

NATURE-BASED SOLUTIONS

Diabetes Prevention & Cardiometabolic Health

How place, exposure, and physiology intersect in prevention

Rachel J. Keith, PhD, APRN
Kentucky Diabetes Symposium • November 8, 2026

VISUAL SYSTEM: forest • science • clinical translation

Disclosure to Participants

Notice of Requirements For Successful Completion:
Please refer to learning goals and objectives
Learners must attend the full activity and complete the evaluation in order to claim continuing education credit/hours
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Objectives

After completion of this activity, the participant should be able to:

1. Discuss the growing burden of diabetes and why the environment matters
2. State biological mechanisms linking Nature and Metabolic Health
3. Summarize human evidence for Nature Based Interventions in Diabetes
4. Summarize future directions and clinical translation

The prevention challenge is too large to solve exclusively one patient at a time.

Diabetes is still accelerating globally

589 million

Adults aged 20–79 living with diabetes in 2024

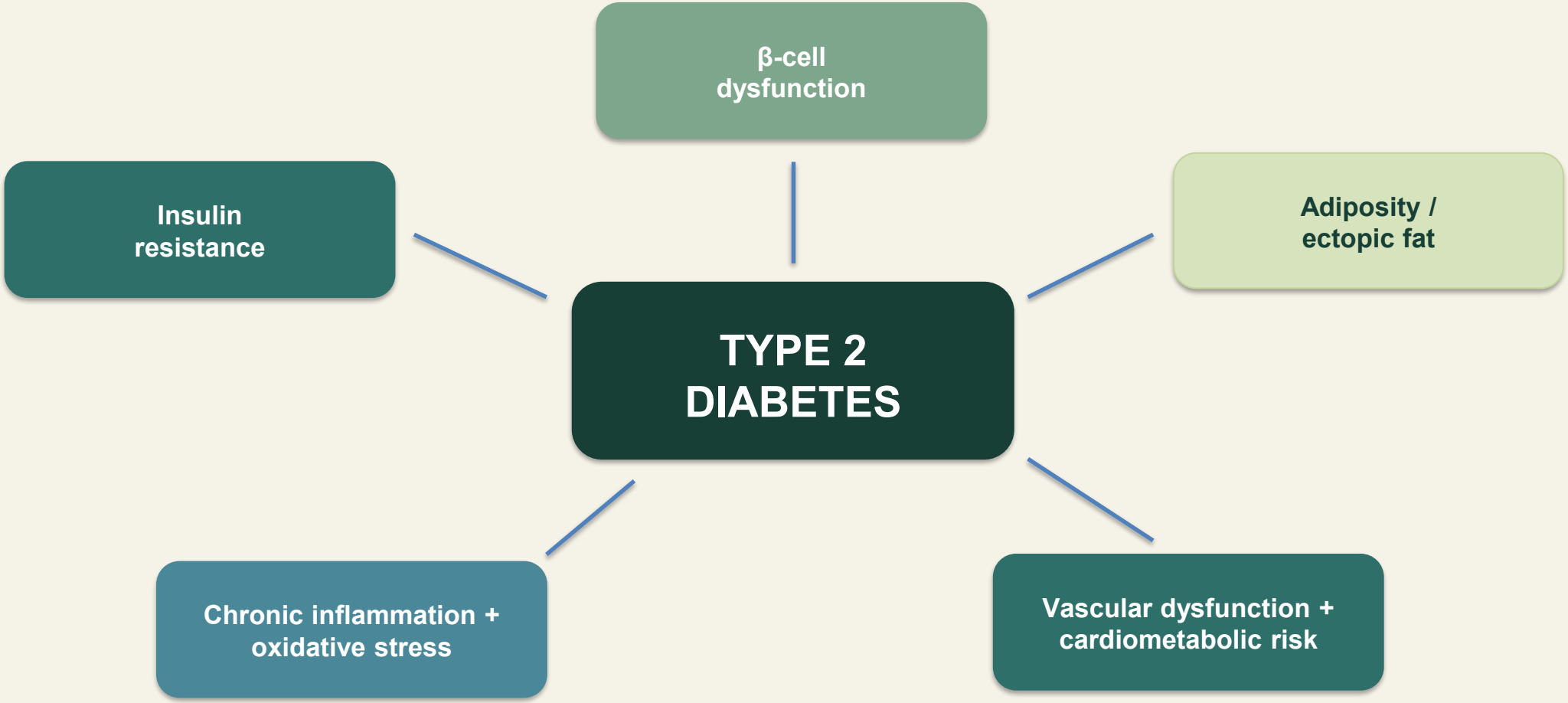
The 2026 publication of the 11th IDF Diabetes Atlas estimates a rise from 589 million adults with diabetes in 2024 to approximately 853 million by 2050, with prevalence increasing from 11.11% to 12.96%.

INTERPRETATION

11.1% Approximately 1 in 9 adults

Genitsaridi I, et al. Lancet Diabetes Endocrinol. 2026;14(2):149–156. doi:10.1016/S2213-8587(25)00299-2

Type 2 diabetes involves multiple interconnected biological systems



Environmental exposures may influence the same biological systems that shape diabetes and cardiometabolic risk.

American Diabetes Association Professional Practice Committee for Diabetes. Diabetes Care. 2026;49(Suppl 1).

Behavior matters, but behavior happens in a place

INDIVIDUAL / HEALTH BEHAVIORS

Nutrition
Physical activity
Sleep
Tobacco / nicotine
Medication adherence + healthcare

shapes opportunity & behavior

PLACE / EXPOSURE

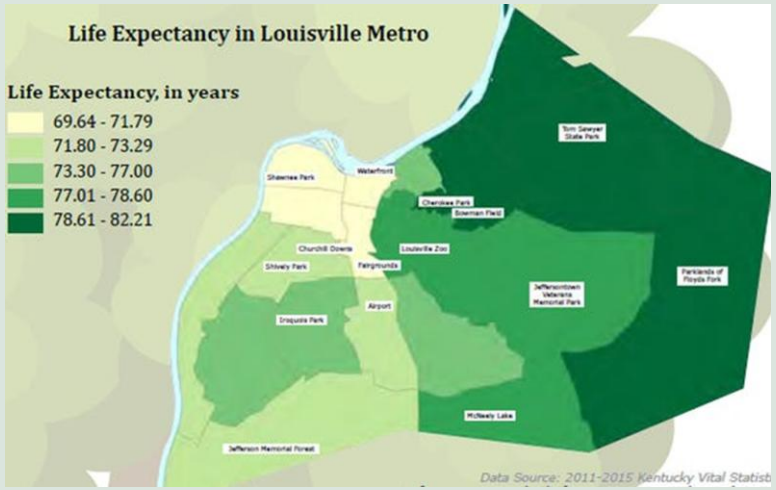
Walkability + safety
Food access
Air pollution + noise
Heat + shade
Greenspace + nature contact
Social conditions + chronic stressors

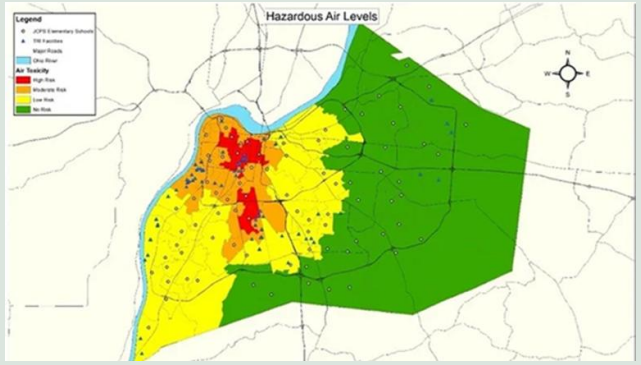
PLACE / EXPOSURE → DIRECT BIOLOGICAL PATHWAYS

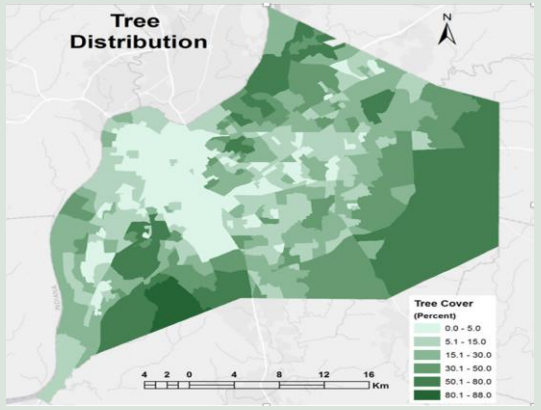
Place can influence both health behaviors and biological exposures relevant to cardiometabolic risk.

Mujahid MS, et al. Diabetes Care. 2023;46(9):1609–1618. doi:10.2337/dci23-0003

WHERE YOU LIVE SHAPES EXPOSURE AND OPPORTUNITY







WHY THIS MATTERS

Health risk, environmental exposures, and opportunities are not randomly distributed.

Health
Diabetes • CVD • mortality
Environment
Heat • air pollution • greenness
Opportunity
Food • activity • healthcare • economic resources

ZIP code does not determine destiny. But exposures and opportunities cluster geographically.

The urban environment is a mixture, not a single exposure



Environmental exposures coexist, interact, and accumulate over time.

Beulens JWJ, Pinho MGM, Abreu TC, et al. Environmental risk factors of type 2 diabetes—an exposome approach. Diabetologia. 2022;65(2):263–274. doi:10.1007/s00125-021-05618-w. Sørensen M, Poulsen AH, Hvidtfeldt UA, et al. Air pollution, road traffic noise and lack of greenness and risk of type 2 diabetes: A multi-exposure prospective study covering Denmark. Environment International. 2022;170:107570. doi:10.1016/j.envint.2022.107570

“Greenspace” is not one exposure

RESIDENTIAL GREENNESS



Vegetation surrounding the home measured by NDVI, canopy, LAI, etc.

ACCESS



Availability and proximity of usable green environments

CONTACT



Actual time spent in a natural environment

GREEN ACTIVITY



Physical activity occurring in a natural setting

ENVIRONMENTAL INTERACTION



The environment itself is deliberately changed

NDVI ≠ park use ≠ forest bathing ≠ neighborhood tree planting.

Different exposures answer different scientific questions.

Keith RJ, Hart JL, Bhatnagar A. Circ Res. 2024;134(9):1179–1196.

Greener environments are associated with lower type 2 diabetes risk

2023 SYSTEMATIC REVIEW

12 of 13

longitudinal cohorts reported lower diabetes incidence with greater green exposure

10 reported statistically significant associations

2024 META-ANALYSIS

HR 0.82

pooled green/open-space estimate
95% CI 0.74–0.92

IMPORTANT

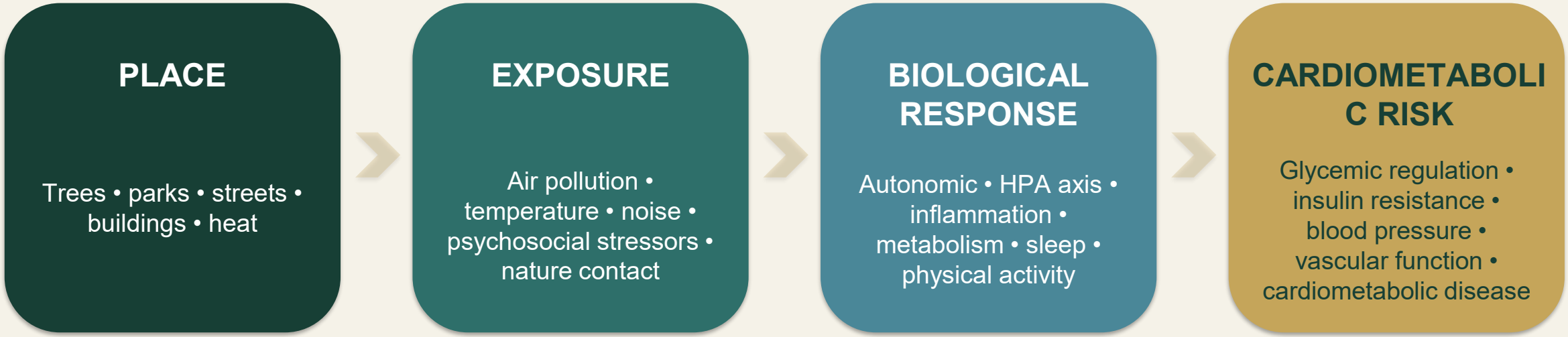
This does not mean planting trees will reduce diabetes incidence by 18%.

Association ≠ intervention effect

The epidemiologic signal provides a rationale for mechanistic and intervention studies.

Ccami-Bernal F, et al. Health Place. 2023;82:103045. | Feyissa TR, et al. Soc Sci Med. 2024;361:117372.

Place → exposure → biological response → cardiometabolic risk



The hypothesis is not simply “green is healthy.”

Each arrow requires evidence.

Keith RJ, Hart JL, Bhatnagar A. Greenspaces and cardiovascular health. Circ Res. 2024;134(9):1179–1196.

How could nature influence metabolic health?

BIOLOGIC RESPONSE

- Stress / autonomic
- HPA axis / cortisol
- Inflammation / immune

ENVIRONMENTAL MODIFICATION

- Air pollution
- Heat / thermal exposure

BEHAVIORAL PATHWAYS

- Physical activity
- Sleep

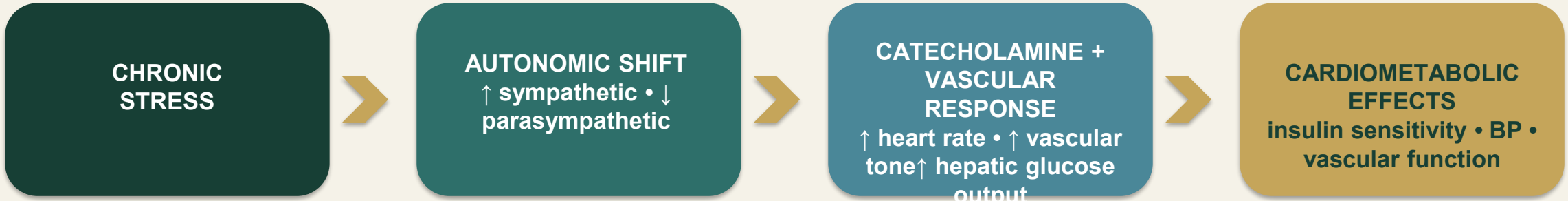
Established determinants of diabetes risk: physical activity • sleep

Keith RJ, Hart JL, Bhatnagar A. Circ Res. 2024;134(9):1179–1196.

Nature's contribution to these pathways, and its direct biological effects, remain under investigation.

MECHANISM 1

Stress physiology: autonomic regulation matters

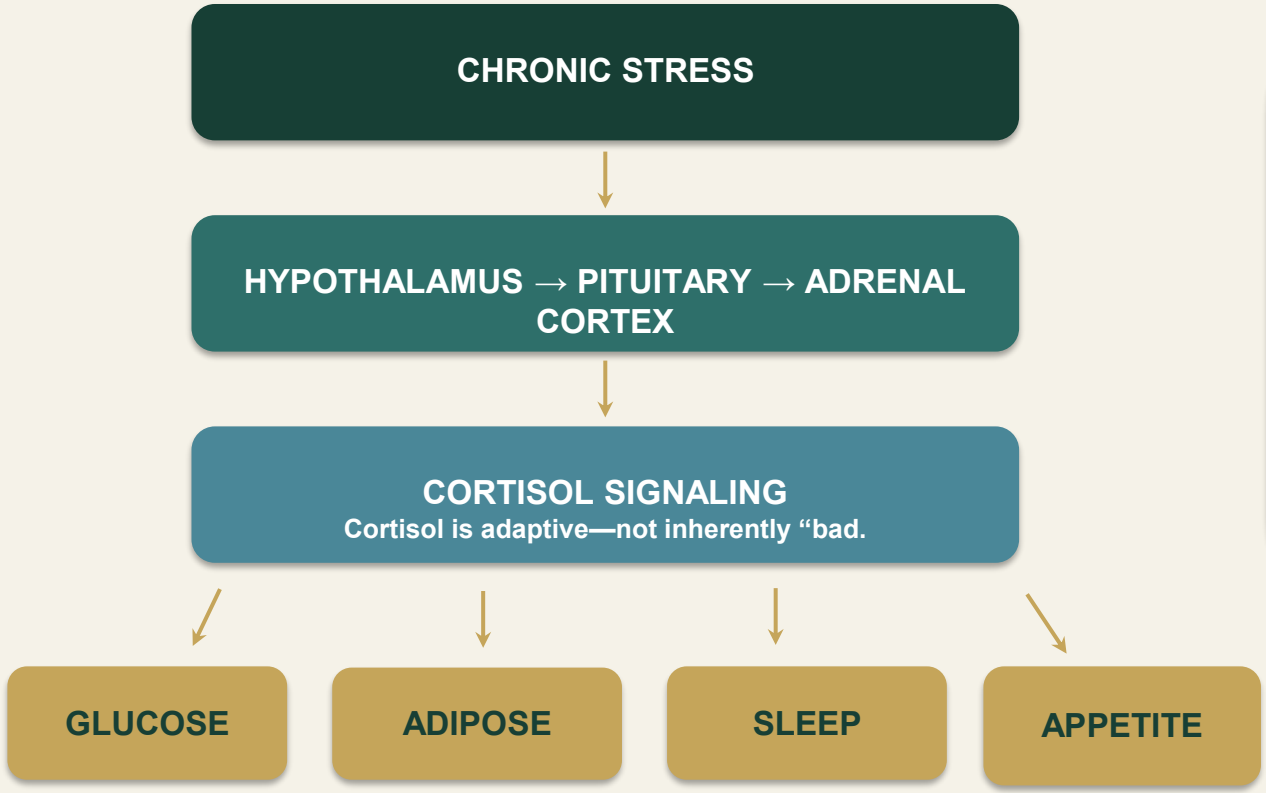


HR and HRV are mechanistic outcomes, not diabetes endpoints.

They indicate environmentally responsive autonomic physiology; clinical significance requires additional evidence.

MECHANISM 2

The HPA axis links chronic stress with metabolic signaling



WHAT DOES NATURE-EXPOSURE RESEARCH SHOW?

Forest-exposure studies report modest average reductions in cortisol.

Results are heterogeneous across studies, populations, exposure protocols, and cortisol sampling methods.

Environmentally responsive ≠ established diabetes intervention

Nature exposure may alter stress physiology; whether this translates into meaningful metabolic benefit remains uncertain.

Qiu Q, et al. Int J Environ Res Public Health. 2023;20(1):458. doi:10.3390/ijerph20010458.

Inflammation is a shared cardiometabolic pathway

WHAT WE KNOW ABOUT DIABETES BIOLOGY

Metabolic dysfunction
Adipose dysfunction
Insulin resistance

↔

Chronic low-grade inflammation

→

Vascular dysfunction and cardiometabolic disease





Cytokines • Immune cells
Acute phase reactants
(e.g., hsCRP)



Insulin resistance
Endothelial dysfunction
Atherosclerosis
Type 2 diabetes
Cardiiovascular disease

GREEN HEART: HUMAN EVIDENCE

2024: NEIGHBORHOOD GREENING
Prelimimary Green Heart intervention findings



13–20% lower hsCRP

Greened neighborhoods compared with unplanted neighborhoods.

Systemic inflammation
High-sensitivity Creactive protein (hsCRP)



Lower hsCRP (13–20%) after neighborhood greening.

2026: RESIDENTIAL GREENNESS
Baseline analysis (cross-sectional)



624 adults

Louisville, KY
baseline analysis

Immune phenotype

- B cells ↓
- Monocytes ↓
- Natural killer cells ↓
- IL-4 ↑

Associations with other cytokines were less consistent.

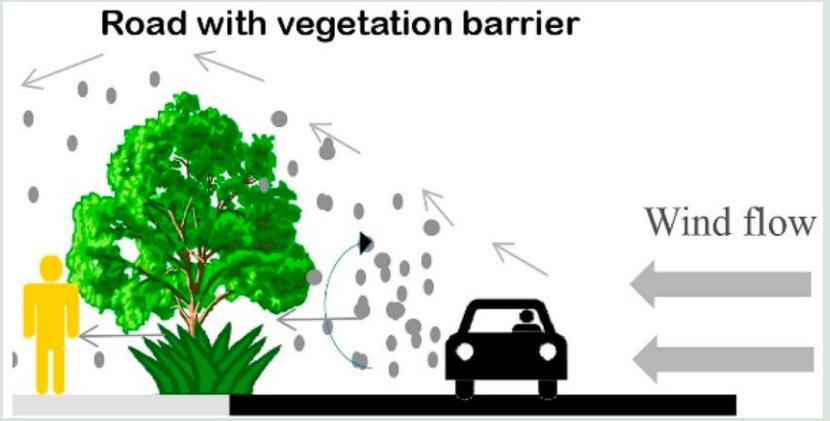
Environmental greenness is associatecl with measurable inflammatory and immune differences.
Whether these translate into diabetes prevention remains unknown.

Riggs DW, et al. Environ Res. 2026;299:124256. doi:10.1016/j.envres.2026.124256

MECHANISM 4

Air pollution is a metabolic exposure

$PM_{2.5}$ → OXIDATIVE STRESS → SYSTEMIC INFLAMMAION + ENDOTHELIAL DYSFUNCTION → INSULIN RESISTANCE + CARDIOMETABOLIC RISK

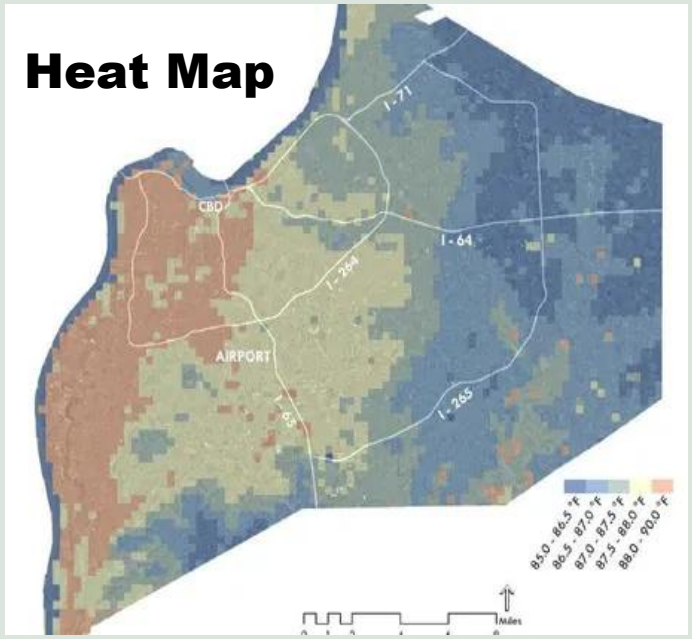


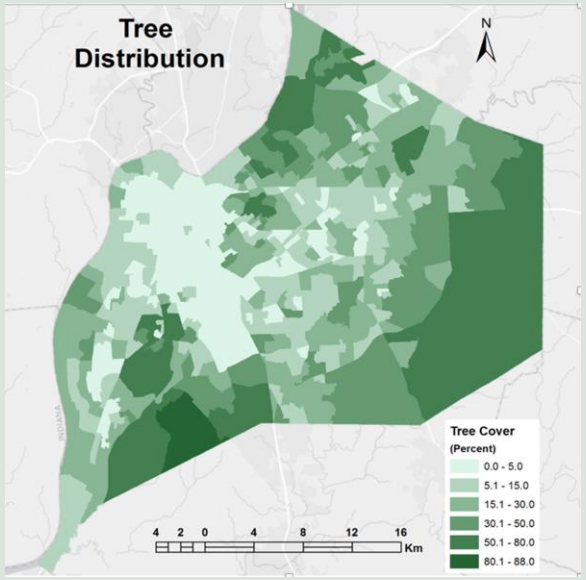
Vegetation can modify pollution exposure—but the effect is contextual.

Species • canopy density • source location • wind/ventilation • street geometry all matter.

Azizi S, et al. Int J Environ Health Res. 2025;35(6):1413–1432. doi:10.1080/09603123.2024.2391993

Heat is an environmental stressor with special cardiometabolic relevance





Greening can modify the exposure, not just the individual's response to it.

WHY DIABETES CAN INCREASE HEAT VULNERABILITY

Comorbid disease
Cardiovascular disease • kidney disease

Physiologic vulnerability
Autonomic/neuropathic dysfunction • impaired thermoregulation • dehydration risk

Treatment considerations
Some medications can affect fluid balance, blood pressure, or heat response

Heat can convert existing cardiometabolic vulnerability into acute physiologic stress.

Liu J, et al. Lancet Planet Health. 2022;6(6):e484–e495. doi:10.1016/S2542-5196(22)00117-6

Physical activity and sleep provide established links to metabolic health

PHYSICAL ACTIVITY

150 min/week

moderate-to-vigorous aerobic activity for most adults with diabetes

+ resistance exercise
+ interrupt prolonged sitting

Nature may support where and how activity occurs.

SLEEP

Duration + quality

Short sleep and poor sleep quality are associated with adverse metabolic outcomes and higher type 2 diabetes risk.

Nature may support these behaviors. The metabolic benefits of healthy sleep are already established.

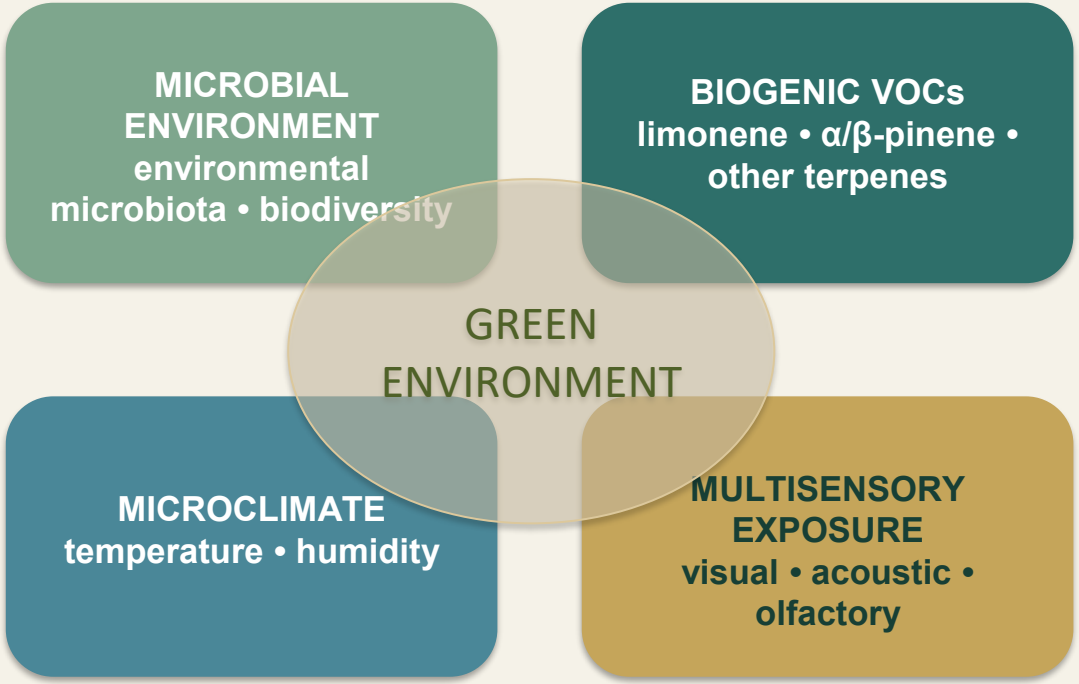
Whether nature provides additional metabolic benefit independent of behavior remains an open question.

American Diabetes Association Professional Practice Committee for Diabetes. Diabetes Care. 2026;49(Suppl 1):S89–S131. doi:10.2337/dc26-S005

Greenness represents more than a visual exposure



Greenness may be a proxy for a complex environmental exposure mixture.



What we measure matters
Satellite greenness → *vegetation surrounding the person*
versus
Direct exposure biomarkers → *what may actually reach the person*

Zhang YD, et al. Environ Int. 2024;187:108662; Xie Z, et al. Environ Res. 2024;245:117991.

TRANSITION POLL

Which pathway currently provides the most established link between greener environments and metabolic health?

POLL #1

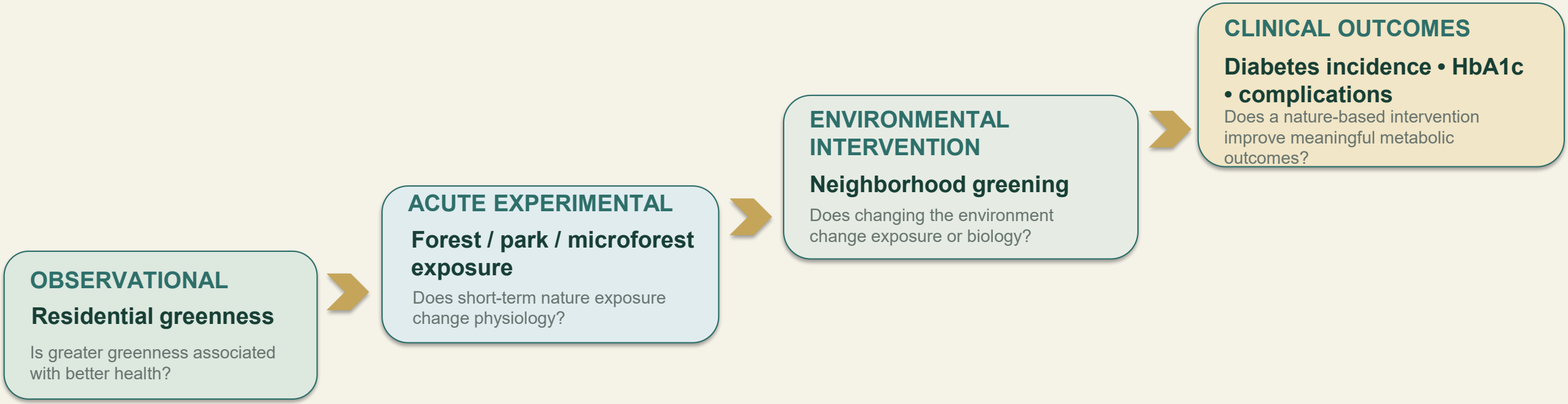
A Direct effects of plant-derived VOCs on insulin sensitivity

B Increased physical activity

C Microbiome modification

D Reduced inflammatory signaling

Not all “nature evidence” answers the same question



Evidence exists across the first three levels, but it answers increasingly different questions.

Major gap: diabetes-specific outcomes from nature-based interventions.

Keith RJ, et al. Circ Res. 2024;134(9):1179–1196; Adewuyi FA, et al. Environ Res. 2023;236(Pt 2):116844.

Experimental nature exposure produces measurable short-term responses

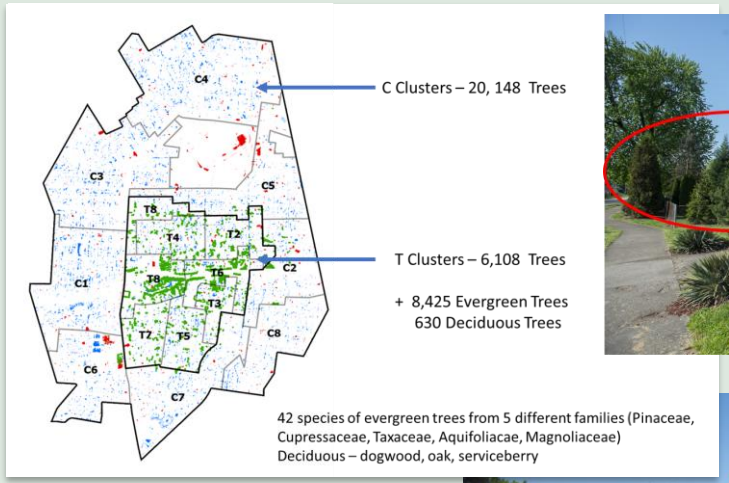


STRESS / ANXIETY	**generally ↓**
HEART RATE / BLOOD PRESSURE	**small or inconsistent ↓**
Cortisol	**modest average ↓**
HRV / autonomic	**potentially favorable**

Acute physiologic response ≠ diabetes prevention

Qiu Q, et al. Int J Environ Res Public Health. 2023;20(1):458; Adewuyi FA, et al. Environ Res. 2023;236(Pt 2):116844.

Green Heart tests what happens when we change the environment







NEIGHBORHOOD-SCALE INTERVENTION

- **Target + control areas**
  Comparison of neighborhoods over time
- **Large-scale tree and shrub planting**
  ~8,000 trees and shrubs planted in the target area
- **Longitudinal human phenotyping**
  Repeated cardiovascular, inflammatory, metabolic + psychosocial measures
- **Environmental characterization**
  Greenness • air pollution • temperature • other exposures

Instead of asking people to visit nature, Green Heart changed the environment where people live.

Bhatnagar A, Keith R, Yeager R, et al. Am J Epidemiol. 2026;195(5):1416–1428. doi:10.1093/aje/kwae458

Green Heart: signals in inflammation and immune biology

2024 • NEIGHBORHOOD GREENING

13–20% lower hsCRP

In the greened area relative to comparison

Systemic inflammation

2026 • BASELINE OBSERVATIONAL ANALYSIS

624 adults

Baseline, cross-sectional analysis

B cells ↓

Monocytes ↓

Natural killer cells ↓

IL-4 ↑

Greenness is linked with measurable inflammatory and immune signals in humans; implications for diabetes remain uncertain.

Green Heart Louisville Project. Preliminary neighborhood greening intervention findings; unpublished data, 2024.; Riggs DW, Cobbold S, Sears CG, et al. Relations of residential greenness with immunity and inflammation. Environ Res. 2026;299:124256. doi:10.1016/j.envres.2026.124256

ACUTE EXPERIMENTAL EVIDENCE

Can a small urban nature intervention produce an acute physiologic response?



RANDOMIZED CROSSOVER

BUILT ENVIRONMENT ⟷ **MICROFOREST**

randomized order • within-person comparison

Anxiety	↓ ~8 points
Walking HR	↓ ~3.5 bpm
SDNN / RMSSD	↑ ~12%
AIx / central AP	favorable signal

PRELIMINARY FINDINGS • mechanistic, not diabetes endpoints

Keith RJ, et al. Trager Microforest Study. Preliminary, unpublished data. University of Louisville; 2026.

What does the totality of evidence actually support?

ESTABLISHED CARDIOMETABOLIC SCIENCE

- **Physical activity improves metabolic health**
- Healthy sleep supports metabolic health
- Air pollution and heat affect cardiometabolic health

EMERGING NATURE EVIDENCE

- **Greener environments ↔ lower incident T2D**
  experimental observational association
- Nature exposure can alter stress physiology
  experimental evidence; effects are heterogeneous
- Greening may alter inflammatory / immune biology
  emerging human evidence

NOT YET DEMONSTRATED

- **A specific nature "dose" prevents T2D**
- Nature independently lowers HbA1c
- Monoterpenes or microbiota prevent T2D

Nature may support cardiometabolic health, but it complements—not replaces—established diabetes prevention and treatment.

Ccami-Bernal F, et al. Health Place. 2023;82:103045; Adewuyi FA, et al. Environ Res. 2023;236:116844; Riggs DW, et al. Environ Res. 2026;299:124256.

What recommendation best reflects the current evidence?

58-year-old with prediabetes, hypertension, high stress, low physical activity, and limited access to safe outdoor space.

A. Replace structured exercise with forest bathing

B. Prescribe a specific weekly “dose” of nature to lower HbA1c

C. Use accessible nature to support activity and stress recovery while continuing evidence-based prevention

D. Recommend monoterpene exposure

What is a nature prescription?

A structured recommendation to spend time or be physically active in natural environments

HOW IT MAY SUPPORT CARE

- Support physical activity
- Support stress recovery
- Increase restorative time outdoors

WHAT WE DO NOT YET HAVE

No validated diabetes-specific nature dose

No established prescription for:
- HbA1c reduction
- diabetes prevention
- complication reduction

Complement established care—not replace it.

Adewuyi FA, et al. Environ Res. 2023;236(Pt 2):116844. doi:10.1016/j.envres.2023.116844

What could I recommend Monday morning?

MOVE

Pair established activity goals with an accessible green setting when feasible.

walk outdoors • break up sitting • choose settings that encourage movement

RECOVER

Consider nature contact as one strategy for stress recovery.

brief outdoor breaks • quiet sitting • restorative walking

CHECK THE SETTING

Consider heat, air quality, shade, safety, and accessibility.

modify timing, location, or activity as needed

Nature-based strategies should support not displace evidence-based diabetes prevention and treatment.

American Diabetes Association Professional Practice Committee for Diabetes. Diabetes Care. 2026;49(Suppl 1):S89–S131; Adewuyi FA, et al. Environ Res. 2023;236:116844.

Environment can be part of the intervention

Shift the question:

"What behavior does this patient need to change?"

→

"What makes that behavior easier or harder where they live?"

- Safety
- Heat + shade
- Air quality
- Walkability
- Food access
- Access to greenspace

Clinical counseling addresses behavior. Population prevention also asks whether the environment supports it.

Mujahid MS, et al. Diabetes Care. 2023;46(9):1609–1618.

Nature prescriptions require accessible nature



WHEN THE ENVIRONMENT CONSTRAINS THE CHOICE
Heat exposure • limited shade • poor walkability • traffic/safety



WHEN THE ENVIRONMENT SUPPORTS THE CHOICE
Canopy + shade • walkability • restorative space • nature contact

“Spend more time outdoors” depends on what outdoors looks like.

Mujahid MS, et al. Diabetes Care. 2023;46(9):1609–1618; Keith RJ, et al. Circ Res. 2024;134(9):1179–1196.

Five take-home messages

1. **Diabetes risk is shaped by biology, behavior, and place.**
2. Greener environments are associated with lower type 2 diabetes risk, but association is not intervention effect.
3. Nature exposure can influence stress, autonomic, inflammatory, thermal, and behavioral pathways.
4. Human studies show measurable biological responses, but diabetes-specific clinical outcomes remain a key evidence gap.
5. **Nature can support established prevention strategies; healthier communities also require health-supportive environments.**

Nature-based solutions are complements to not substitutes for evidence-based diabetes prevention and care.

ENVIRONMENT
DIABETES
HEALTHIER COMMUNITIES

Questions?



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