Urban Trees in A Desert City: Seeing the Forest Through the Trees

Dr. Greg McPherson
US Forest Service, PSW
Davis, California

U.S. Department of Agriculture
Pacific Southwest Research Station
Science that makes a difference

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Today

- Evolution of Urban Forests
- Transitioning to the Future
  - What & How?
- Tools/Strategies
  - Tree BVOC Index
  - Climate-Ready Tree Evaluation

Tree - Neighborhood - City

Sacramento

City of Trees

Photo credit: Chris Aschenbrener

Photo credit: David Roberts

Gold: Population Boom

Photo credit: David Roberts

Why Plant?

- Health – swamp reduction
- Flood protection
- Shade
- Food
- Aesthetics

Early Mistakes

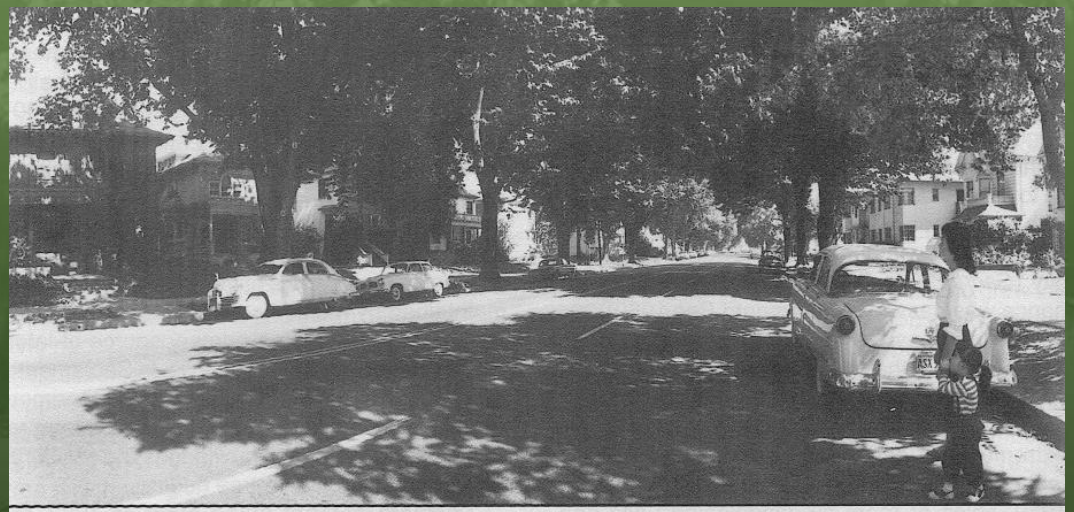
85/24/1698

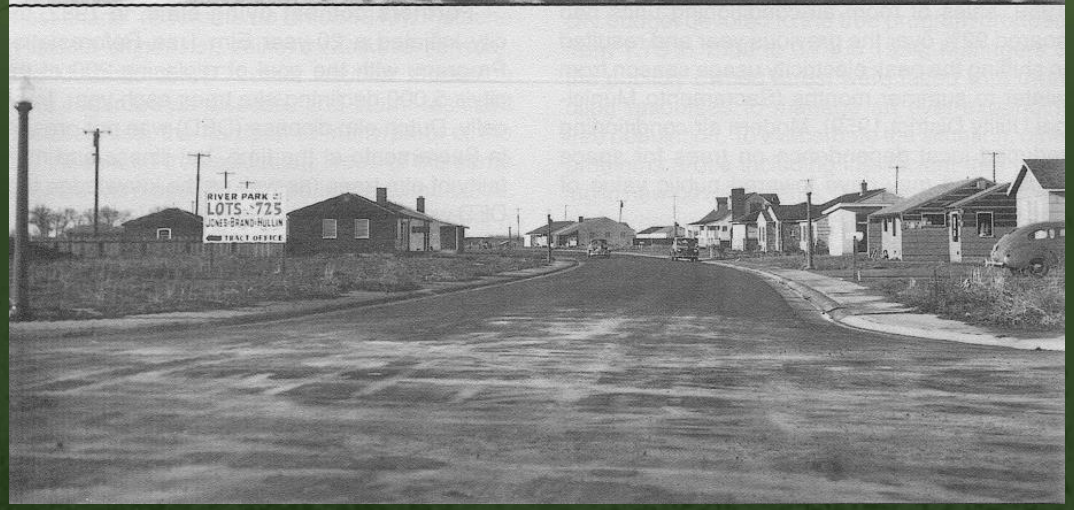
Northwest corner of 17th & M street.
Feburary 10th, 1938.

Causes

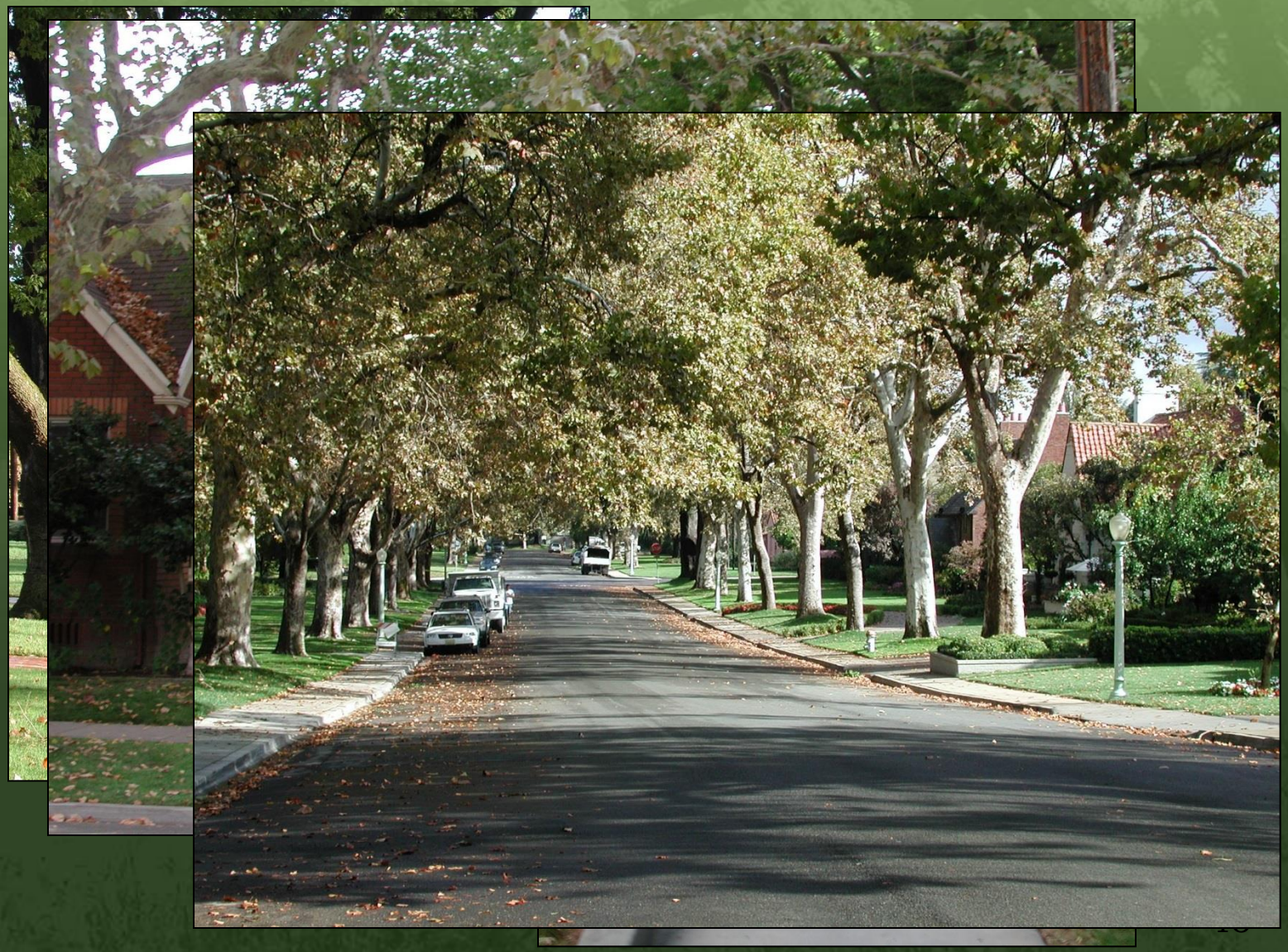
- Improper planting
- Improper pruning
- Roots cut
- Elms “too big”
- Began removals

Before and After Air Conditioning





Park Neighborhoods Study



Planting Space Effects

- Planting space
- Planting distance
- Tree growth
  - Height
  - Crown diameters
- Longevity
- Replacement issues

Findings

- Strips <15’
  - Ht and Crn Dia stunted
  - 50-95% sidewalk replacement w/root pruning
  - Smaller space, poorer conditions

Our research: Larger space = larger tree + longer life

Larger tree = greater benefits for longer period

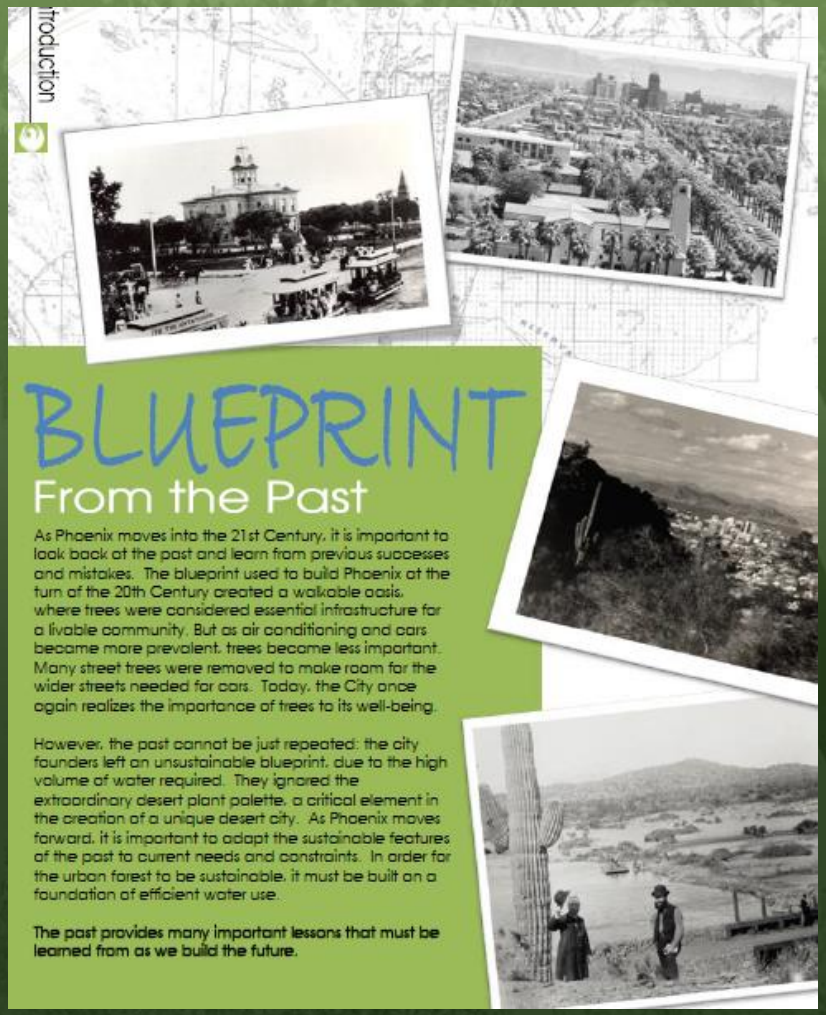
Smaller Space?

Plant smaller tree for lower costs + more benefits

Oakland, CA

Neighborhood Stands

- Unique structures reflect past values
- Prescriptions for transitioning & resilience differ



Current Challenges

- Air Quality
- Water
- Climate Change

- Trees pose solutions and problems

Transitioning to Climate-Ready Urban Forest

- What Do We Want?
  - Quantity
    - Extensive canopy cover & fully stocked streets & parks
  - Quality
    - Diversity, well-adapted species, good health
    - High level of services & controlled costs
  - Civic Engagement
    - Leadership, resources, management skills

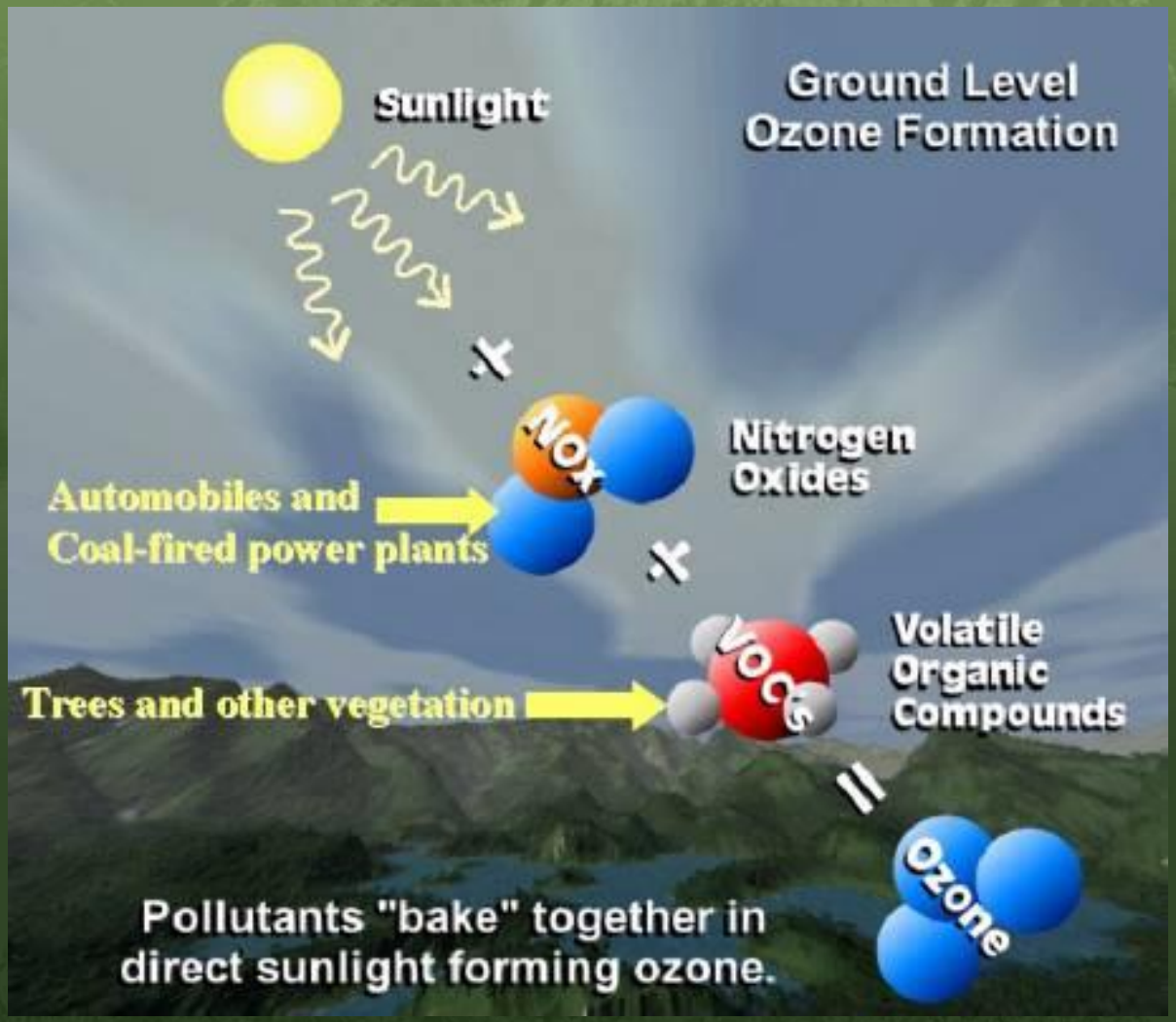
Transitioning to Climate-Ready Urban Forest

- How Do We Get There?
  - Avoid sudden canopy loss
  - Canopy-friendly ordinances
  - Consider impacts one-scale up
  - Simplicity & Diversity
    - Unite around simple canopy goal
    - Local goals, local actions
  - Translate to Communicate
  - Data Sharing & Continuous Improvement

Strategies & Tools

- Tree BVOC Index
- Climate-Ready Tree Species Evaluation

Tree BVOC Index

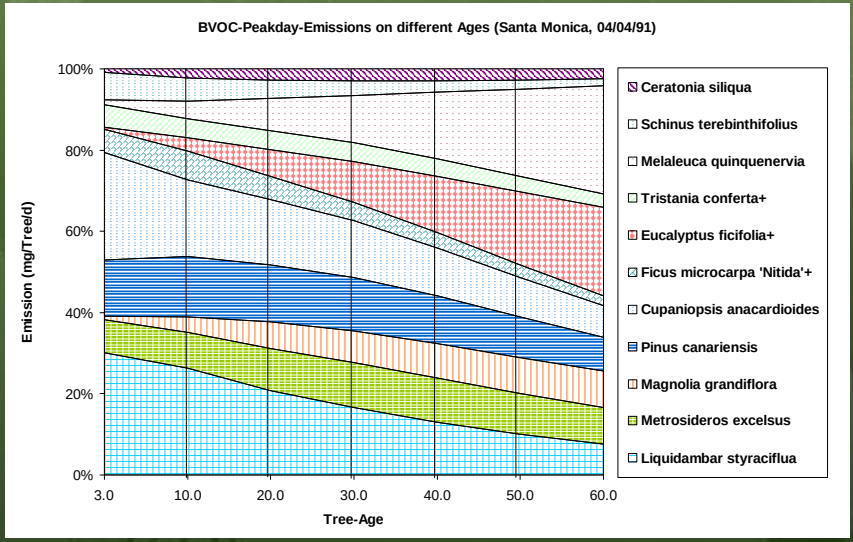


Air Quality and Urban Trees

- BVOC emissions (Biogenic Volatile Organic Compounds)
  - Tree species & size
  - Emissions due to tree care
- Net ozone effects
  - Deposition- removal of ozone and NOx
  - Avoided NOx emissions from energy savings
  - Temperature reduction and other climatic effects
  - Emission reduction from cooling of parked automobiles; startup emissions

Current Issues

- Emission rates
  - Generic substitutes
    - Brisbane (3 sp, 16%)
    - i-Tree Eco: 182 vs 6,283 kg/yr
  - Local species screening
  - Field measurements
  - Accounting for size
- Modeling
  - Local microclimate effects
  - Spatial components



Consider Limiting These

High Allergenicity	High BVOC Emitters
Ash	Ash
Beefwood	Beefwood
Cypress	Carrotwood
Elm	Date palm
Juniper	Eucalyptus
Mulberry	Fan palm
Oak	Fig
Olive	Goldenrain tree
Persimmon	Oak
Sweetgum	Sweetgum
Sycamore	Sycamore

Tree BVOC Index Tool

- Greenprint & SMAQMD
  - 7 million urban trees (35% high emitters)
  - Significant BVOC source
  - Potential AQ funds for tree planting
- Ozone non-attainment area
- First time trees in a SIP
- Trees have regulatory issues
  - slow to grow
  - may be removed over time

SIP Compliance issues

shift to lower emitters

- Changing percent of Low (<1), Medium (1-10), High (>10 µg BVOC g^{-1} dry leaf hr^{-1})
- 10-fold range of possible values within an emitter class
- Emitter labeling- resistance to participation (native oaks are bad)
- Mature tree size effects not included

Tree BVOC Index

$$TBI = \frac{E}{E_{target}} = \frac{\text{emissions from proposed planting}}{\text{target emissions for compliance}}$$

- TBI ≤ 1.0 indicates project compliance
- The TBI can be used for:
  - Project compliance: initial projection based on user supplied planting schedule and mortality.
  - Project adjustments: mid-course correction(s) in which future planting is adjusted based on records of surviving trees to date.
  - Project or individual partner scale
- Tree BVOC Index paper:

http://www.treesearch.fs.fed.us/pubs/38808

Example

Tree species	BVOC emissions (E_i[§]) (g-C/tree/day)	No. Planted (n_i)	BVOCs x number ($E_i \times n_i$; g-C/sp/day)
Crape myrtle	0.00	9	0.00
Zelkova	0.00	24	0.00
Bigleaf Maple	0.20	3	0.59
Red oak	1.01	18	18.26
Trident maple	0.02	28	0.57
Chinese pistache	0.54	18	9.65
Total		100	29.07
Proposed planting Emissions: (**E**; g-C/tree/day)			0.29
Target emissions: compliance (**E_{target}**; g-C/tree/day)			0.57
TBI for planting (TBI=**E/E_{target}**≤1 indicates compliance)			0.51

[§]includes adjustments for air temperature, solar radiation; leaf biomass of average age trees

Bottom Line: TBI

- Focus- the practitioner & regulator
- Accurate emission estimates
- Provides clearly defined target and easy method to monitor progress
- Eliminates labeling of tree species
- Facilitates verification and enforcement
- Works at partner or project level

Water & Climate Change

- Climate-Ready Tree Species Evaluation

Approximately 50% of the rise in near surface air temperatures since the 1960s is attributable to land use

Impact of urbanization and land-use change on climate

Eugenia Kalnay & Ming Cai

University of Maryland, College Park, Maryland 20770-2425, USA

The most important anthropogenic influences on climate are the emission of greenhouse gases[1] and changes in land use, such as urbanization and agriculture[2]. But it has been difficult to separate these two influences because both tend to increase the daily mean surface temperature[3,4]. The impact of urbanization has been estimated by comparing observations in cities with those in surrounding rural areas, but the results differ significantly depending on whether population data[5] or satellite measurements of night light[6–8] are used to classify urban and rural

use the difference between trends in observed
ures in the continental United States and the
nds in a reconstruction of surface temperatures
a reanalysis of global weather over the past 50
ensitive to surface observations, to estimate the
se changes on surface warming. Our results
f the observed decrease in diurnal temperature
ban and other land-use changes. Moreover, our
C mean surface warming per century due to

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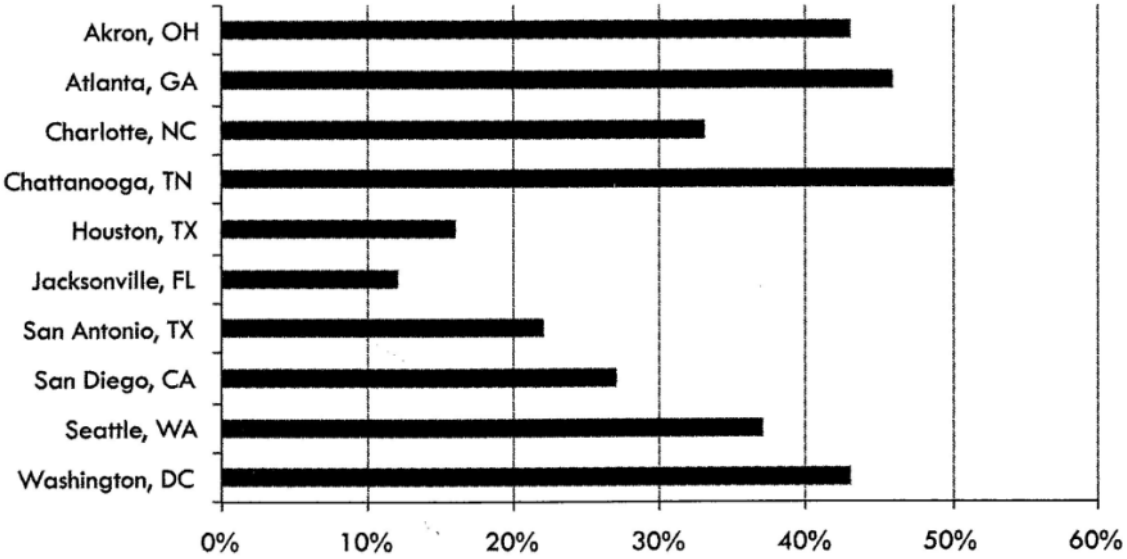
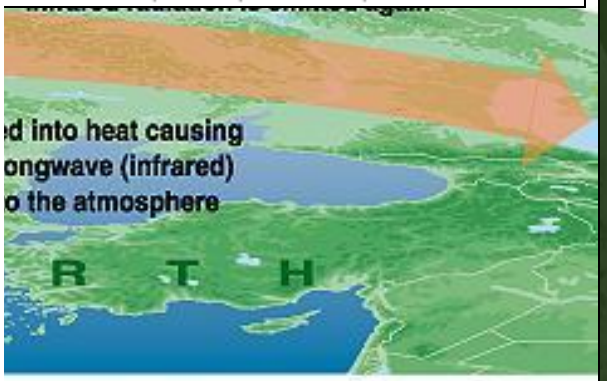


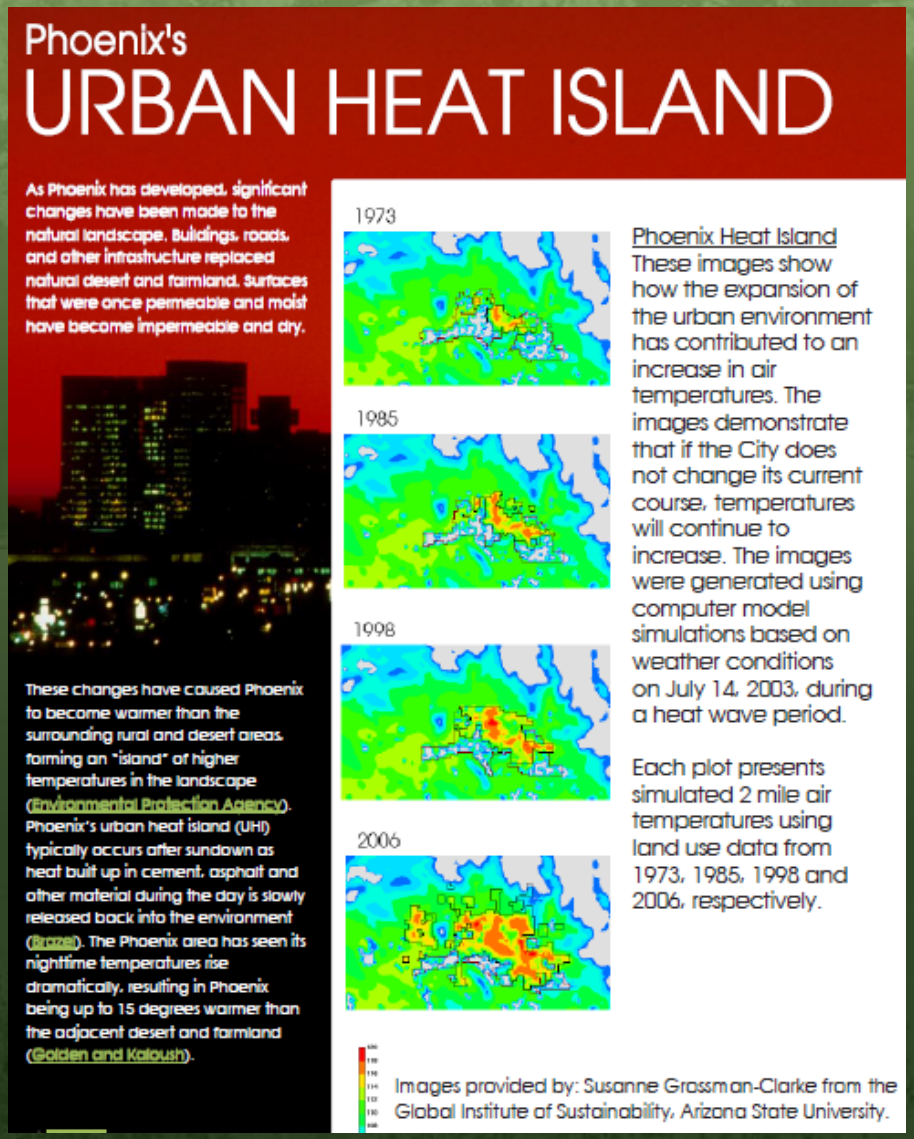
Figure 4.1 Percent decline in tree canopy of large U.S. cities. All trends are reported for a period of at least 10 years between 1973 and 2008. *Source:* American Forests.



nmental Protection Agency (EPA), Washington; Climate change
mate change, UNEP and WMO, Cambridge university press, 1996.

Urban Heat Islands

- Physical form
- Materials
- Urban activities



Urban Heat Islands

- Large US cities warming is 50-100% greater than nearby rural areas
- Magnitude of warming attributable to UHIs over past 50 years is greater than attributable to GHGs

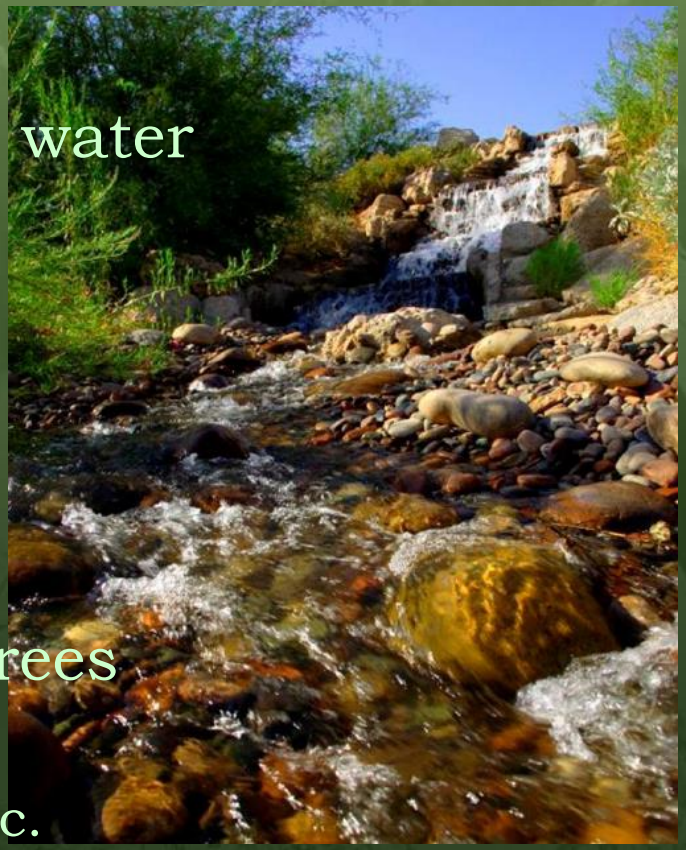
Figure 3.8 Decadal rates of change in urban heat island intensity: 1961–2010. Trends are reported for the 50 most populous U.S. cities for which continuous temperature data are available during this period. *Source:* Temperature-trend data obtained from the Goddard Institute for Space Studies, NASA.

Impacts

- Energy
- Air Quality
- Human Health
- Water Use
- Tree Health
- Environmental Justice

Water and the Urban Forest

- Water use
  - Tree species and size
  - Potable, harvested, reclaimed water
- Net effects
  - Temperature reduction
  - Reduced BVOC emissions
  - Reduced ozone formation
  - Other benefits from healthy trees
    - CO_2 stored & avoided emissions
    - Interception & runoff control, etc.



Cool Urban Spaces Project

- Increase UTC 10-15% = 3.6 °F cooling
- Increase UTC 10-25% = 7.9 °F cooling
- Adding grass patches = 0.5 °F cooling

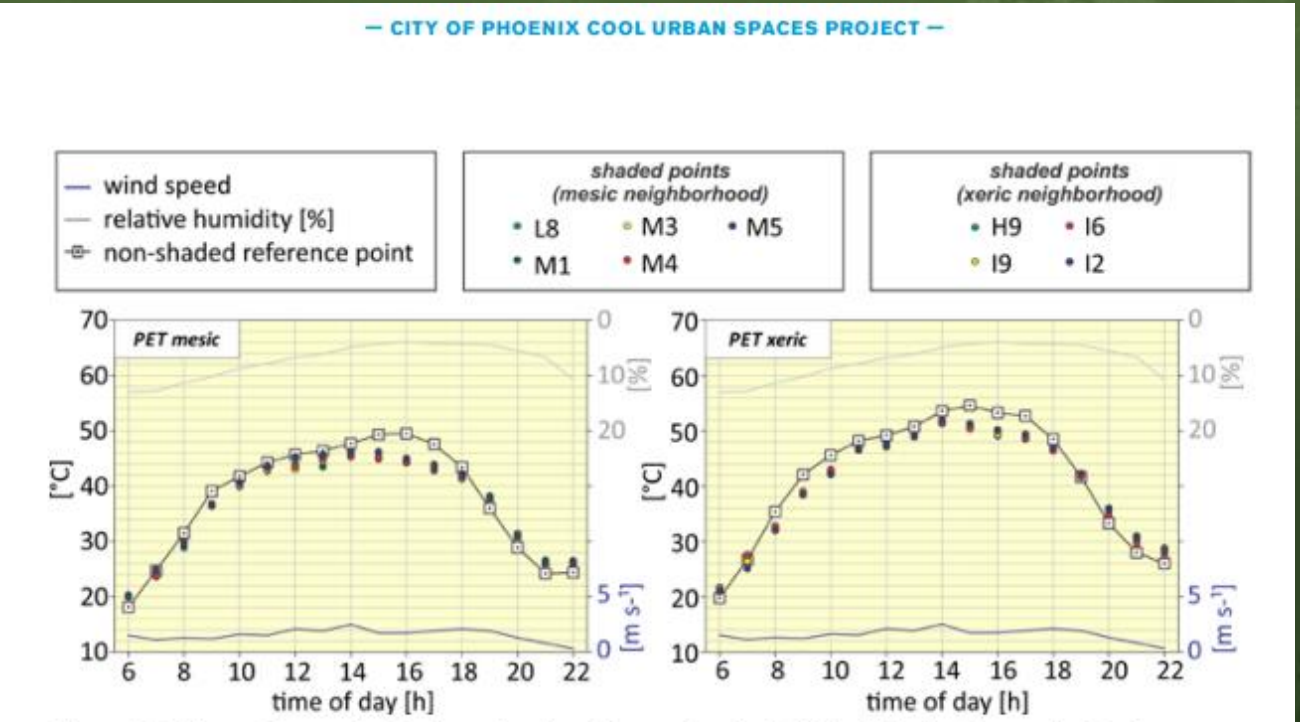


Figure 8: RayMan model output for the observation sites in the mesic and xeric NDV neighborhood at non-shaded reference points and under nine selected trees. Thermal comfort measures MRT and PET for a woman, 65 kg, 1.60 m, 35 years, t-shirt and skirt, standing (Middel et al., 2014b).

Million Trees LA – CO_2 Sink or Source?

- Sink
  - Emissions 46% of Uptake
  - Net Uptake = -98,053 t

Removal	CO_2 (t)	Release	CO_2 (t)
Stored (Live trees)	-73,703	Equipment	4,704
Stored (Roots)	-4,139	Vehicles	3,602
Avoided (Energy)	-101,679	Water	8,095
Avoided (Biopower)	-1,940	Tree Prod. Mats.	648
		Mulch Decomp.	45,269
		Root Decomp.	9,023
		Wood Combustion	12,067
Total	-181,460	Total	83,408
Net Total	-98,053	Net/tree/yr (kg)	-26.7

Hot Spots

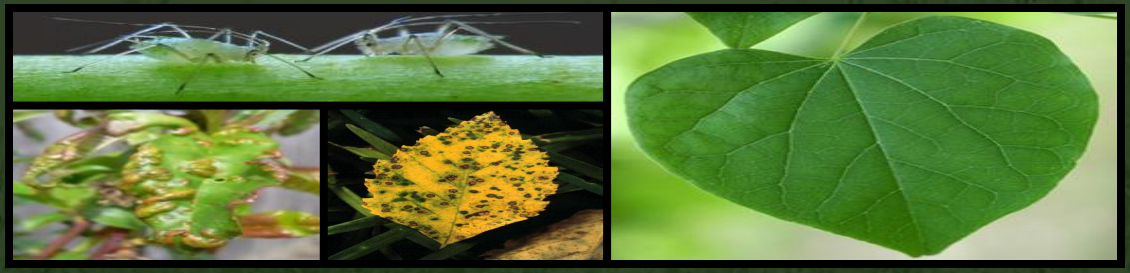
- Decomposition
  - Wood products
  - Bioenergy
- Water
  - Species: 9 low, 34 mod water use
  - Soil management
  - Irrigation efficiency & rainwater harvesting
- Mortality & Removal
  - Vehicle & equipment emissions
  - Creates biomass to process & decomposition
  - Reduces uptake by live trees

Trade-offs

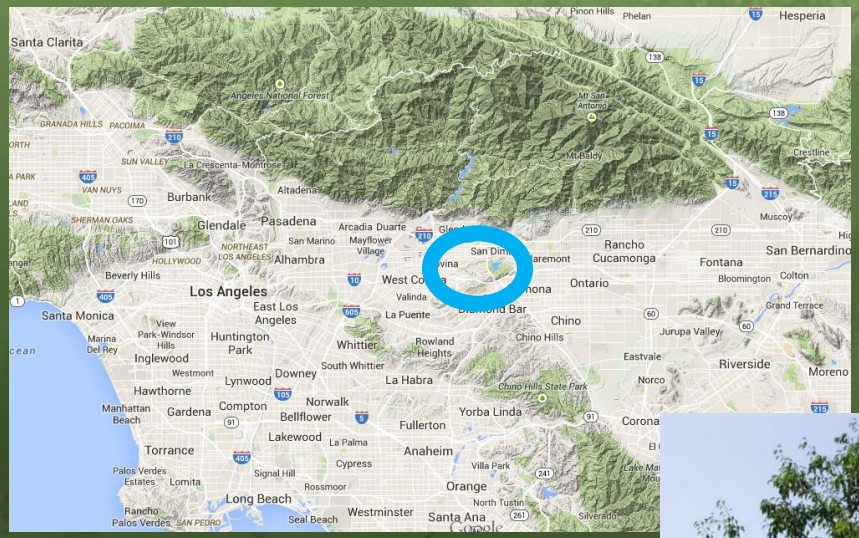
- Drought-tolerant trees = efficient use of water for quality of life
- Use water efficiently: harvest, soil banking, real time soil sensors
- Speak on value of healthy canopy, water will follow

Climate-Ready Tree Species Evaluation

- Risk of tree loss
  - Limited diversity
  - Poorly-adapted species
- Two points of leverage
  - Tree selection
  - Tree maintenance



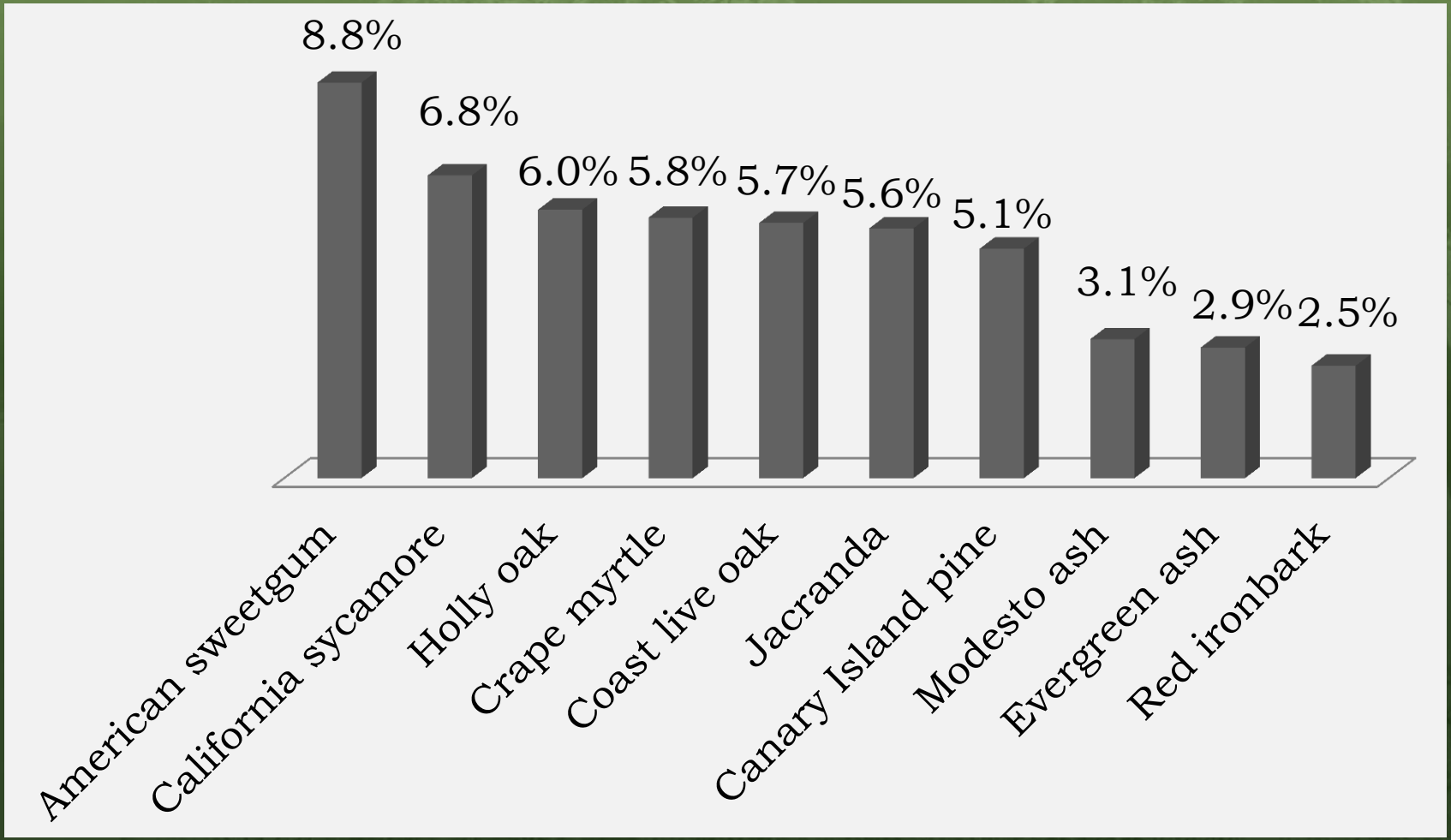
Example 1: Remeasurement of Claremont's Street Trees



2000

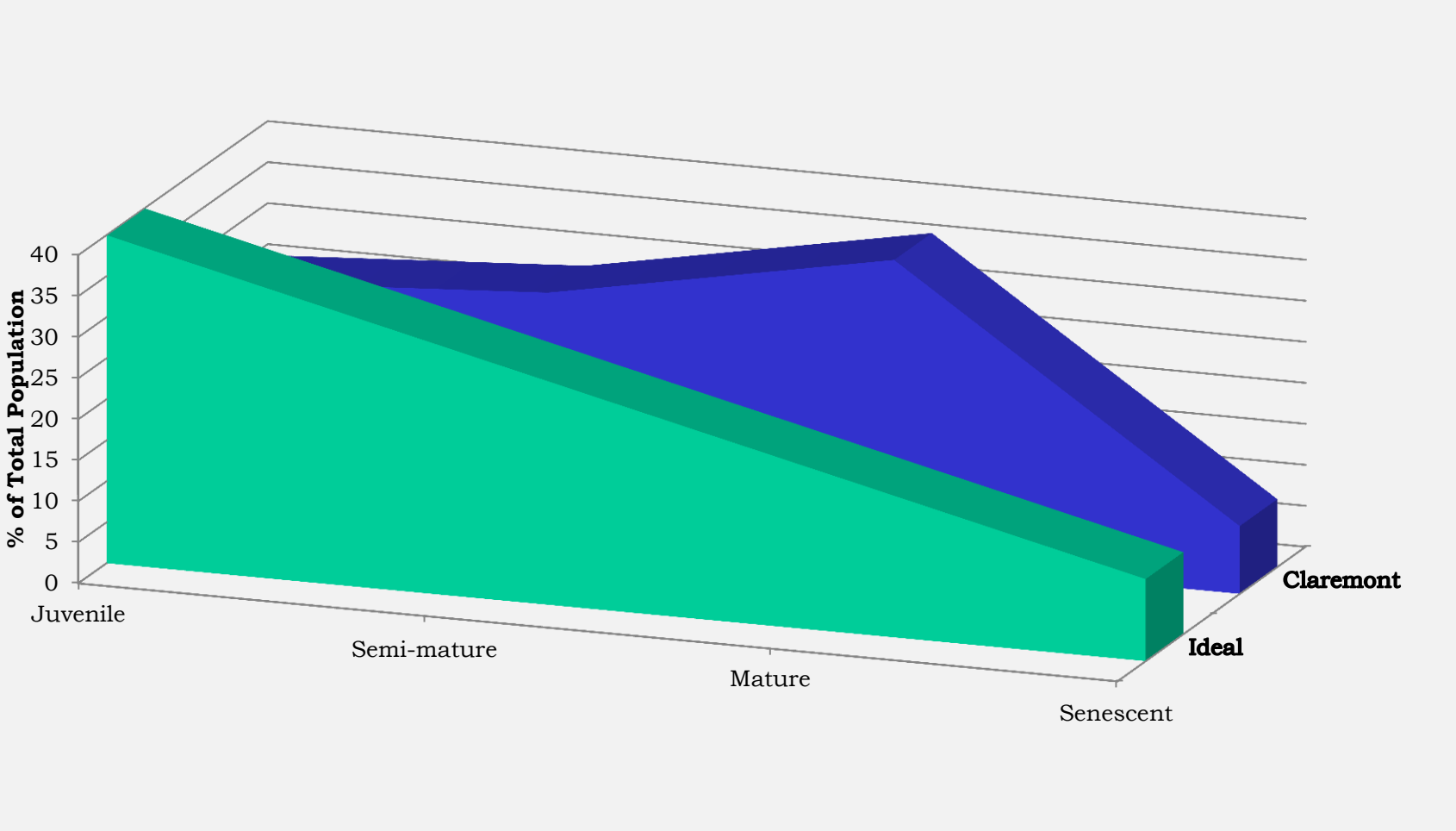
2014

Top ten species based on importance value



Data source: 2011 municipal tree inventory (WCA)

Street tree population is maturing (more than is "ideal")



Data source: 2011 municipal tree inventory (WCA)

Maturing street tree population…

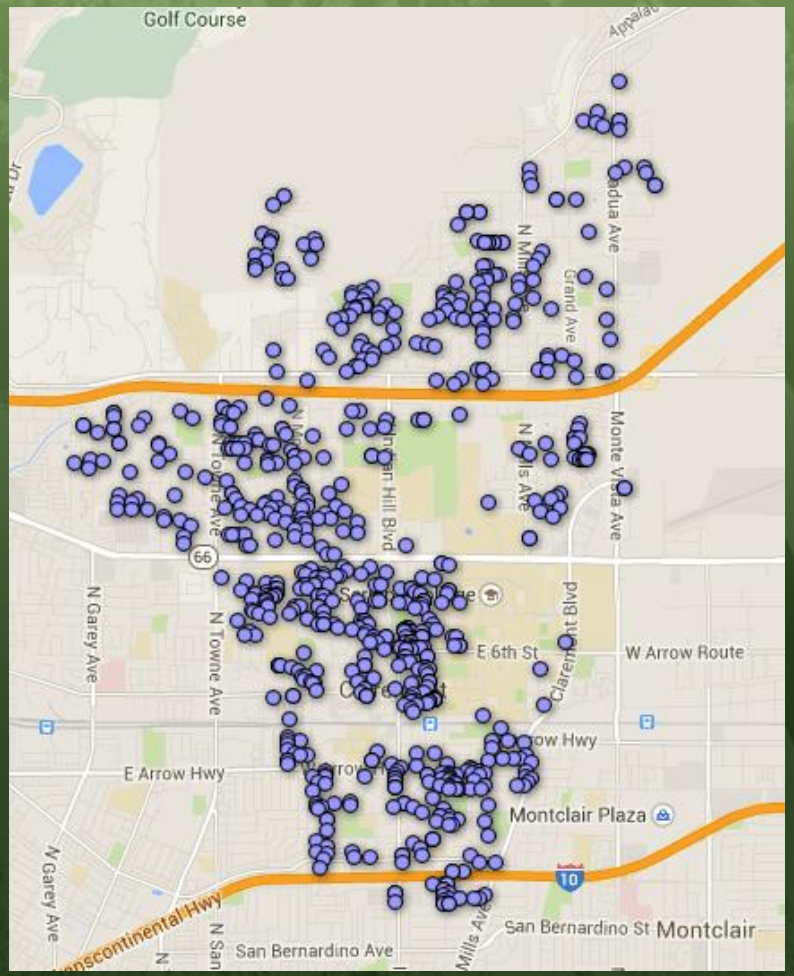
…with management challenges

Street tree population dynamics

- Growth, removal, & replacement rates?
- Resilient to a changing climate?

Methods

- 762 sites visited in 2000 & 2014
- 21 most abundant species
- Random selection stratified by size class

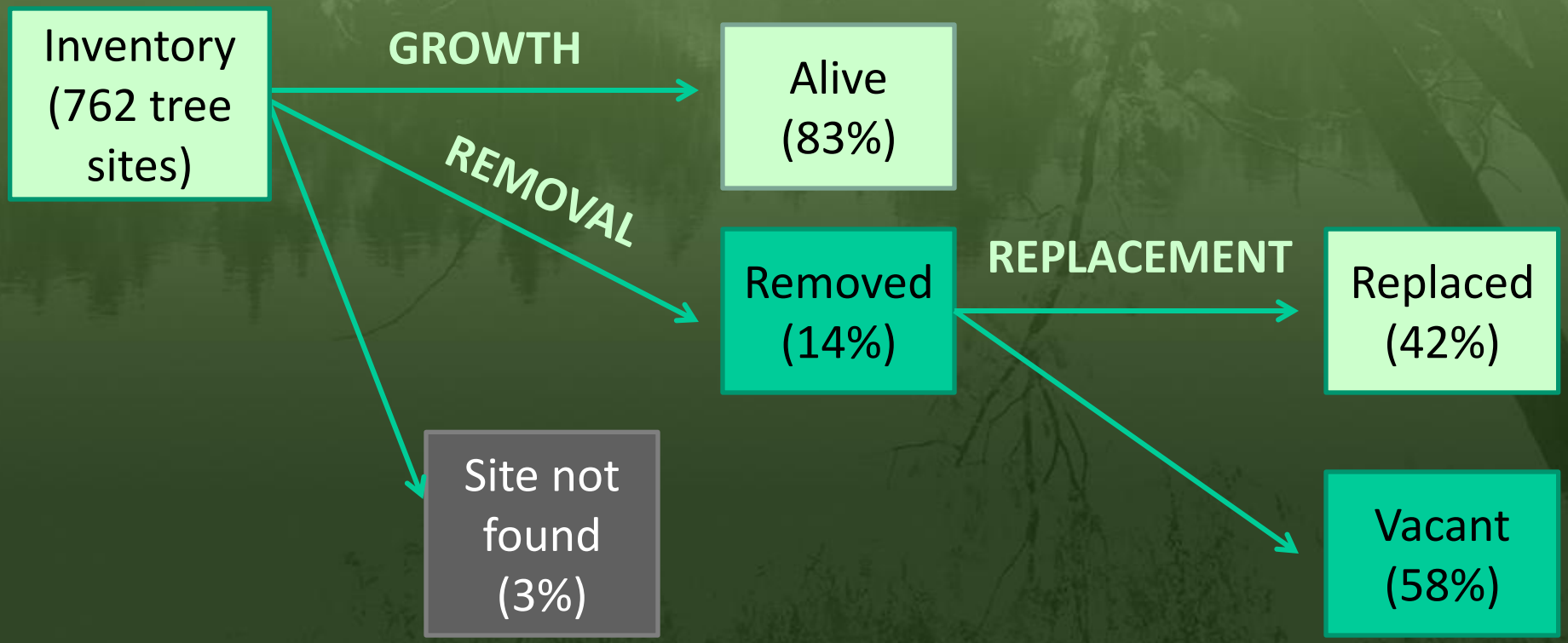


Methods

- DBH, tree height, crown diameter
- Sidewalk damage, utility lines

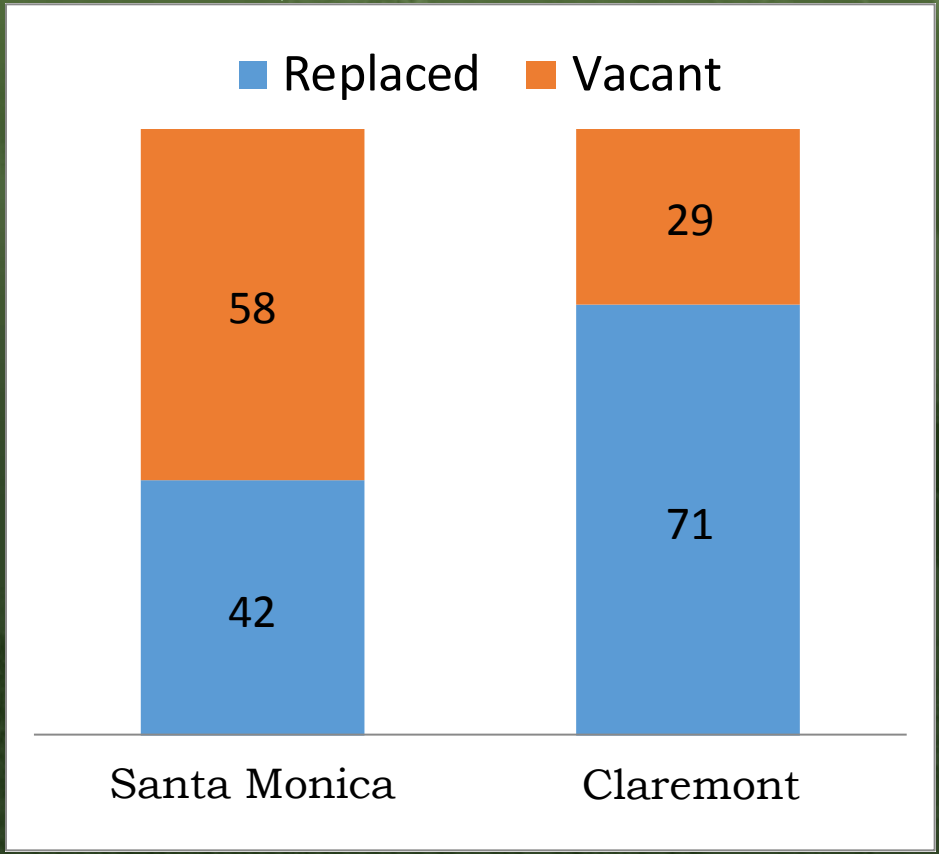
Challenges: to measure the same tree as before!

Tree sites [2000 - 2014]



Context: Claremont vs. Santa Monica

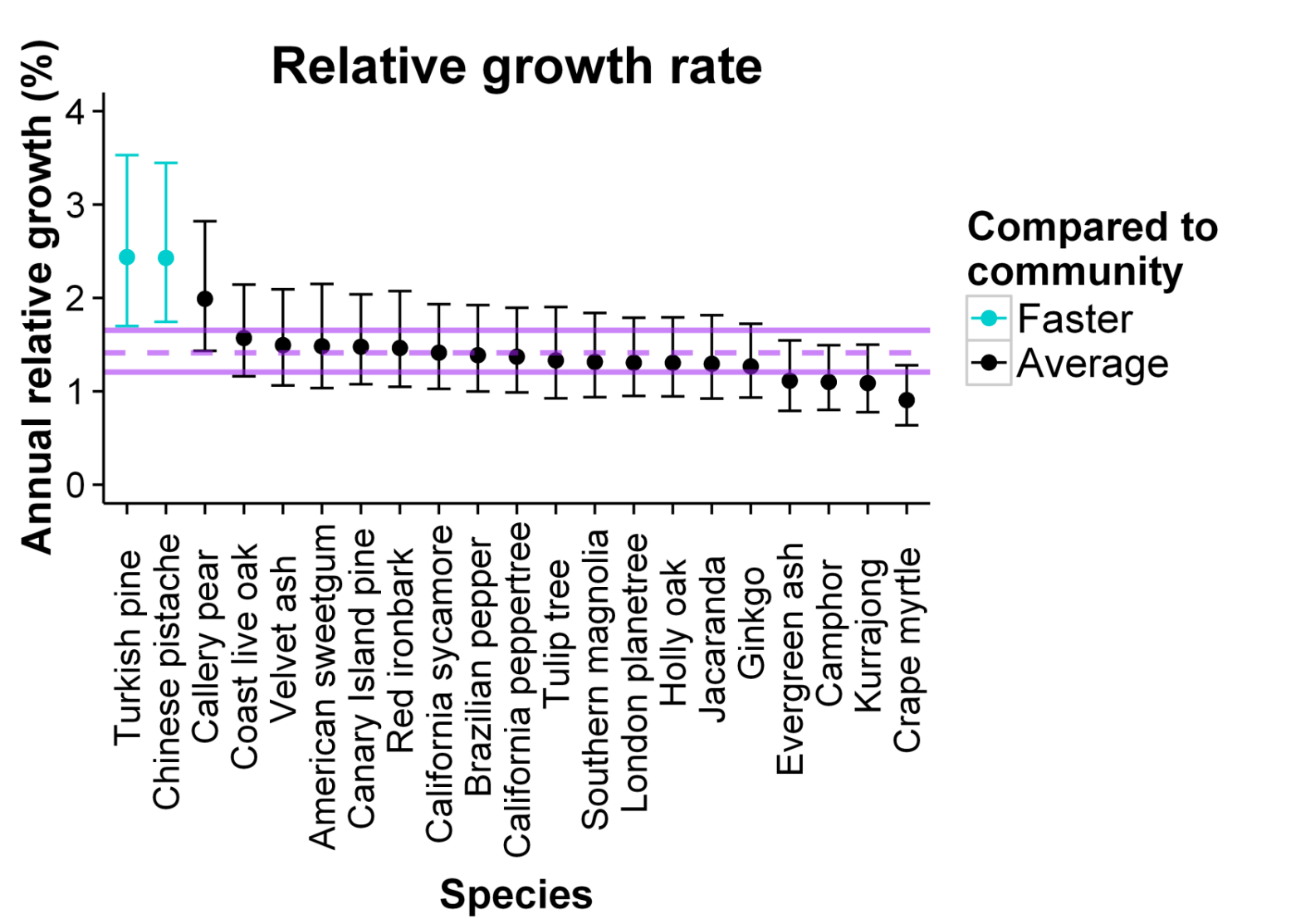
- In SM, more trees were removed (23% vs. 14%)
- and yet more sites replanted (71% vs. 42%)
- Budgets



GROWTH

REMOVAL

REPLACEMENT

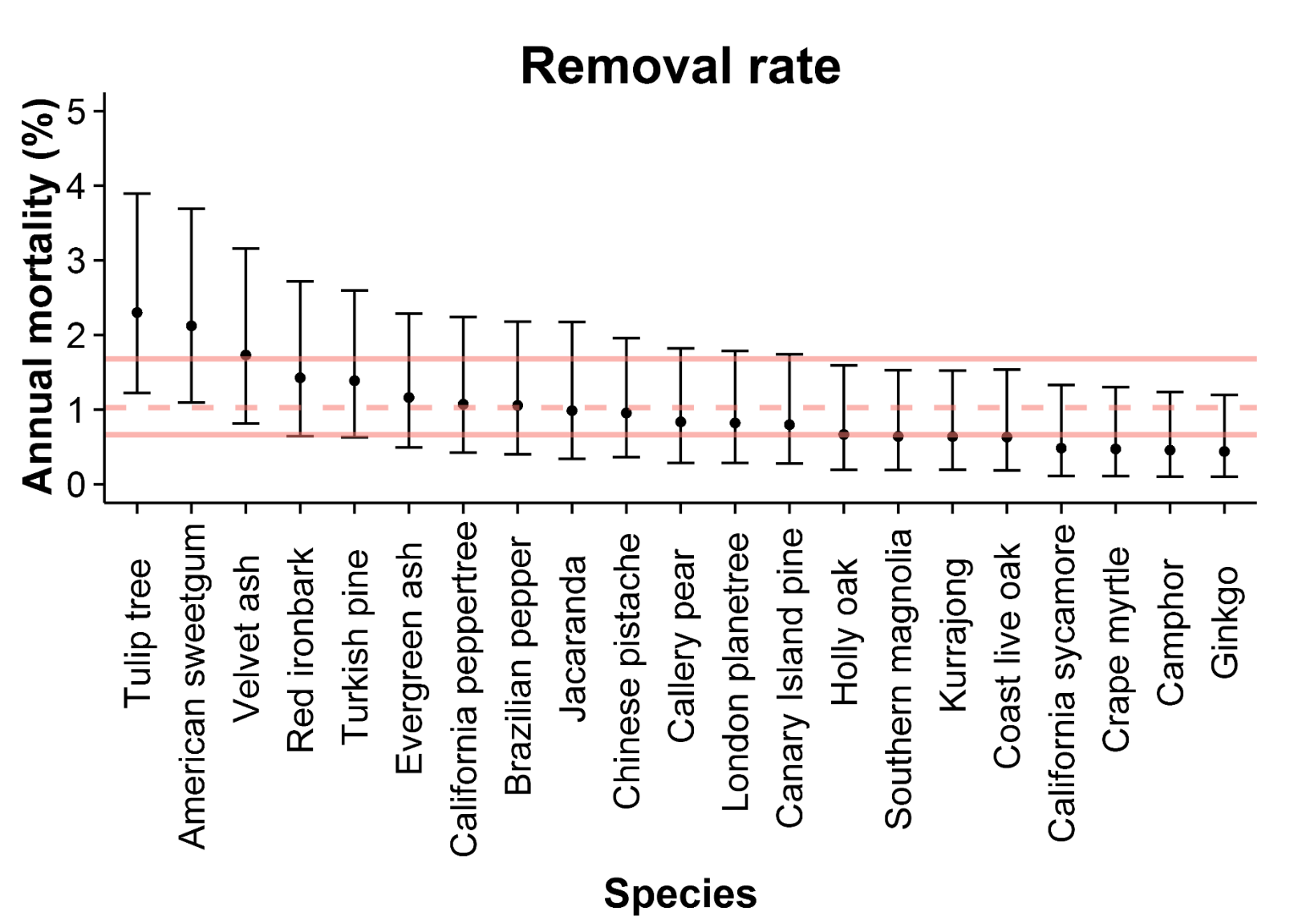


* Median ± 95% credibility intervals

GROWTH

REMOVAL

REPLACEMENT



* Median ± 95% credibility intervals

GROWTH

REMOVAL

REPLACEMENT

Factors contributing to tree removal

Tree size

Growing space

Sidewalk damage

TREE REMOVAL

Utility lines

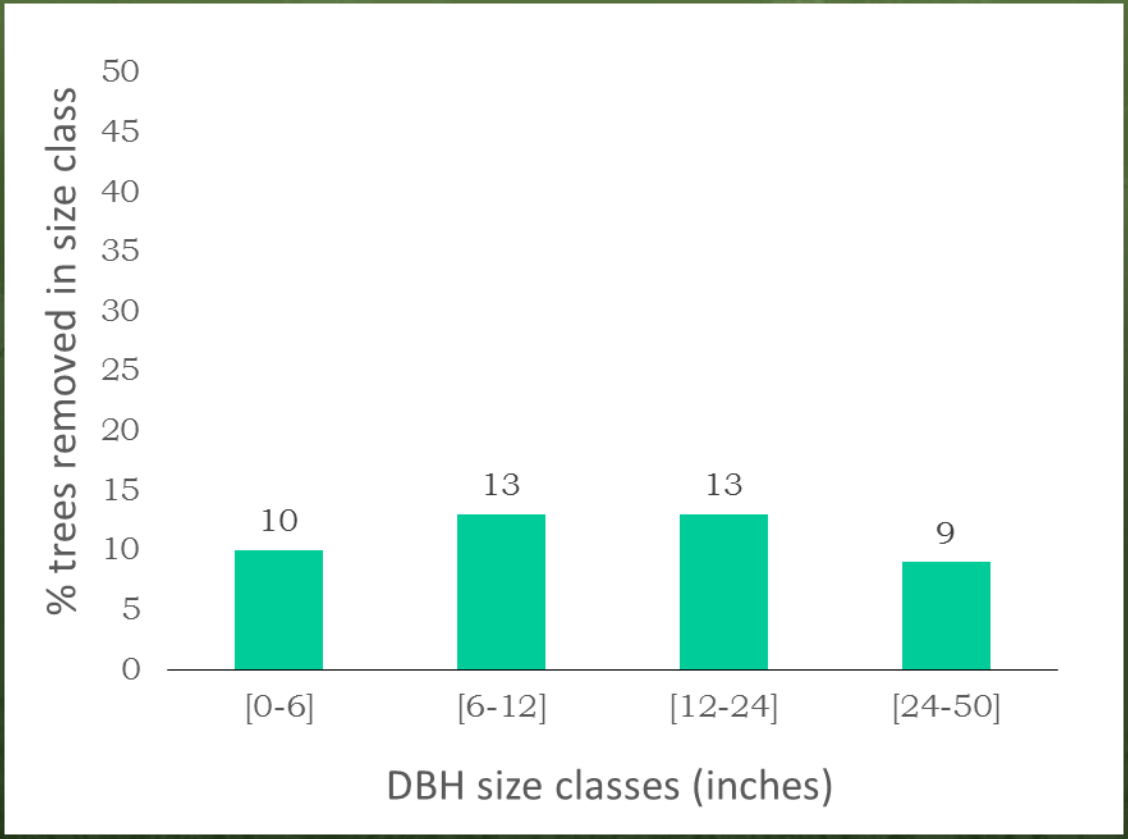
Poor condition (damage, lack of watering, poor stock)

GROWTH

REMOVAL

REPLACEMENT

Was the largest size class preferentially removed? No.



GROWTH

REMOVAL

REPLACEMENT

Did lack of growing space promote removal? No.

Smallest growing space

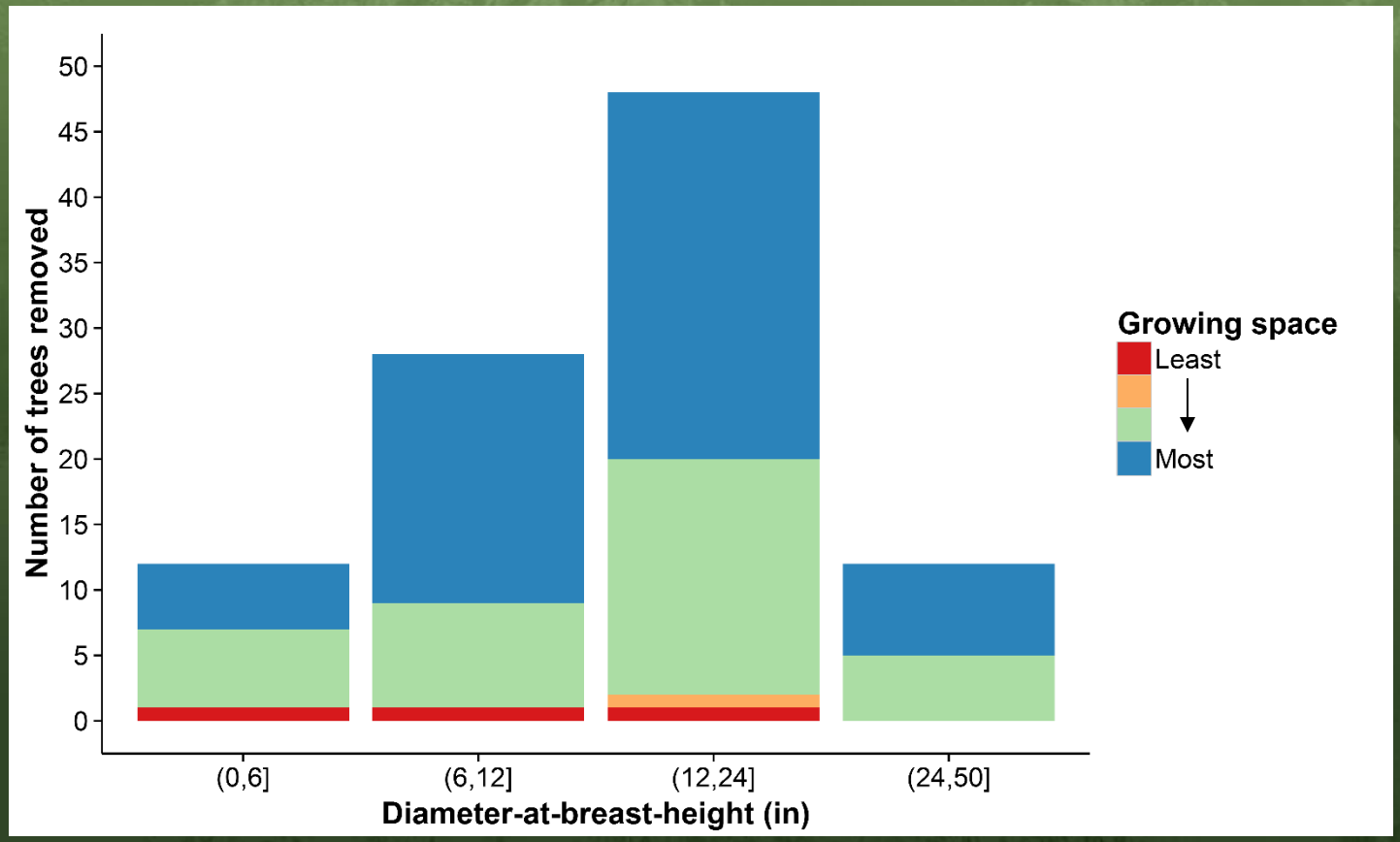
Largest growing space

GROWTH

REMOVAL

REPLACEMENT

- 59% of removals had the most amount of growing space



GROWTH

REMOVAL

REPLACEMENT

Did proximity to utility lines contribute to removal? No.

- Only 2 out of the 100 removals were under utility lines
- But many trees pruned (topped) – eventual decline?

Red ironbark eucalyptus removed after 2000

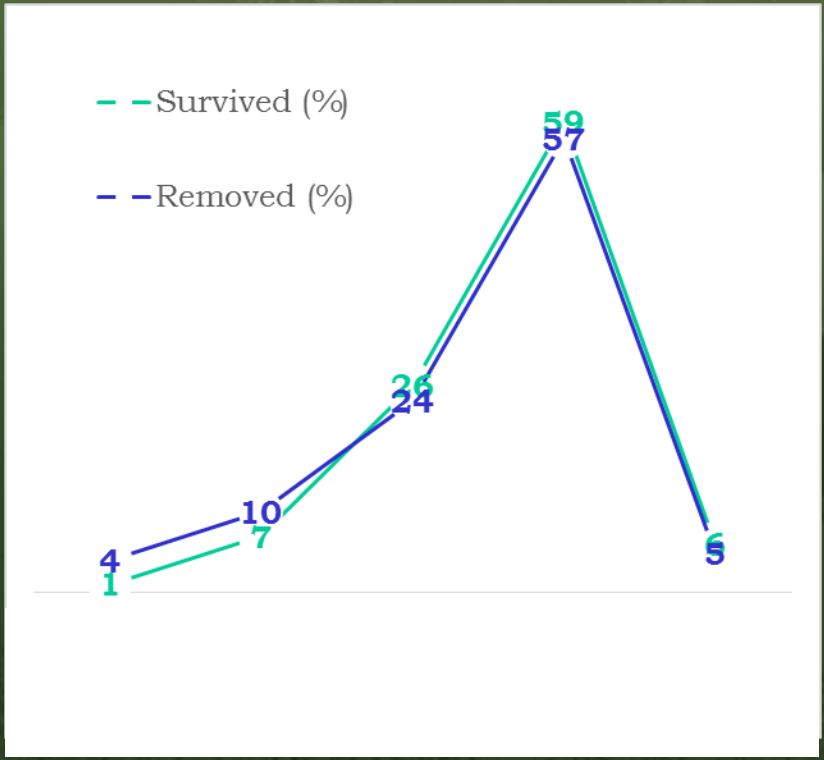
GROWTH

REMOVAL

REPLACEMENT

Did condition of the tree in 2000 contribute to removal? Yes.

- 14% of removed trees (vs. 8% of survivors) were in poor condition in 2000



GROWTH

REMOVAL

REPLACEMENT

Did sidewalk damage contribute to removal? Likely yes.

Year	Damaged sites
2000	50%
2014	4%

- 58% of removed trees were in damaged sites

- By 2014, many repairs had been made →

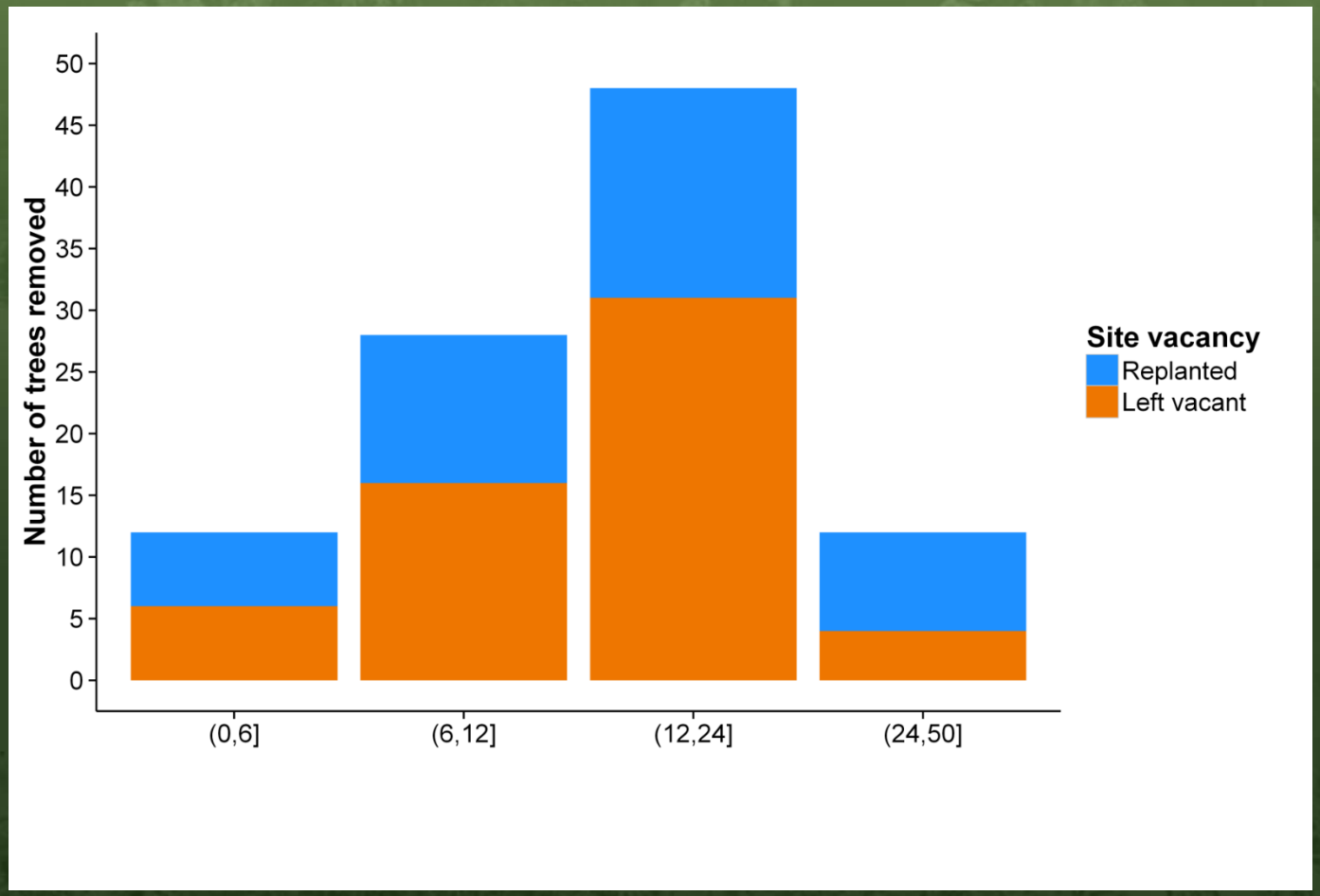
GROWTH

REMOVAL

REPLACEMENT

Replaced or left vacant?

- 58% of sites were left vacant
- Highest vacancy in semi-mature class



GROWTH

REMOVAL

REPLACEMENT

Example:
Holly oak removed and not replaced

2000

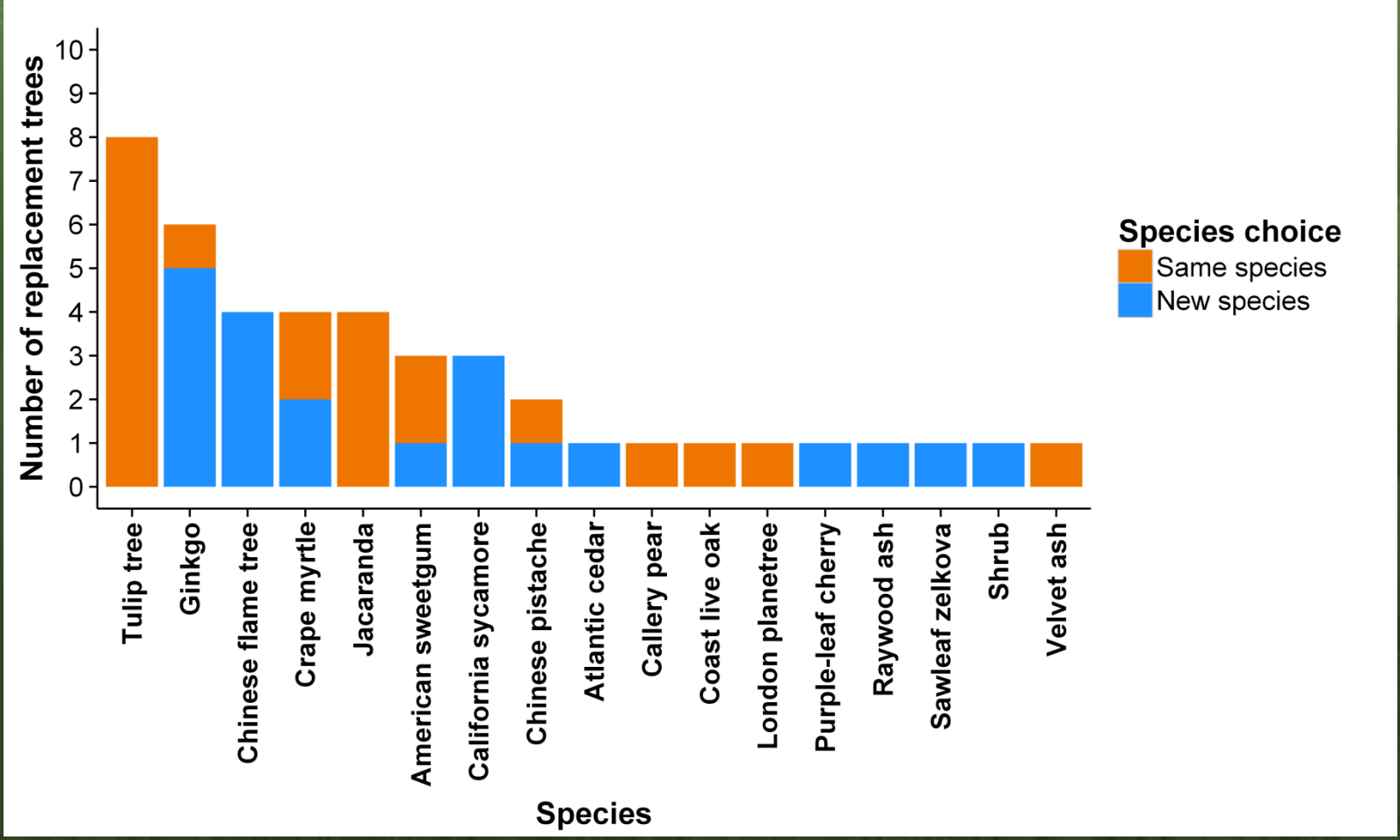
2014

GROWTH

REMOVAL

REPLACEMENT

What are removed trees being replaced with?



GROWTH

REMOVAL

REPLACEMENT

Species' Climate-Readiness Scoring

Habitat	Physiology	Biological interactions
Soil moisture	Drought tolerance	Invasiveness
Soil texture and pH	Wind tolerance	Major or minor pest and disease threats
Sunlight exposure	Salt tolerance	Emerging pest and disease threats
	Cold hardiness	

Credit: E. Roeble

GROWTH

REMOVAL

REPLACEMENT

Climate-readiness ✚

Special Features
Biogenic emissions
Shade potential
Longevity
Biodiversity
Aesthetics
Root damage potential
Litter
Native to CA
Carbon storage

GROWTH

REMOVAL

REPLACEMENT

Climate-Readiness Results

	Climate Ready
Pinus brutia	5
Schinus molle	5
Brachychiton populneus	4
Pinus canariensis	3
Pistacia chinensis	3
Schinus terebinthifolius	3
Quercus agrifolia	3
Quercus ilex	3
Ginkgo biloba	3
Eucalyptus sideroxylon	3
Cinnamomum camphora	2
Platanus racemosa	1
Cedrus atlantica 'Glauca'	1
Fraxinus uhdei	1
Platanus x hispanica	1
Fraxinus angustifolia	0
Lagerstroemia indica	0
Koelreuteria bipinnata	0
Pyrus calleryana	0
Zelkova serrata	-1
Jacaranda mimosifolia	-1
Fraxinus velutina	-1
Liquidambar styraciflua	-1
Liriodendron tulipifera	-2
Prunus cerasifera 'Atropurpurea'	-2
Magnolia grandiflora	-2

+

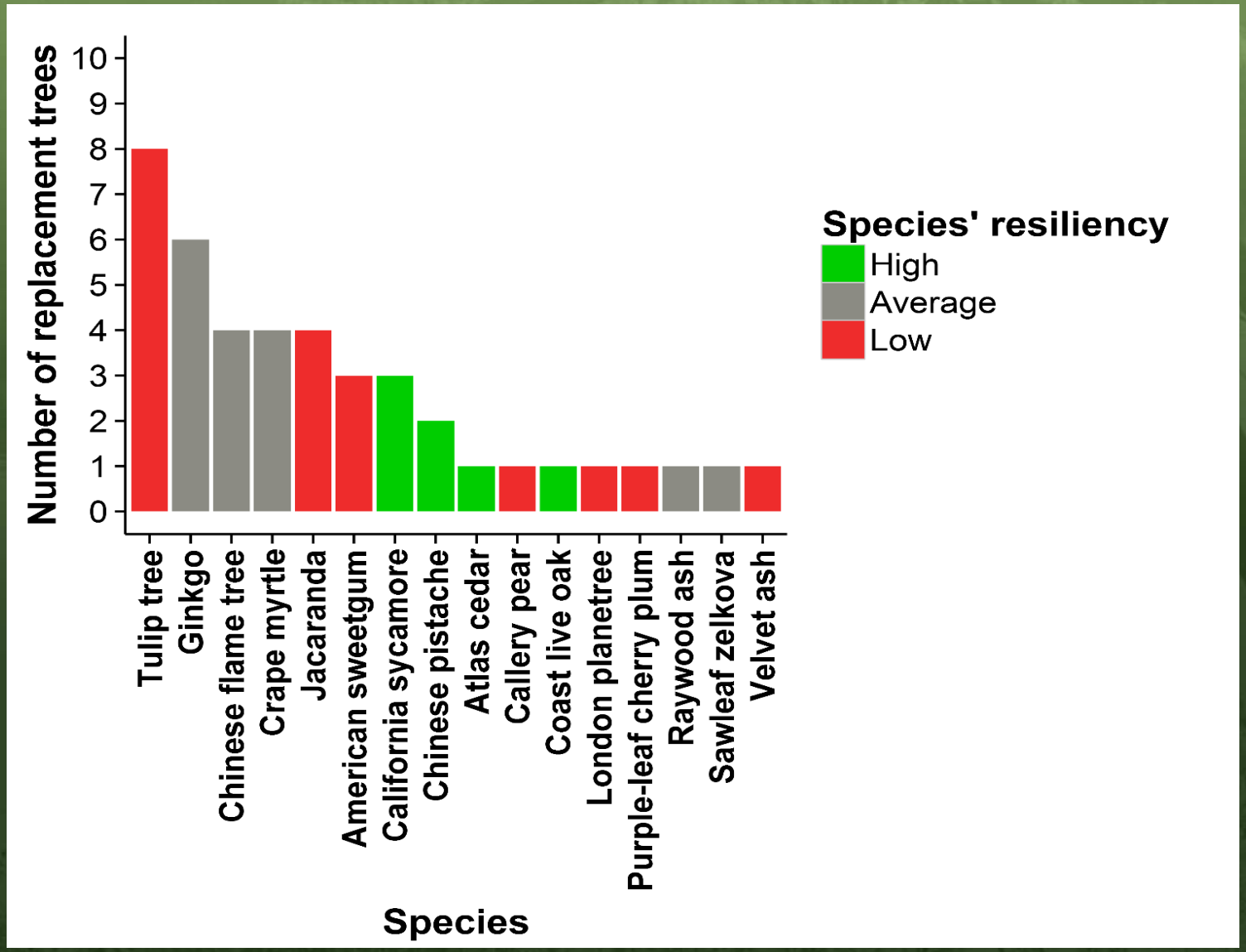
Special Features	GRAND TOTAL	
4	9	Pinus brutia
5	8	Pinus canariensis
2	7	Schinus molle
2	6	Brachychiton populneus
3	6	Pistacia chinensis
5	6	Cedrus atlantica 'Glauca'
2	5	Schinus terebinthifolius
2	5	Quercus agrifolia
2	5	Quercus ilex
4	5	Platanus racemosa
1	4	Ginkgo biloba
2	4	Cinnamomum camphora
0	3	Eucalyptus sideroxylon
3	3	Fraxinus angustifolia
3	2	Zelkova serrata
0	1	Fraxinus uhdei
1	1	Lagerstroemia indica
1	1	Koelreuteria bipinnata
0	0	Pyrus calleryana
1	0	Jacaranda mimosifolia
2	0	Liriodendron tulipifera
-2	-1	Platanus x hispanica
1	-1	Prunus cerasifera 'Atropurpurea'
1	-1	Magnolia grandiflora
-1	-2	Fraxinus velutina
-2	-3	Liquidambar styraciflua

GROWTH

REMOVAL

REPLACEMENT

Replacement Species



Recommendations

- Care for aging tree population
  - Aggressively remove least resilient species

- Replace removals with climate-ready species

- Select larger-canopy trees where practical
- Reduce pest vulnerability:
  - increase species diversity & spatial heterogeneity

Example 2: Testing Climate-Ready Trees

Drs. Greg McPherson &
Natalie van Doorn
US Forest Service
PSW Research Station
Davis, CA

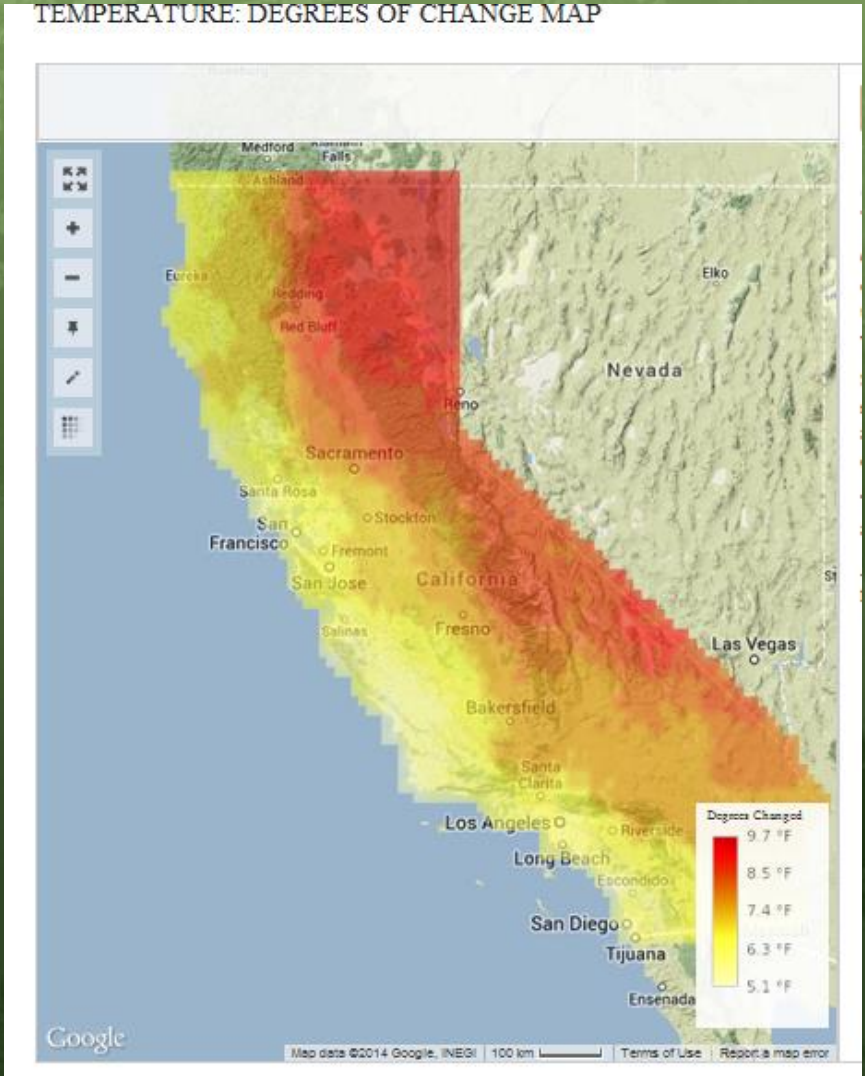
Dr. Alison Berry
Dept. of Plant Sciences
UC Davis, Davis, CA

Goal

- Change tree palette to more resilient species
- 20-year study to test promising cultivars
  - Resilience to climate change
  - Other qualities
- Network of sites and collaborators
- Share performance information

Adaptation

- Exposure – extent?
  - Temperature
  - Precipitation
  - Wind
- Sensitivity – how react?
- Adaptive Capacity – potential to adapt?



Projected Climate

- Temperature
  - 1½ zone changes
- Precipitation
  - 110% increase
  - More winter, less summer

Projected Changes in USDA Hardiness Zones				
City	2010-2019 Avg Min Temp (°F)	Current Hardiness Zone	2080-2089 Avg Min Temp (°F)	Predicted Hardiness Zone
Redding	34.1	**9B** ->10A	40.6	10A-> **11A**
Sacramento	36.7	**9B** ->10B	42.4	10B-> **11A**
Merced	33.6	**9A** ->10A	38.9	10A-> **10B**
Fresno	34.6	**9B** ->10A	40.0	10A-> **11A**
Bakersfield	36.3	**9B** ->10B	41.5	10B-> **11A**

http://cal-adapt.org/tools/

Profiles for 12 Species

TRAIT	Source	Description
HABITAT SPECIFICITY		
Soil Moisture	Selec Tree	Soil moisture required by tree species for establishment.
Soil Texture and pH	Selec Tree	Trees species tolerance of a range of soil pH and textures.
Sunlight Exposure	Selec Tree	Tree species tolerance of full sun, shade, and filtered exposure.
PHYSIOLOGY		
Drought Tolerance	WUCOLS	Water needs of tree species: high, moderate, or low water needs.
Wind Tolerance	Selec Tree	Branch strength of tree species: strong, medium, weak.
Salt Tolerance	Selec Tree and Wu and Dodge 2005	Salinity tolerance
Cold Hardiness	USDA Cal-Adapt	Species tolerance of minimum temperatures in Central Valley.
BIOLOGICAL INTERACTIONS		
Invasiveness	Cal-IPC	Potential for species invasiveness: severe, moderate, minor.
Current Pest and Disease Threats	Pest Vulnerability Matrix (PVM)	Current pest and disease threats that pose risk to tree species.
Emerging Pest and Disease Threats	Pest Vulnerability Matrix (PVM)	Emerging pest and disease threats that could pose risk to tree species in the future.

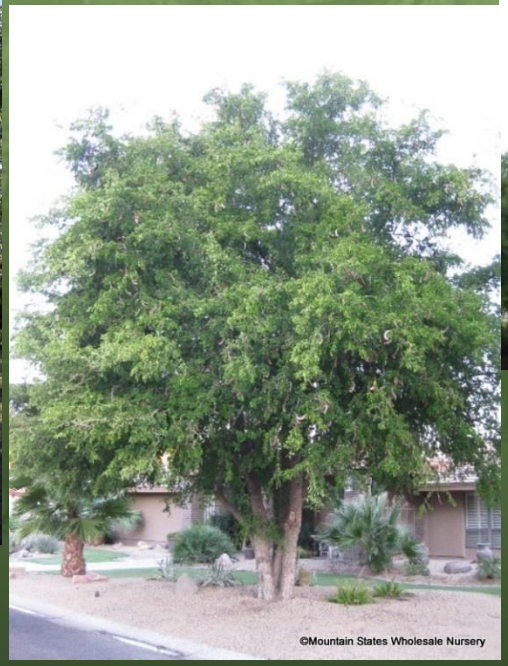
Southwest US

Desert Willow

Honey Mesquite

Palo Verde "Desert Museum"

Osage Orange 30’-50’



Texas Ebony (thorns, borer)

Canby Oak – up to 50’

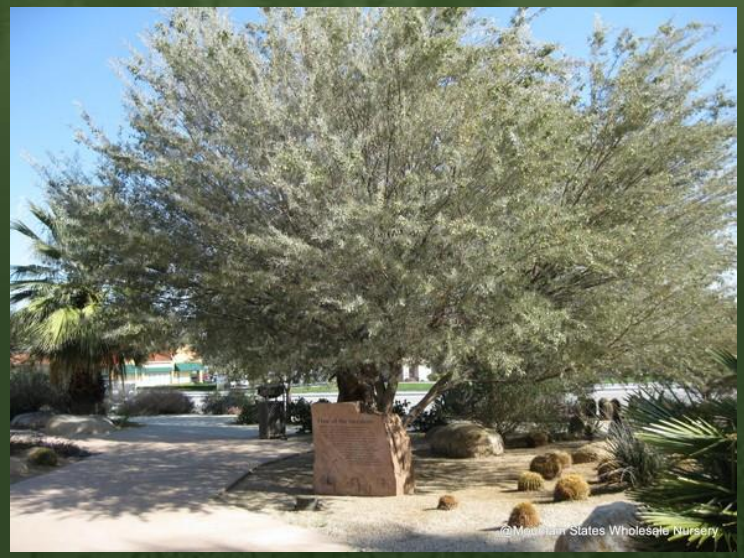
Oklahoma, West Texas

Netleaf Hackberry - up to 80’

Australia

Shoestring acacia

Ghost gum (*Eucalyptus papuana*), 60’ height



Mulga (*Acacia aneura*)

Asia

Elm ‘Emerald Sunshine’
Ulmus davidiana v *japonica*

35’; DED, elm leaf beetle resistance

Rosewood (*Dalbergia sissoo*; India)

60’, full leafy crown, highly decay resistant, few pests (root suckers)

Experimental Design

- Control plot UCD (48)
- 4 Sacramento parks (24 at each)
- Measure
  - Tree size
  - Crown vigor
  - Pruning, pest, disease
  - Soil type, temp, moisture
  - ET, minimum temperatures
  - Leafing out date
- 2016 in SoCal

SPCODE	Scientific	Common_Nam	Size
AA	Acacia aneura	Mulga	#15
AS	Acacia stenophylla	Shoestring acacia	#15
CR	Celtis reticulata	Netleaf Hackberry	#15
CL	Chilopsis linearis 'Bubba'	Desert Willow	#15
DS	Dalbergia sissoo	Rosewood	#15
EE	Ebenopsis ebano	Texas Ebony	24 box
EP	Eucalyptus papuana	Ghost gum	#15
MP	Maclura pomifera 'White Shield'	White Shield Osage Orange	BR
PD	Parkinsonia x 'Desert Museum'	Desert Muesum Palo Verde	#15
PG	Prosopis glandulosa x Maverick	Thornless Honey Mesquite	24 box
QC	Quercus canbyi	Canby's oak	24 box
UP	Ulmus propinqua	Emerald Sunsine Elm	BR

CAUTION

Wrap-Up

Summary

- Are the Goals of Increased UTC, Cleaner Air, Less Water Use Mutually Exclusive?
  - Not if goal is to make Phoenix more livable
- Have a Plan (What and How)
- Prepare A Diversity of Prescriptions
- Leverage Points: tree selection, removals
- Smooth the Transition
  - Monitor and respond to threats

Questions?