Li, Global, regional, and national burden of mortality associated with non-optimal ambient temperatures from 2000 to 2019: a three-stage modelling study. *The Lancet Planetary Health* **5**, e415–e425 (2021).

98. T. Carleton, A. Jina, M. Delgado, M. Greenstone, T. Houser, S. Hsiang, A. Hultgren, R. E. Kopp, K. E. Mccusker, I. Nath, J. Rising, A. Rode, H. K. Seo, A. Viaene, J. Yuan, A. T. Zhang, Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits. *THE QUARTERLY JOURNAL OF ECONOMICS*.

99. C. Lesk, P. Rowhani, N. Ramankutty, Influence of extreme weather disasters on global crop production. *Nature* **529**, 84–87 (2016).

100. World Food Programme, "Pakistan - Flood Impact Assessment" (2010); https://documents.wfp.org/stellent/groups/public/documents/ena/wfp225987.pdf.

101. K. Wonsik, I. Toshichika, H. Nanae, T. Masahiro, H. Yukiko, Flood impacts on global crop production: advances and limitations. *Environmental Research Letters* **18** (2023).

102. G. C. Nelson, J. Vanos, G. Havenith, O. Jay, K. L. Ebi, R. J. Hijmans, Global reductions in manual agricultural work capacity due to climate change. *Global Change Biology* **30**, e17142 (2024).

103. N. S. Diffenbaugh, M. Burke, Global warming has increased global economic inequality. *Proceedings of the National Academy of Sciences* **116**, 9808–9813 (2019).

104. Christpopher W. Callahan, Justin S. Mankin, Globally unequal effect of extreme heat on economic growth. *Science Advances* **8** (2022).

105. L. R. V. Zeppetello, L. A. Parsons, J. T. Spector, R. L. Naylor, D. S. Battisti, Y. J. Masuda, N. H. Wolff, Large scale tropical deforestation drives extreme warming. *Environ. Res. Lett.* **15**, 084012 (2020).

106. A. S. Cohn, N. Bhattarai, J. Campolo, O. Crompton, D. Dralle, J. Duncan, S. Thompson, Forest loss in Brazil increases maximum temperatures within 50 km. *Environ. Res. Lett.* **14**, 084047 (2019).

107. N. Gaoua, S. Racinais, J. Grantham, F. El Massioui, Alterations in cognitive performance during passive hyperthermia are task dependent. *International Journal of Hyperthermia* **27**, 1–9 (2011).

108. J. T. Spector, Y. J. Masuda, N. H. Wolff, M. Calkins, N. Seixas, Heat Exposure and Occupational Injuries: Review of the Literature and Implications. *Curr Envir Health Rpt* **6**, 286–296 (2019).

109. Y. J. Masuda, T. Garg, I. Anggraeni, N. H. Wolff, K. Ebi, E. T. Game, J. Krenz, J. T. Spector, Heat exposure from tropical deforestation decreases cognitive performance of rural workers: an experimental study. *Environ. Res. Lett.* **15**, 124015 (2020).

110. Y. J. Masuda, T. Garg, I. Anggraeni, K. Ebi, J. Krenz, E. T. Game, N. H. Wolff, J. T. Spector, Warming from tropical deforestation reduces worker productivity in rural communities. *Nat Commun* **12**, 1601 (2021).

111. Y. J. Masuda, L. A. Parsons, J. T. Spector, D. S. Battisti, B. Castro, J. T. Erbaugh, E. T. Game, T. Garg, P. Kalmus, T. Kroeger, V. Mishra, D. Shindell, M. Tigchelaar, N. H. Wolff, L. R. Vargas Zeppetello, Impacts of warming on outdoor worker well-being in the tropics and adaptation options. *One Earth* **7**, 382–400 (2024).

112. K. L. Ebi, J. Vanos, J. W. Baldwin, J. E. Bell, D. M. Hondula, N. A. Errett, K. Hayes, C. E. Reid, S. Saha, J. Spector, P. Berry, Extreme Weather and Climate Change: Population Health and Health System Implications. *Annual Review of Public Health* **42**, 293–315 (2021).

113. L. Gillerot, D. Landuyt, P. De Frenne, B. Muys, K. Verheyen, Urban tree canopies drive human heat stress mitigation. *Urban Forestry & Urban Greening* **92**, 128192 (2024).

114. L. A. Parsons, J. Jung, Y. J. Masuda, L. R. Vargas Zeppetello, N. H. Wolff, T. Kroeger, D. S. Battisti, J. T. Spector, Tropical deforestation accelerates local warming and loss of safe outdoor working hours. *One Earth* **4**, 1730–1740 (2021).

115. N. H. Wolff, L. R. V. Zeppetello, L. A. Parsons, I. Aggraeni, D. S. Battisti, K. L. Ebi, E. T. Game, T. Kroeger, Y. J. Masuda, J. T. Spector, The effect of deforestation and climate change on all-cause mortality and unsafe work conditions due to heat exposure in Berau, Indonesia: a modelling study. *The Lancet Planetary Health* **5**, e882–e892 (2021).

116. T. He, Y. Hu, A. Guo, Y. Chen, J. Yang, M. Li, M. Zhang, Quantifying the impact of urban trees on land surface temperature in global cities. *ISPRS Journal of Photogrammetry and Remote Sensing* **210**, 69–79 (2024).

117. R. I. McDonald, T. Kroeger, P. Zhang, P. Hamel, The Value of US Urban Tree Cover for Reducing Heat-Related Health Impacts and Electricity Consumption. *Ecosystems* **23**, 137–150 (2020).

118. T. Iungman, M. Cirach, F. Marando, E. P. Barboza, S. Khomenko, P. Masselot, M. Quijal-Zamorano, N. Mueller, A. Gasparrini, J. Urquiza, M. Heris, M. Thondoo, M. Nieuwenhuijsen, Cooling cities through urban green infrastructure: a health impact assessment of European cities. *The Lancet* **401**, 577–589 (2023).

119. V. Venkataramanan, A. I. Packman, D. R. Peters, D. Lopez, D. J. McCuskey, R. I. McDonald, W. M. Miller, S. L. Young, A systematic review of the human health and social well-being outcomes of green infrastructure for stormwater and flood management. *Journal of Environmental Management* **246**, 868–880 (2019).

120. P. Hu, Q. Zhang, P. Shi, B. Chen, J. Fang, Flood-induced mortality across the globe: Spatiotemporal pattern and influencing factors. *Science of The Total Environment* **643**, 171–182 (2018).

121. Y. Hirabayashi, R. Mahendran, S. Koirala, L. Konoshima, D. Yamazaki, S. Watanabe, H. Kim, S. Kanae, Global flood risk under climate change. *Nature Clim Change* **3**, 816–821 (2013).

122. P. M. Kam, G. Aznar-Siguan, J. Schewe, L. Milano, J. Ginnetti, S. Willner, J. W. McCaughey, D. N. Bresch, Global warming and population change both heighten future risk of human displacement due to river floods. *Environ. Res. Lett.* **16**, 044026 (2021).

123. D. L. Paterson, H. Wright, P. N. A. Harris, Health Risks of Flood Disasters. *Clinical Infectious Diseases* **67**, 1450–1454 (2018).

124. R. P. Schwarzenbach, T. Egli, T. B. Hofstetter, U. von Gunten, B. Wehrli, Global Water Pollution and Human Health. *Annual Review of Environment and Resources* **35**, 109–136 (2010).

125. B. Tellman, R. I. McDonald, J. H. Goldstein, A. L. Vogl, M. Flörke, D. Shemie, R. Dudley, R. Dryden, P. Petry, N. Karres, K. Vigerstol, B. Lehner, F. Veiga, Opportunities for natural infrastructure to improve urban water security in Latin America. *PLOS ONE* **13**, e0209470 (2018).

126. Robert McDonald, Daniel Shemie, "Urban Water Blueprint: Mapping conservation solutions to the global water challenge" (Nature Conservancy, 2014).

127. I. Grammatikopoulou, D. Vačkářová, The value of forest ecosystem services: A meta-analysis at the European scale and application to national ecosystem accounting. *Ecosystem Services* **48**, 101262 (2021).

128. Y. Han, J. Lee, G. Haiping, K.-H. Kim, P. Wanxi, N. Bhardwaj, J.-M. Oh, R. J. C. Brown, Plant-based remediation of air pollution: A review. *Journal of Environmental Management* **301**, 113860 (2022).

129. M. Ferraguti, S. Magallanes, M. Suarez-Rubio, P. J. J. Bates, A. Marzal, S. C. Renner, Does land-use and land cover affect vector-borne diseases? A systematic review and meta-analysis. *Landsc Ecol* **38**, 2433–2451 (2023).

130. A. J. MacDonald, E. A. Mordecai, Amazon deforestation drives malaria transmission, and malaria burden reduces forest clearing. *Proceedings of the National Academy of Sciences* **116**, 22212–22218 (2019).

131. M. C. Rulli, M. Santini, D. T. S. Hayman, P. D'Odorico, The nexus between forest fragmentation in Africa and Ebola virus disease outbreaks. *Sci Rep* **7**, 41613 (2017).

132. D. Rowland, A. Ickowitz, B. Powell, R. Nasi, T. Sunderland, Forest foods and healthy diets: quantifying the contributions. *Environmental Conservation* **44**, 102–114 (2017).

133. R. S. Olesen, C. M. Hall, L. V. Rasmussen, Forests support people's food and nutrition security through multiple pathways in low- and middle-income countries. *One Earth* **5**, 1342–1353 (2022).

134. M. Jenkins, B. Schaap, Forest ecosystem services. *Background analytical study* **1** (2018).

135. T. Vanneste, L. Depauw, E. De Lombaerde, C. Meeussen, S. Govaert, K. De Pauw, P. Sanczuk, K. Bollmann, J. Brunet, K. Calders, S. A. O. Cousins, M. Diekmann, C. Gasperini, B. J. Graae, P.-O. Hedwall, G. Iacopetti, J. Lenoir, S. Lindmo, A. Orczewska, Q. Ponette, J. Plue, F. Selvi, F. Spicher, H. Verbeeck, F. Zellweger, K. Verheyen, P. Vangansbeke, P. De Frenne, Trade-offs in biodiversity and ecosystem services between edges and interiors in European forests. *Nat Ecol Evol*, 1–8 (2024).

136. F. A. Taye, M. V. Folkersen, C. M. Fleming, A. Buckwell, B. Mackey, K. C. Diwakar, D. Le, S. Hasan, C. S. Ange, The economic values of global forest ecosystem services: A meta-analysis. *Ecological Economics* **189**, 107145 (2021).

137. A. Bauer, N. D. White, Time in Nature: A Prescription for the Prevention or Management of Hypertension. *American Journal of Lifestyle Medicine* **17**, 476–478 (2023).

138. G. N. Bratman, C. B. Anderson, M. G. Berman, B. Cochran, S. de Vries, J. Flanders, C. Folke, H. Frumkin, J. J. Gross, T. Hartig, P. H. Kahn, M. Kuo, J. J. Lawler, P. S. Levin, T. Lindahl, A. Meyer-Lindenberg, R. Mitchell, Z. Ouyang, J. Roe, L. Scarlett, J. R. Smith, M. van den Bosch, B. W. Wheeler, M. P. White, H. Zheng, G. C. Daily, Nature and mental health: An ecosystem service perspective. *Science Advances* **5**, eaax0903 (2019).

139. D. Rojas-Rueda, M. J. Nieuwenhuijsen, M. Gascon, D. Perez-Leon, P. Mudu, Green spaces and mortality: a systematic review and meta-analysis of cohort studies. *The Lancet Planetary Health* **3**, e469–e477 (2019).

140. G. B. Bonan, *Ecological Climatology: Concepts and Applications* (Cambridge University Press, Cambridge, ed. 2, 2008; https://www.cambridge.org/core/books/ecological-climatology/A34E4E35888ADC3554B24AE733C673E6).

141. P. D'Odorico, Y. He, S. Collins, S. F. J. De Wekker, V. Engel, J. D. Fuentes, Vegetation–microclimate feedbacks in woodland–grassland ecotones. *Global Ecology and Biogeography* **22**, 364–379 (2013).

142. D. Ortiz, F. Moreno, M. C. Díez, Photosynthesis, growth, and survival in seedlings of four tropical fruit-tree species under intense radiation. *Acta Amaz.* **51**, 1–9 (2021).

143. J. M. Bosch, J. D. Hewlett, A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. *Journal of Hydrology* **55**, 3–23 (1982).

144. C. Runyan, P. D'Odorico, *Global Deforestation* (Cambridge University Press, Cambridge, 2016; https://www.cambridge.org/core/books/global-deforestation/98F13A8A288B2C8D3A81BCDB892A2444).

145. L. Ricciardi, P. D'Odorico, N. Galli, D. D. Chiarelli, M. C. Rulli, Hydrological implications of large-scale afforestation in tropical biomes for climate change mitigation. *Philosophical Transactions of the Royal Society B: Biological Sciences* **377**, 20210391 (2022).

146. G. Yosef, R. Walko, R. Avisar, F. Tatarinov, E. Rotenberg, D. Yakir, Large-scale semi-arid afforestation can enhance precipitation and carbon sequestration potential. *Sci Rep* **8**, 996 (2018).

147. O. Branch, V. Wulfmeyer, Deliberate enhancement of rainfall using desert plantations. *Proceedings of the National Academy of Sciences* **116**, 18841–18847 (2019).

148. S. M. Alagele, S. Jose, S. H. Anderson, R. P. Udawatta, Hydraulic lift: processes, methods, and practical implications for society. *Agroforest Syst* **95**, 641–657 (2021).

149. A. N. A. Baladon, “Agricultural uses of occult precipitation” (Food and Agriculture Organization (FAO); European Union; World Meteorologigal Organization (WMO), Ornex, France, 1995).

150. G. Singh, K. Lal, Review and Case Studies on Biodrainage: An Alternative Drainage System to Manage Waterlogging and Salinity. *Irrigation and Drainage* **67**, 51–64 (2018).

151. H. Breman, J.-J. Kessler, *Woody Plants in Agro-Ecosystems of Semi-Arid Regions: With an Emphasis on the Sahelian Countries* (Springer Science & Business Media, 1995)vol. 23.

152. S. Kuyah, C. W. Whitney, M. Jonsson, G. W. Sileshi, I. Öborn, C. W. Muthuri, E. Luedeling, Agroforestry delivers a win-win solution for ecosystem services in sub-Saharan Africa. A meta-analysis. *Agron. Sustain. Dev.* **39**, 47 (2019).

153. J. Bayala, I. Prieto, Water acquisition, sharing and redistribution by roots: applications to agroforestry systems. *Plant Soil* **453**, 17–28 (2020).

154. S. Jose, J. Dollinger, Silvopasture: a sustainable livestock production system. *Agroforest Syst* **93**, 1–9 (2019).

155. L. A. Garibaldi, I. Steffan-Dewenter, R. Winfree, M. A. Aizen, R. Bommarco, S. A. Cunningham, C. Kremen, L. G. Carvalheiro, L. D. Harder, O. Afik, I. Bartomeus, F. Benjamin, V. Boreux, D. Cariveau, N. P. Chacoff, J. H. Dudenhöffer, B. M. Freitas, J. Ghazoul, S. Greenleaf, J. Hipólito, A. Holzschuh, B. Howlett, R. Isaacs, S. K. Javorek, C. M. Kennedy, K. M. Krewenka, S. Krishnan, Y. Mandelik, M. M. Mayfield, I. Motzke, T. Munyuli, B. A. Nault, M. Otieno, J. Petersen, G. Pisanty, S. G. Potts, R. Rader, T. H. Ricketts, M. Rundlöf, C. L. Seymour, C. Schüepp, H. Szentgyörgyi, H. Taki, T. Tscharntke, C. H. Vergara, B. F. Viana, T. C. Wanger, C. Westphal, N. Williams, A. M. Klein, Wild Pollinators Enhance Fruit Set of Crops Regardless of Honey Bee Abundance. *Science* **339**, 1608–1611 (2013).

156. W. De Schuyter, E. De Lombaerde, L. Depauw, P. De Smedt, A. Stachurska-Swakoń, A. Orczewska, B. Teleki, B. Jaroszewicz, D. Closset, F. Máliš, F. Mitchell, F. H. Schei, G. Peterken, G. Decocq, H. Van Calster, J. Šebesta, J. Lenoir, J. Brunet, K. Reczyńska, K. Świerkosz, M. Diekmann, M. Kopecký, M. Chudomelová, M. Hermy, M. Macek, M. Newman, M. Wulf, O. Vild, O. Eriksson, P. Horchler, P. Petrik, R. Pielech, T. Heinken, T. Dirnböck, T. A. Nagel, T. Durak, T. Standovár, T. Naaf, W. Schmidt, L. Baeten, P. De Frenne, M. Bernhardt-Römermann, R. Hédl, D. Waller, K. Verheyen, Declining potential nectar production of the herb layer in temperate forests under global change. *Journal of Ecology* **112**, 832–847 (2024).

157. D. Singh, H. Zerriffi, R. Bailis, V. LeMay, Forest, farms and fuelwood: Measuring changes in fuelwood collection and consumption behavior from a clean cooking intervention. *Energy for Sustainable Development* **61**, 196–205 (2021).

158. C. Wright, R. Sathre, S. Buluswar, The global challenge of clean cooking systems. *Food Sec.* **12**, 1219–1240 (2020).

159. D. Lawrence, P. D'Odorico, L. Diekmann, M. DeLonge, R. Das, J. Eaton, Ecological feedbacks following deforestation create the potential for a catastrophic ecosystem shift in tropical dry forest. *Proceedings of the National Academy of Sciences* **104**, 20696–20701 (2007).

160. C. W. Runyan, P. D'Odorico, D. Lawrence, Physical and biological feedbacks of deforestation. *Reviews of Geophysics* **50** (2012).

161. O. Deschenes, Temperature, productivity, and income. *IZA World of Labor*, doi: 10.15185/izawol.505 (2023).

162. P. A. Hancock, J. M. Ross, J. L. Szalma, A Meta-Analysis of Performance Response Under Thermal Stressors. *Hum Factors* **49**, 851–877 (2007).

163. R. J. Park, J. Goodman, M. Hurwitz, J. Smith, Heat and Learning. *American Economic Journal: Economic Policy* **12**, 306–339 (2020).

164. M. Burke, V. Tanutama, "Climatic constraints on aggregate economic output" (National Bureau of Economic Research, 2019).

165. R. Colacito, B. Hoffmann, T. Phan, Temperatures and Growth: A Panel Analysis of the United States. [Preprint] (2018). https://doi.org/10.2139/ssrn.2546456.

166. E. Somanathan, R. Somanathan, A. Sudarshan, M. Tewari, The Impact of Temperature on Productivity and Labor Supply: Evidence from Indian Manufacturing. *Journal of Political Economy* **129**, 1797–1827 (2021).

167. P. Zhang, O. Deschenes, K. Meng, J. Zhang, Temperature effects on productivity and factor reallocation: Evidence from a half million chinese manufacturing plants. *Journal of Environmental Economics and Management* **88**, 1–17 (2018).

168. H. Akbari, Shade trees reduce building energy use and CO2 emissions from power plants. *Environmental Pollution* **116**, S119–S126 (2002).

169. Y. Ko, Trees and vegetation for residential energy conservation: A critical review for evidence-based urban greening in North America. *Urban Forestry & Urban Greening* **34**, 318–335 (2018).

170. R. S. J. Tol, The Economic Impacts of Climate Change. *Review of Environmental Economics and Policy* **12**, 4–25 (2018).

171. A. M. Mapulanga, H. Naito, Effect of deforestation on access to clean drinking water. *Proceedings of the National Academy of Sciences* **116**, 8249–8254 (2019).

172. S. Singh, A. Mishra, Deforestation-induced costs on the drinking water supplies of the Mumbai metropolitan, India. *Global Environmental Change* **27**, 73–83 (2014).

173. C. J. A. Bradshaw, N. S. Sodhi, K. S. -H. Peh, B. W. Brook, Global evidence that deforestation amplifies flood risk and severity in the developing world. *Global Change Biology* **13**, 2379–2395 (2007).

174. D. Lallemant, P. Hamel, M. Balbi, T. N. Lim, R. Schmitt, S. Win, Nature-based solutions for flood risk reduction: A probabilistic modeling framework. *One Earth* **4**, 1310–1321 (2021).

175. N. D. Mueller, J. S. Gerber, M. Johnston, D. K. Ray, N. Ramankutty, J. A. Foley, Closing yield gaps through nutrient and water management. *Nature* **490**, 254–257 (2012).

176. D. Lawrence, K. Vandecar, Effects of tropical deforestation on climate and agriculture. *Nature Clim Change* **5**, 27–36 (2015).

177. A. Costinot, D. Donaldson, C. Smith, Evolving Comparative Advantage and the Impact of Climate Change in Agricultural Markets: Evidence from 1.7 Million Fields around the World. *Journal of Political Economy* **124**, 205–248 (2016).

178. C. Carter, X. Cui, D. Ghanem, P. Mérel, Identifying the Economic Impacts of Climate Change on Agriculture. *Annual Review of Resource Economics* **10**, 361–380 (2018).

179. A. T. Leite-Filho, B. S. Soares-Filho, J. L. Davis, G. M. Abrahão, J. Börner, Deforestation reduces rainfall and agricultural revenues in the Brazilian Amazon. *Nat Commun* **12**, 2591 (2021).

180. S. H. Cheng, K. MacLeod, S. Ahlroth, S. Onder, E. Perge, P. Shyamsundar, P. Rana, R. Garside, P. Kristjanson, M. C. McKinnon, D. C. Miller, A systematic map of evidence on the contribution of forests to poverty alleviation. *Environ Evid* **8**, 3 (2019).

181. S. J. K. Frey, A. S. Hadley, S. L. Johnson, M. Schulze, J. A. Jones, M. G. Betts, Spatial models reveal the microclimatic buffering capacity of old-growth forests. *Science Advances* **2**, e1501392 (2016).

182. A. L. Vogl, J. H. Goldstein, G. C. Daily, B. Vira, L. Bremer, R. I. McDonald, D. Shemie, B. Tellman, J. Cassin, Mainstreaming investments in watershed services to enhance water security: Barriers and opportunities. *Environmental Science & Policy* **75**, 19–27 (2017).

183. F. Imaizumi, R. C. Sidle, R. Kamei, Effects of forest harvesting on the occurrence of landslides and debris flows in steep terrain of central Japan. *Earth Surface Processes and Landforms* **33**, 827–840 (2008).

184. N. Grima, D. Edwards, F. Edwards, D. Petley, B. Fisher, Landslides in the Andes: Forests can provide cost-effective landslide regulation services. *Science of The Total Environment* **745**, 141128 (2020).

185. J. van den Hoogen, N. Robmann, D. Routh, T. Lauber, N. van Tiel, O. Danylo, T. W. Crowther, A geospatial mapping pipeline for ecologists. bioRxiv [Preprint] (2021). https://doi.org/10.1101/2021.07.07.451145.

186. R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, (2021).

187. RStudio Team. RStudio: Integrated Development for R. RStudio, PBC, Boston, MA, (2020).

188. WickhamWickham, H. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York. ISBN 978-3-319-24277-4, (2016).

189. Hijmans R. raster: Geographic Data Analysis and Modeling. R package version 3.6-28, (2024).

190. Hijmans R. terra: Spatial Data Analysis. R package version 1.7-81, (2024).

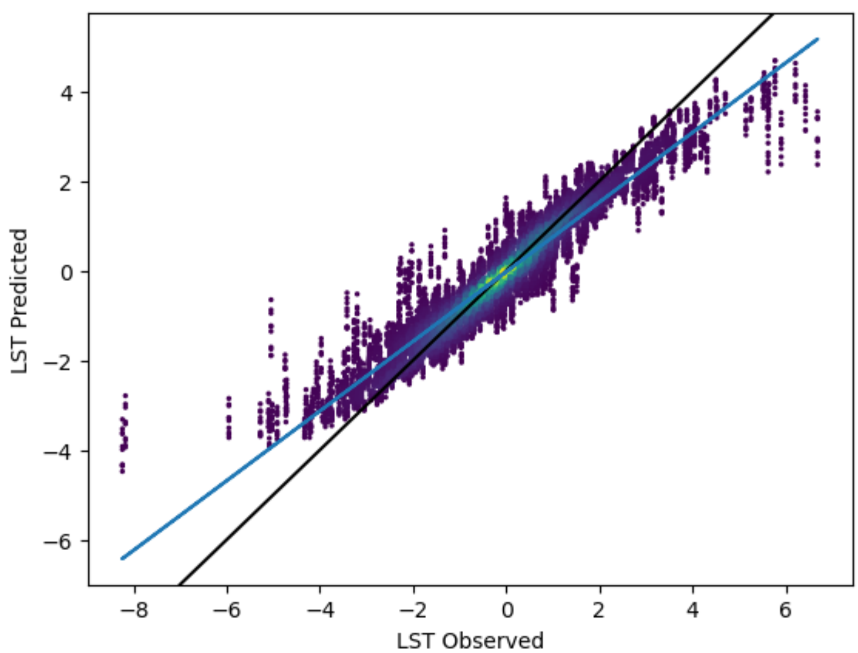
Supplementary Material

Materials and Methods
Figures 2 and 3 were produced in R (*186*) version 4.3.2 using Rstudio (*187*) and packages ggplot2 (*188*), raster (*189*), and terra (*190*).

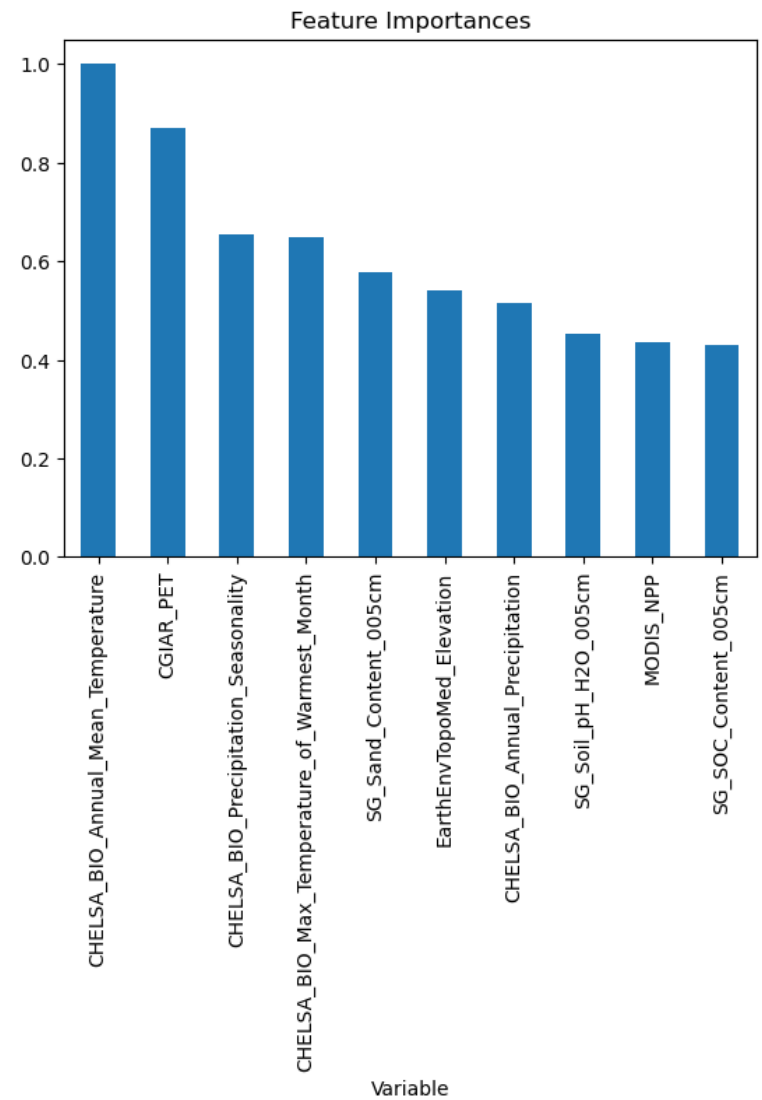
Fig.2 Maps:
2A) For local forest – non-forest temperature, ground-measured point data from ref (*16*) was plotted according to longitude and latitude. LST data from ref (*15*) (Figure 1c, daily average) was extrapolated to global scale according to ref (*185*) (default settings), using a Random Forest model and environmental predictor variables. For details please refer to ref (*185*), an overview over the model and performance is provided below.

The following environmental predictor variables were used:
Global potential evapotranspiration, annual mean temperature, annual precipitation, max. temperature of the warmest month, precipitation seasonality, human development percentage (land cover), landcover class barren, land cover class deciduous broadleaf trees, landcover class evergreen broadleaf trees, landcover class evergreen deciduous needleleaf trees, landcover class herbaceous vegetation, landcover class mixed other trees, landcover class shrubs, coefficient of variance of enhanced vegetation index (EVI), correlation of EVI, homogeneity of EVI, aspect cosine, aspect sine, elevation, slope, topography position index, burned areas probability, population density, aboveground biomass, permafrost extent, net primary productivity, soil and sedimentary deposit thickness, depth to bedrock, sand content at 5cm depth, soil organic carbon content at 5cm depth, soil pH (H_2O) at 5cm depth, human footprint (2009).

Model performance of predicted vs. observed LST offsets:



10 most important features:



In order to assess the degree of extrapolation in multivariate space, we again followed the method detailed in ref (*185*). The multiband image of predictor variables as well as the training data are transformed into the same principal component (PC) space. PCs are chosen to explain > 90% of variation. For each pixel in the predictor variable composite and each bivariate combination of the chosen PCs, it is tested whether the pixel falls within the convex hull enclosing the training points within the same PC space. This results in a map with pixel values indicating the proportion of bands, where the pixel value does fall into the hull enclosing the training data.

In order to limit extrapolation in our final image, we used that map to only include points with <10% extrapolation.

2B) Current above ground tree carbon density raster from ref (*3*) was aggregated by a factor of 5 before plotting.
2C) Fraction of precipitation lost to interception using the data underlying ref (*20*), Fig. 4b.
2D) Change in water yield following restoration or forest cover expansion with data from ref (*59*). Where multiple measurements were available for the same coordinates, each observed outcome (positive, negative, neutral) is shown. Points with the same coordinates and the same outcome are only shown once. Inconclusive outcomes were excluded.
2E) Fraction of precipitation resulting from continental evaporation was plotted using data from ref (*93*), Figure 3.1, masking out oceans.

Fig.3:
Net climate impact is estimated in carbon equivalents by estimating the carbon storage potential of tree cover and accounting for albedo change based on ref (*21*). The carbon equivalents refer only to the additional carbon that could be accumulated by restoring tree cover, not the one already present. The albedo change is estimated for a transition of the observed or most likely open land cover class (open shrublands, grasslands, croplands, and cropland/natural vegetation mosaics) to the observed or most likely forest type and radiative forcing converted to carbon equivalents. In order to estimate a net impact, this is compared to maximum potential carbon storage above and belowground in woody plant biomass (but excluding soil organic matter). Potential % tree cover is based on ref (*2*), estimating the % for potential tree canopy cover based on environmental conditions and observed tree cover in protected regions.
3A) To map the net climate impact of regions with at least 30% tree cover potential, the net carbon impact map was reprojected to the same resolution as the potential tree cover and subset for regions, where that tree cover potential was at least 30%.
3B) For the net climate impact of tree cover in a location based on the % of tree cover the location could naturally support the potential tree cover % was reprojected to the same resolution as the net carbon impact map. 10’000 points were sampled at random and exclusion of NA’s led to a total of 8484 points plotted.