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Temperature Variability Differs in Urban Agroecosystems across Two Metropolitan Regions

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Abstract: Climatically similar regions may experience different temperature extremes and weather patterns that warrant global comparisons of local microclimates. Urban agroecosystems are interesting sites to examine the multidimensional impacts of climate changes because they rely heavily on human intervention to maintain crop production under different and changing climate conditions. Here, we used urban community gardens across the California Central Coast metropolitan region, USA, and the Melbourne metropolitan region, Australia, to investigate how habitat-scale temperatures differ across climatically similar regions, and how people may be adapting their gardening behaviors to not only regional temperatures, but also to the local weather patterns around them. We show that, while annual means are very similar, there are strong interregional differences in temperature variability likely due to differences in the scale and scope of the temperature measurements, and regional topography. However, the plants growing within these systems are largely the same. The similarities may be due to gardeners' capacities to adapt their gardening behaviors to reduce the adverse effects of local temperature variability on the productivity of their plot. Thus, gardens can serve as sites where people build their knowledge of local weather patterns and adaptive capacity to climate change and urban heat. Climate-focused studies in urban landscapes should consider how habitat-scale temperature variability is a background for interesting and meaningful social-ecological interactions.

Keywords: temperature variation; community gardens; urban food production; crop choice; California; Australia

1. Introduction

Climate variability and extremes are increasingly impacting society as more people live in urban areas affected by climate change [1,2]. Urban populations are expected to experience longer and more frequent extreme heat events [3], drought and flooding [4]. Variation in temperature and precipitation affect the biophysical functioning of urban ecosystems [5]. Urban vegetation is sensitive to high heat and water stress, and urban plants are partially limited by temperatures as management can alleviate some of these stressors [6]. However, due to the extent of these changes, urban ecosystems are forecast to decline in canopy cover and health in the next decades because many plant species that currently populate urban landscapes may not survive or thrive in the more variable and extreme future climate scenarios of some cities [7–9]. These declines are concerning because vegetation within habitats across an urban landscape can regulate local microclimate and provide cooling benefits to cities [10].

Local management of urban vegetation can work to combat high temperatures and their duration. Changes in urban temperatures are thus shaping the way that some cities approach current and future urban greening efforts [11,12] to improve climate regulation services and sustainable resource management [13].

Additionally, climate variability impacts everyday urban life and prompts behavioral adaptation strategies to perceived and expected impacts, even over short-term periods. Urban heat and temperature variability generally reduce the comfort and health of urban populations [14,15]. People may change how they use urban green and blue spaces for recreation or socializing in response to perceived urban temperatures and weather patterns [16,17]. Changes in behavior in response to temperature and precipitation variability are forms of climate adaptation decision-making made by individuals. Behavioral adaptation refers to both long- and short-term strategies that can reduce the negative effects of or enhance the resilience and reduce the vulnerability of people to climate change impacts [18]. In the context of climate change, people's perception of change, beliefs about risk, and the ability to adapt drive the adaptation process [19,20]. Psychological dimensions of adaptation are also important. Specifically, the perceptions of climate change risks and perceived adaptive capacity [19]: people may enact precautionary behaviors to protect against perceived risk or may enact mitigation behaviors in response to predicted change. Such types of adaptive responses to climate-related impacts likely shift with individual's experiences, motivations, and perceptions, as well as with the social-environmental context in which they live [18]. With climate change increasingly impacting urban residents and environmental management, behavioral adaptation to climate changes will be necessary to reduce social and environmental vulnerability to change. This is especially true for urban agroecosystems (food production systems), including home and community allotment gardens, where extreme weather events have implications for food production, management decisions, and food security. These urban social-ecological systems are sensitive to climate stressors in ecosystem function and the delivery of ecosystem services, food provision, and human well-being.

The implications of increasing temperature variability on urban ecosystems and urban human populations are prominent in opinion and theory [5,21,22], yet few studies measure temperature variability (e.g., in gardens, parks, and forests) in conjunction with environmental management and the human experience [13]. Most studies use global databases or modeled projections to collect information on the temperature at the regional scale for analyses of urban areas (e.g., [23,24]), rather than systematically measuring temperatures at the local habitat-scale [25,26]. While coarse assessments are useful, more information on temperatures at fine spatial and temporal scales is needed to understand local habitat-scale temperature variability and its potential influence on environmental management, human populations, and their ability to respond and adapt to climate change. Further, while most studies evaluate cities' climate change adaptation policies, we still lack information about if and how urban residents are experiencing weather patterns at short time scales and adapting to climate changes in their behaviors and management [27]. Together, this reduces climate to a model-based entity that is more abstract than intimately connected to the lived experience and management decisions of people [28] in systems such as urban gardens.

This paper synthesizes research in urban community gardens across two continents in two climatically-similar urban regions forecast to have increasingly variable climates and growing human populations: the Central Coast Metropolitan Region in California, USA, and the Melbourne Metropolitan Region in Victoria, Australia. These regions of Australia and California have similar more wet vs. more dry seasons and annual temperatures according to long-term climate pattern averages [29] and share similar urban challenges in the context of global environmental change. A range of factors such as urban heat, local vegetation, and others combine to modify these regional climates to create the lived experience of temperature at any one place. Both regions continue to face water shortages and drought crises that challenge their cities and urban residents to sustainably manage environmental resources (e.g., water and urban vegetation). Our work used community gardens as a model system for an interregional comparison of plot-level temperature variability—a scale matching the experience of people and garden plants. Previous research has shown that local vegetation (e.g., vegetation height and cover, canopy cover, and shading) can affect local microclimate, reducing ambient temperatures and mitigating heating factors at the local scale [30–32]. However, the research in these sites found that the local effects were much smaller than regional landscape effects [32,33]. In this study, we focused on larger-scale differences, aiming to identify differences in temperature measurements between the regions and to place garden environmental management and gardener behavioral adaptation within a broader context of their perceptions of local weather patterns and climate variability. To test whether gardens within these climatically similar regions experience similar temperatures at fine spatial and temporal scales, we measured plot-level temperatures within gardens across the regions during the summer growing season. While historical temperature averages for these regions predicts relatively similar temperature would occur within gardens across these regions, assuming similar gradients of local effects on climate, we hypothesized that these habitats do experience differences in local temperature variability and the lived experience of temperature would be different for plants and gardeners between regions. To understand how temperature variability affects aspects of agroecosystem management and peoples' experience in these systems, we surveyed gardeners about the plant populations that they reported having in their plots, and their experience with and perceptions of local weather patterns and regional climatic changes. Here, we hypothesized that: (a) regional similarities in temperatures may lead to similar plant species grown, but that (b) management differences at the local garden scale that create local microclimate differences would lead to different plant species grown.

2. Methods

2.1. Study System

The research took place in nine urban community gardens (henceforth "gardens") across two climatically similar regions: the greater Melbourne region in Victoria, Australia (five gardens) and three counties in the California Central California, USA (four gardens). Melbourne is the capital of Victoria, covers 9992.5 km^2 and has approximately 4.7 million residents (study area center point: 37°50′8.60″ S 145°2′15.31″ E) [34]. Melbourne's climate is temperate with a relatively wet and dry season and is generally considered highly variable across short periods (commonly known for having "four seasons in one day") [34,35]. The California Central Coast region in which we worked covers 12,430 km^2 and has approximately 2.6 million residents (includes Monterey (36.2400° N, 121.3100° W), Santa Clara (37.3600° N, 121.9700° W), and Santa Cruz (37.0300° N, 122.0100° W) counties). The climate is Mediterranean and generally has two annual seasons, one wet and one dry, with some spatial variability across the region. Global time-scale databases of long-term averages in these regions report similar annual average temperature measurements between the regions (0.35 °C difference in annual temperatures and 1.11 °C difference in warmest quarter temperatures), with Melbourne on average receiving relatively more precipitation (Table 1) [29].

The gardens are located within four ecoregions—two ecoregions in Victoria and two ecoregions in California. Ecoregions are a landscape-scale approach to classify the environment of a region using attributes of climate, geomorphology, geology, soils, vegetation, wildlife, and hydrology. An ecoregion is similar in its ecology, biotic and abiotic conditions, the ecosystems within it, and in its environmental resources. In Melbourne, Victoria, the two major ecoregions include the Gippsland Plain in the east of the city and the Victorian Volcanic Plain in the west. The Gippsland Plain is characterized by marine and non-marine Cainozoic sediments, often well-drained fertile alluvial soils, and mild temperatures. Mean annual rainfall ranges 600–1100 mm, and daily mean temperature across the bioregion ranges 9–21 °C [36]. The Volcanic Plain is characterized by Cainozoic volcanic deposits forming a basaltic plain, variable soils from shallow to loams and clays, and mild temperatures. Mean annual precipitation ranges 450–840 mm, and daily mean temperature across the regions ranges 9–21 °C [36]. Much of the landscape in both ecoregions is urbanized and converted to agricultural land use [37]. The central and western neighborhoods of the region are more industrial and developed than those in the east (Figure 1).

Table 1. Climate variables from WorldClim v2 Bioclim data for regions and ecoregions in which the gardens were located to show the relative similarity in annual temperatures between regions [29]. Bioclim (v2) data are spatially-explicit data calculated over a 1970–2000 baseline period and represent long-term average data. All temperatures are in degrees Celsius. A quarter is $\frac{1}{4}$ of the 12-month calendar year.

Region	Ecoregion	Avg. Annual Mean Temp. (°C)	Avg. Mean Temp. of Warmest Quarter (°C)	Avg. Mean Temp. of Coldest Quarter (°C)	Avg. of Annual Precipitation (mm)
Central Coast, California		14.35	18.25	10.23	481.50
	Santa Clara Valley	15.15	19.95	10.05	412.00
	Monterey Bay Plains	13.55	16.55	10.40	551.00
Melbourne, Victoria		14.58	19.36	9.76	757.60
	Gippsland Plain	14.43	19.20	9.63	827.67
	Victorian Volcanic Plain	14.80	19.60	9.95	652.50

Figure 1. Study regions in the California Central Coast, CA, USA, and Melbourne, Victoria, Australia. Community gardens (white balloons) located in the California Central Coast (**a**) spanning two ecoregions including the Santa Clara Valley (**b**) and the Monterey Bay Plains (**c**,**d**); Gardens located in the Melbourne Metropolitan Region spanning two ecoregions including the Gippsland Plain and Victorian Volcanic Plain (**e**); an example of a garden in this system (**f**). Images are courtesy of Google Earth satellite imagery [38] and M. Egerer.

In the Central California Foothills and Coastal Mountain region, the two dominant ecoregions in which people live (i.e., urban areas) and where the gardens are located include the Lower Santa Clara Valley and the Monterey Bay Plains. The Lower Santa Clara Valley is characterized by alluvial plains, xeric soil moisture regimes, thermic soil temperatures, and a Mediterranean climate (Figure 1). Mean annual rainfall is 300–400 mm, and daily mean temperature ranges 9–20 °C [39]. Historically, the landscape was vegetatively characterized by coast live oak trees, California oatgrass, and needlegrass grasslands; however, today, the dominant land use is nearly all urban and residential. The Monterey Bay Plains is characterized by alluvial plans and terraces, xeric soil moisture regimes, isomesic soil temperatures, and a marine-influenced climate including heavy summer fog. Mean rainfall ranges 700–800 mm (2–155 mm per month), and daily mean temperature ranges 9–17 °C [40]. The natural vegetation includes coast live oak, California oatgrass, and coastal shrub. A long frost-free period supports cropland agricultural land use.

2.2. Climate Data and Temperature Measurements

2.2.1. Regional Long-Term Climate Data

To inform a broader context of the regional climates in which the gardens are located, we collected temperature and precipitation measurements from WorldClim v2 Bioclim for each garden location. These spatially-explicit data are calculated over a 1970–2000 baseline period to provide long-term averaged data on annual means, seasonality and extreme factors historically and in future climate scenarios for a specific geographic location [29]. We used these data: (1) to inform the similarities and differences in long-term climate data between regions; and (2) to better contextualize the short-term local weather data of temperature variability within the gardens (from the loggers, see Section 2.2.2). We did not use these climate (long-term) data to directly compare to the local weather (short-term) data from the gardens, as these data are not directly comparable at the temporal scales in which they are measured.

2.2.2. Local-Scale Short-Term Weather Data

We monitored a total of 20 plots across all gardens within each region. In the California Central Coast region, we worked in five garden plots in each of four community gardens in two ecoregions; in the Greater Melbourne Metropolitan region, we worked in four plots in five community gardens in two ecoregions (Figure 1). The gardens and plots studied were selected based on the criteria that they: (a) were allotment gardens in which individuals or households manage their plots; (b) spanned the two bioregions within each region; and (c) had voluntary participation through garden management. We worked with garden managers to identify volunteer gardeners' plots that were spatially distributed within the garden in which to monitor fine spatial and temporal scale temperatures. The plots were monitored for six-weeks in the summer to collect measurements of short-term temperature variability within the plots (California: 5 August–15 September 2017; Melbourne: 15 December 2017–10 February 2018). Plots ranged approximately 3–30 m^2 in size. Each plot was monitored with a temperature logger (Onset HOBO UA-001-08; 5.8 cm × 3.3 cm × 2.3 cm in size, 8 K in Memory; www.onsetcomp.com/products/data-loggers/ua-001-08; Table S1) to collect hourly averaged ambient temperature measurements. The loggers have an operating range of −2° to 70 °C, an accuracy of ±0.53 °C within 0–50 °C, and a temperature resolution of 0.14 °C at 25 °C. Loggers were calibrated and tested at the University of Melbourne, Burnley campus garden and the University of California campus garden before the experiments. Multiple plots were measured because there is potential variability in surrounding vegetation structure that may affect temperatures around each plot. Temperature loggers were placed 1.3 m above the ground in the plot at the edge of the plot to record temperatures (°C) directly around the plot. Data loggers were protected from ultraviolet radiation with white plastic shields (6 cm × 12 cm well-ventilated white bowls) fastened over them. The loggers were checked and maintained throughout the survey period to ensure that they were in good working order and to ensure that there was no indication of radiation error (e.g., temperatures >50 °C). Data from loggers within each plot were readout locally using an Optic USB interface at the end of the survey periods, quality checked and cleaned.

For each plot, we calculated measures of daily ambient temperature for each garden plot recorded throughout the sampling period. The temperature measurements included: mean daily temperature, mean daily maximum temperature, mean daily minimum temperature, interday variation in daily mean temperature, interday variation in maximum temperature, and interday variation in minimum temperatures. The temperature was calculated from the hourly temperatures recorded at each hour throughout the sample period. Mean daily maximum and minimum temperature measurements were calculated based on first calculating the maximum or minimum temperature per day and then averaging the temperatures across the sample period. Temperature variation was calculated based on the standard deviation (SD) [41]. These measurements of fine spatial and temporal scale temperatures of local weather were used as explanatory variables to examine how garden temperatures differed between regions and among ecoregions at fine temporal scales.

2.3. Gardener Questionnaires

To gather information about gardeners' relationship to climate in the context of management decisions, we studied gardener perceptions around and management responses to local weather patterns and climate change. The background of this study is presented in more detail in previous papers [33,42], and we bring this information into this study to contextualize temperature patterns in human perception and behaviors. Both case studies deal with gardeners' responses to the perceived climate variability and environmental change around them. We distributed a questionnaire to the 40 gardeners in each region whose plots were monitored for temperature. We designed the questionnaire to gather responses on gardener decision making around plant selection and about how perceived local weather patterns and regional climate affects gardening practices and behaviors. The questionnaire asked gardeners about the plants growing in their plots, their watering practices, their perceptions about weather patterns (temperature, precipitation) and climate change. While the questionnaire in each region was unique, key questions were similarly asked in both, including: (1) "what plants are growing in your plot right now?" (open-ended, both regions); and (2) describe the weather/climate patterns over the past 12 months and how they influence your watering and planting practices (open-ended, both regions). In Melbourne, the questionnaire was distributed in paper format by the researchers and garden managers opportunistically, and in an online format by the garden managers to the community garden e-mail list. The questionnaire was distributed to over 300 gardeners as part of a broader study [33], and we draw from these gardeners' responses on climate-related perceptions and influences to support this study. In California, the questionnaire was distributed in a paper format and an online format by the researchers with assistance from garden managers. The questionnaire was conducted predominantly in English and translated to foreign language speakers by garden managers as needed. All gardeners received a packet of seeds in gratitude for their participation.

2.4. Analysis

We used linear mixed-effects models (LMMs) to examine the relationship between the plot level, local-scale temperature measures collected from the loggers between regions and ecoregions (explanatory variables in Table 2) using maximum likelihood. The LMMs modeled plot scale temperature measurements in response to region and ecoregion and included garden plot nested within garden as a random effect to account for pseudo-replication [43]. We used the *lme* function in the *lme4* package [44] in the R statistical environment [45] to perform the analysis. For the between-region models, we fit the full models and ran an Analysis of Variance using the *Anova* function in the *car* package [46] to assess temperature differences between regions for each model. For the ecoregion models, we fit the full models and ran a post-hoc test using the *glht* function in the *multcomp* package [47] to assess temperature differences between ecoregions for each model.

Table 2. Structure of linear mixed-effects models to examine differences in the local-scale weather data collected in the garden plots between regions (a) and among ecoregions (b) in the analysis.

Models	Explanatory Variables (Local-Scale Temperature Data in Gardens)
(a) Between regions: California vs. Melbourne, Victoria (b) Between ecoregions	Average temperature Temperature variability SD Average maximum temperature Maximum temperature SD Average minimum temperature Minimum temperature SD

The gardener questionnaire data were reviewed, cleaned and quality checked prior to analysis. For the question about plants grown in plots, we compiled a list of plants reported by each gardener in each region. We reviewed the list of gardener reported plants and revised based on taxonomic inconsistencies (i.e., various names for the same plant species; e.g., common names for *Beta vulgaris* included "chard," "Swiss chard" and "silver beet"). While some gardeners identified the specific variety or cultivar of the plant, we decided to generalize for comparative purposes across data sets (e.g., Japanese long cucumber and Lebanese cucumber both generalized to "cucumber" (*Cucumis sativus*)). We calculated the relative frequency of the reported plants across the gardeners for each region. For the question about how the weather/climate over the previous 12 months has influenced gardening practices, we used an inductive approach, thematically coding responses to allow new themes to emerge from the data, rather than testing pre-conceived concepts. The key themes identified included: (1) observations on how gardeners perceive the climate is changing; and (2) reported behavioral changes or management adaptations (i.e., through plant selection or watering) to perceived climate changes. We situated these response themes and perceptions in the context of the regional temperature comparison.

3. Results

3.1. Differences in Long-Term Climate Patterns, and Short-Term Local Temperatures in Gardens across Regions and Ecoregions

Long-term climate patterns of means and maximum temperatures (Bioclim data) are similar between California and Melbourne at this regional scale, and at the ecoregion scale with some variation at this finer spatial scale (two ecoregions per metropolitan area) (Figures 2 and 3).

The mean local-scale, short-term temperature measurements within gardens also did not differ between regions for mean, maximum or the minimum temperatures (Table 3 and Figure 2). However, the variation in interday temperature measurements at this fine local-scale significantly differed between regions. Gardens in the California Central Coast have higher variation (SD) in mean temperatures than gardens in Melbourne (Figure 2b), while gardens in Melbourne have significantly higher variation in maximum (Figure 2d) and minimum temperatures (Figure 2f).

Temperature measurements within gardens differed between some, but not all, ecoregions (Table 3 and Figure 3). Ecoregions within the California Central Coast significantly differed from one another in mean temperatures compared to those in Melbourne (Figure 3a). In California, gardens in the Santa Clara Valley ecoregion had significantly higher mean temperatures than all other ecoregions, and higher variation in mean temperatures than gardens in ecoregions in Melbourne, which were similar to one another and to the Monterey Bay Plains. The Santa Clara Valley also had significantly higher average maximum temperatures (Figure 3c), but significantly lower interday variation in those maximum temperatures than gardens in ecoregions in the Monterey Bay Plains and in Melbourne (Figure 3d), which were both higher than those gardens in California's ecoregions. The minimum temperatures among ecoregions across regions was quite different (Figure 3). The Santa Clara Valley (CA) had higher average minimums than the Monterey Bay Plains (CA) and Gippsland Plain (Melbourne), which were similar to one another in daily minimum temperatures (Figure 3e). Here, the Victorian Volcanic Plain

(Melbourne) had similarly higher minimums to the Santa Clara Valley (CA). The interday variation in minimum temperatures was significantly higher in gardens in both ecoregions in Melbourne than in those in California (Figure 3f). Here, the interday minimums were different within gardens between ecoregions: gardens in the Monterey Bay Plains had higher interday variation in temperature minimums than gardens in the Santa Clara Valley and the Gippsland Plain.

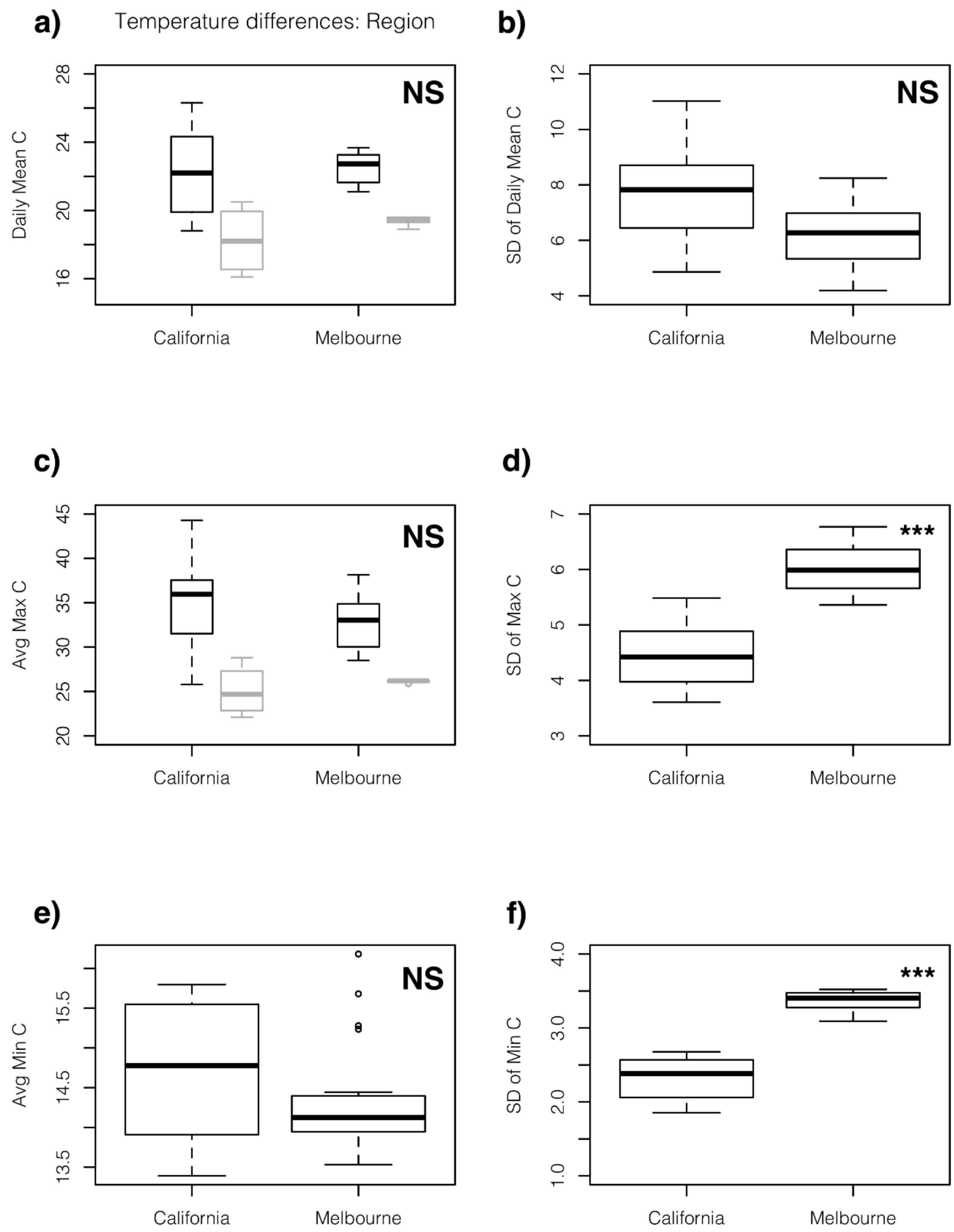

Figure 2. Average, maximum and minimum temperatures and their variation as measured by standard deviation (SD) observed in the gardens over the study period for the regional models (**a**–**f**). In gray, available WorldClim v2 Bioclim data plotted for a context of long-term temperature averages (**a**,**c**). WorldClim data are the mean temperature of the warmest quarter (BIO9) (**a**) and the maximum temperature of the warmest month (BIO5) (**c**). Box-and-whisker plots of the grouped values indicate the median, maximum, minimum, and 75% and 25% quantiles. Circles indicate outliers. Significant differences between local-scale temperature measurements (from logger data) are denoted by asterisks (*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$) and no difference denoted by "NS".

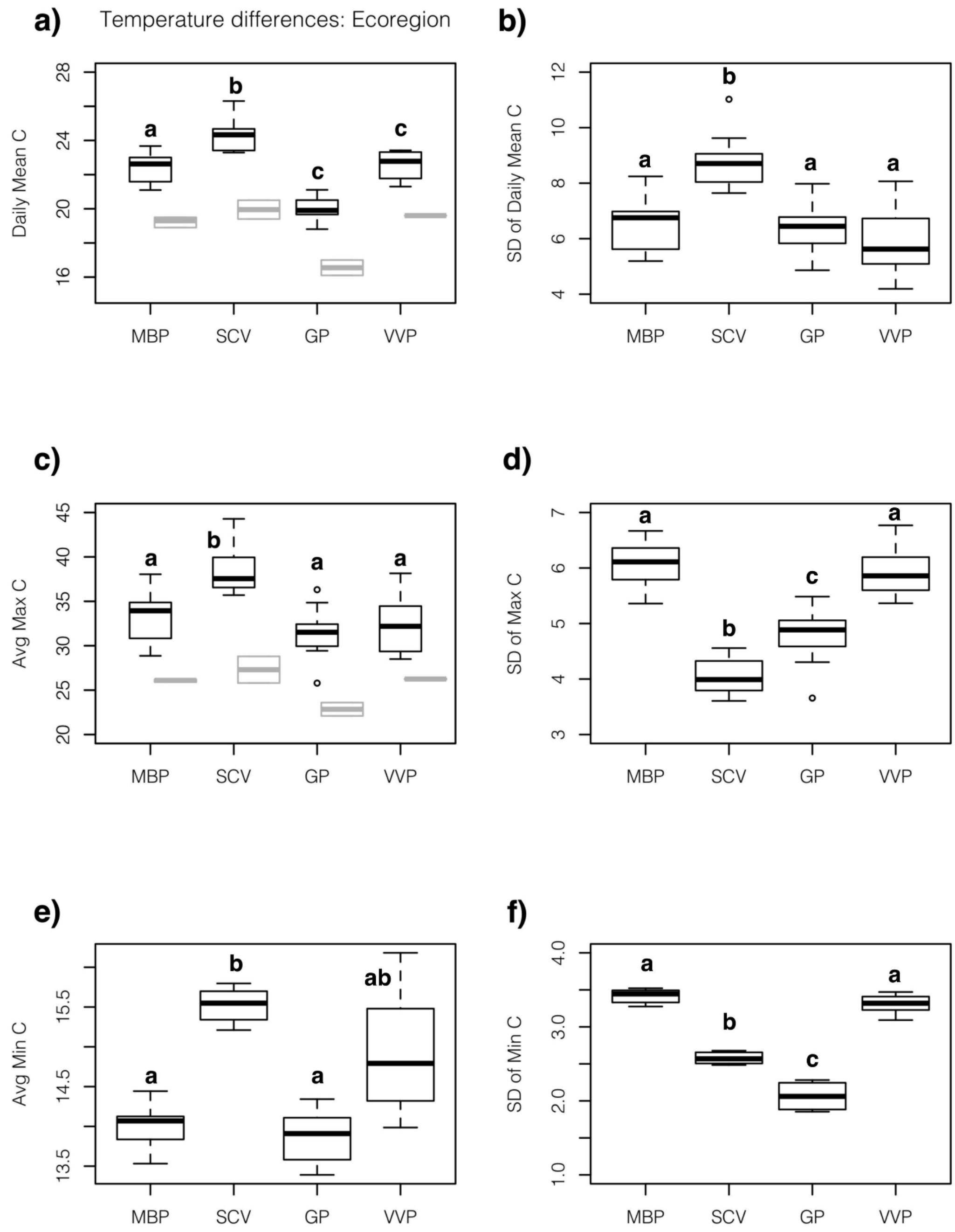

Figure 3. Average, maximum and minimum temperatures and their variation as measured by standard deviation (SD) in the gardens for the ecoregional models (**a**–**f**). In gray, available WorldClim v2 Bioclim data plotted for a context of long-term temperature averages (**a**,**c**). WorldClim data are the mean temperature of the warmest quarter (BIO9) (**a**) and the maximum temperature of the warmest month (BIO5) (**c**). Box-and-whisker plots of the grouped values indicate the median, maximum, minimum, and 75% and 25% quantiles. Circles indicate outliers. Different lowercase letters indicate statistically significant differences between local-scale temperature measurements (from logger data) among ecoregions assessed using post-hoc tests. (California: MBP, Monterey Bay Plains; SCV, Santa Clara Valley; Melbourne: GP, Gippsland Plain; VVP, Victorian Volcanic Plain).

Table 3. Analysis of measured temperature variables in gardens (logger data) as a response to region and ecoregion. Reference level (the level of contrast) for region models is Melbourne, and reference level for ecoregion models is the Gippsland Plain; model intercepts represent estimates for these reference levels (Melbourne and Gippsland Plain, respectively). The superscripted letters (a,b,c) indicate significant differences ($P \leq 0.05$) among ecoregions assessed through post-hoc comparison tests. (CA, California; M, Melbourne; MBP, Monterey Bay Plains; SCV, Santa Clara Valley; VVP, Victorian Volcanic Plain; SE, standard error; DF, degrees of freedom).

	Model			Coefficient	SE	DF	t	*p*	AIC
a)	Mean Temp	~	Intercept	22.18	0.83	31	26.67	<0.001	128.46
			Region (M)	0.30	1.12	7	0.26	0.80	
	Mean Temp	~	Intercept (M-GP)	22.41	0.28	31	80.69	<0.001	112.02
			CA-SCV [b]	1.90	0.42	5	4.52	0.006	
			CA-MBP [c]	−2.37	0.42	5	−5.64	0.002	
			M-VVP [a]	0.15	0.44	5	0.33	0.75	
b)	SD of Temp	~	Intercept	7.61	0.52	31	14.73	<0.001	134.72
			Region (M)	−1.33	0.70	7	−1.90	0.10	
	SD of Temp	~	Intercept (M-GP)	6.54	0.34	31	19.37	<0.001	127.01
			CA-SCV [b]	2.23	0.51	5	4.36	0.007	
			CA-MBP [a]	−0.08	0.51	5	−0.16	0.88	
			M-VVP [a]	−0.65	0.53	5	−1.21	0.28	
c)	Avg Max C	~	Intercept	35.04	1.50	31	23.41	<0.001	215.74
			Region (M)	−2.16	2.03	7	−1.07	0.32	
	Avg Max C	~	Intercept (M-GP)	33.24	0.89	31	37.35	<0.001	202.69
			CA-SCV [b]	5.34	1.33	5	4.01	0.01	
			CA-MBP [a]	−1.74	1.33	5	−1.31	0.25	
			M-VVP [a]	−0.91	1.41	5	−0.65	0.55	
d)	SD of Max C	~	Intercept	4.44	0.16	31	27.78	<0.001	67.60
			Region (M)	1.57	0.22	7	7.17	<0.001	
	SD of Max C	~	Intercept (M-GP)	6.06	0.13	31	48.37	<0.001	65.19
			CA-SCV [b]	−1.98	0.19	5	−10.65	<0.001	
			CA-MBP [c]	−1.26	0.19	5	−6.79	0.001	
			M-VVP [a]	−0.13	0.20	5	−0.64	0.55	
e)	Avg Min. C	~	Intercept	14.69	0.42	31	35.16	<0.001	38.78
			Region (M)	−0.33	0.56	7	−0.58	0.58	
	Avg Min. C	~	Intercept (M-GP)	14.00	0.28	31	50.19	<0.001	32.51
			CA-SCV [b]	1.52	0.44	5	3.46	0.02	
			CA-MBP [a]	−0.13	0.44	5	−0.29	0.78	
			M-VVP [ab]	0.92	0.44	5	2.09	0.09	
f)	SD of Min C	~	Intercept	2.32	0.12	31	20.05	<0.001	−52.87
			Region (M)	1.05	0.16	7	6.77	<0.001	
	SD of Min C	~	Intercept (M-GP)	3.42	0.08	31	41.97	<0.001	−53.52
			CA-SCV [b]	−0.84	0.13	5	−6.55	0.001	
			CA-MBP [c]	−1.35	0.13	5	−10.54	<0.001	
			M-VVP [a]	−0.11	0.13	5	−0.85	0.43	

3.2. Similarities in Reported Plants Grown by Gardeners

The reported species diversity of plants within the monitored garden plots were similar across the regions and ecoregions. In California, the most frequently reported, broadly categorized plants growing in gardens included: squash (n = 22 counts), tomato (19), pepper (13), beans (11) and cucumber (10). Only one gardener of the 20 did not report growing tomatoes, and some gardeners reported growing multiple varieties of squash (hence, why >20 squashes). Similarly, in Melbourne, the most frequently reported plants growing in the 20 garden plots included: squash (23), tomato (19), beans (18), pepper (12), onion (10), and cucumber (10). These common plants were followed by approximately 50 singleton species in California and 35 in Melbourne. The singleton plant species across datasets generally consisted of ornamental flower species (e.g., gladiolas, snapdragons, comfrey, and sea holly), and plants used as a culinary herb, spice or flavor (e.g., ginseng, tarragon, turmeric, and lemongrass). There were no clear differences in singleton species between regions.

3.3. Climate and Gardeners

The surveyed gardeners described their perceptions of how the environment is changing around them and how this is impacting the garden and their garden management (Table 4). Many of the gardeners in California describe the region by the drought landscape in their observations (60%; 12 of 20), while many gardeners in Melbourne describe the region as variable and also sensitive to drought and extreme heat in their observations (55%; 11 of 20). Surveyed gardeners in California connected what they perceive is occurring in the region with a garden's weather patterns and with gardening practices (40%; 8 of 20). As previously described [33], surveyed gardeners in Melbourne are very responsive to the perceived temperature and precipitation fluctuations in the region in caring for their plants. Gardeners reported increasing their watering frequency and amount because of longer extreme heat events (40%; 8 of 20), and reported being "always mindful" of the temperatures and "more conscientious" of their watering to maintain plant survival. Further, few surveyed gardeners are shifting the timing of when they grow plants or adopting new planning strategies to grow their plants, such as changing the species composition and design of their vegetation to be more climate resilient in response to perceived weather patterns and climate change (Table 4).

Table 4. Comparing gardener descriptions of perceptions of the weather patterns and climate change and its relation to the garden and garden management practices in the two study regions, coded according to a theme. Here, we show examples of the dominant responses of gardener perceptions. See Section 3.3. for summary.

Theme	Surveyed Gardeners in the Central Coast, California	Surveyed Gardeners in Melbourne, Victoria
Climate change	Perceived drought: • "In constant drought with more water use than rain." • "We are going to have ongoing drought." • "Improved from the last few years but still at risk and future water stability is a concern."	Perceived drought, extreme heat, and unpredictability: • "It has been unpredictable." • "This year has been a bit milder than others with few very long heat waves." • "The summer/autumn weather pattern seems to be changing: dry with then heavy downpours. The rain systems appear to be shifting with rainfall from tropical systems coming from the NW of the continent mixing with the normal west to east systems to bring heavy rain episodes."
Effects on garden	Perceived water availability in the garden: • "The garden gets very dry between watering." • "Water limited in the garden." • "We should always use like we are in a drought and start putting more infrastructure to support the water needs."	Perceived effects on garden plants: • "This summer the temperature fluctuation has been a problem." • "Some vegetables have failed to fully grow or produce usual crops." • "We have had to water all through the winter here in Melbourne. Planting new plants requires more watering in and care time to establish. The late heat in late 2017 meant tomatoes didn't establish until much later. Direct sowing is more challenging with less reliable rainfall."
Effects on gardening practice	Reported effects on watering behavior (e.g., timing, amount used): • "I change my watering a lot daily and weekly depending on weather and seasonal plantings." • "Water more after early in the morning and to not neglect my seed starts." • "I am fairly consistent in the amount of water I use each time. Though I definitely used more in the really hot week we had (100 F+)."	Reported effects on watering behavior (e.g., timing, amount used) and plant selection: • "Watering by the weather and plant needs." • "Influences when I come—the planning of when I garden." • "Water less frequently but for longer in lead up to extreme heat and mulch all bare soil." • "Since the last drought we had in Melbourne, I water less often but more deeply. I use more mulch and put shade covering over my garden during extreme heat." • "I am considering changing the type of raspberries that I grow to ones that produce in spring rather than autumn to avoid the summer heat burning the fruit. I will also be planting taller plants e.g., sunflowers, to shelter tender plants e.g., lettuces, sorrel."

4. Discussion

We examined urban gardens embedded within climatically similar regions (based on long-term climate models, e.g., WorldClim Bioclim) in California, USA, and Australia to ask how they differ in the variability of their local temperatures, and to contextualize these findings in gardeners' management practices, perceptions, and experience. We found that, although gardens within these regions have relatively similar climates (long-term temperatures) and observed fine-scale short-term daily mean temperatures, the gardens differ in fine-scale interday fluctuations of temperatures and temperature extremes, supporting our initial hypothesis. Nevertheless, gardeners across regions report growing very similar plant species and respond to perceived temperature changes by altering their water use behavior. These findings suggest that, although differences in microclimate might drive different plant compositions in natural systems, gardens can retain similar plants due to intensive management and adaptive responses of gardeners to local weather patterns and perceived climate change. We discuss: (1) how differences in topographic features of urban regions may drive this variability in local temperatures between regions that gardens and people managing them experience and perceive; (2) the climate-mediated relationship between gardeners and their plots; and (3) the importance of considering variability in temperatures at fine temporal and spatial scales.

4.1. Relationships between Urban Regional Topography, Agroecosystem Abiotic and Biotic Features, and Environmental Management

We measured fine spatial and temporal scale temperatures and their interday variation in urban gardens as an indicator of the experience of plants and people to temperatures in these habitats. This is in contrast to many climate analyses that employ modeled temperature averages (e.g., mean annual temperature (MAT) data) in the climatic modeling of ecological phenomena [23,24,48,49]. We found that local-scale, short-term temperatures in the gardens are quite variable, although long-term average temperatures in these regions are very similar. In comparing the long-term climate patterns between the regions, the regional similarities could be due to two reasons. First, long-term temperature averages are not as influenced by short-term climate events (e.g., drought events, La Niña event, and anomalies), especially over a larger geographic region. Second, the temperature data we used (WorldClim v2 Bioclim) does not account for urban heat—a significant climate feature of urban landscapes [50]. Urban areas can register around 5–10 °C warmer than surrounding areas due to urban heat effects [51], and gardens surrounded by more impervious land cover experience consistently higher temperatures for longer periods than gardens surrounded by less urbanized areas with more natural vegetation [32,33]. The elimination of urban heat effects in the long-term modeled temperature averages may contribute to overall similarities across regions. We found similar patterns at the finer ecoregion scale, but some variation and differences are visible between the ecoregions (e.g., Santa Clara Valley vs. Gippsland Plain; discussed below). Such findings suggest looking at this finer spatial extent in future climate comparisons.

In comparing our local fine-scale temperature measurements, differences in temperature patterns in gardens between regions may be explained by differences in the heterogenous topography of these regions including mountain ranges, coastlines, and rolling plains. The variation in the amount of surrounding urban impervious land cover also likely plays a role. The frequency and severity of extreme heat events are stronger in more sprawling metropolitan regions than those that are more compact [52]. Melbourne is a sprawling metropolitan region lacking physical barriers (e.g., mountains) or social barriers (e.g., planning restrictions) to urban expansion. In the California Central Coast Metropolitan region, urbanization between valley and coast is more fragmented due to the mountainous topography of the landscape, and building density is consequently much higher in the Santa Clara Valley. Thus, the impact of urban form on temperatures and the severity of extreme events (e.g., heat) in metropolitan regions through urban heat [52] informs the different temperature patterns observed in the gardens between ecoregions and regions of different urbanization patterns. We found that the gardens in California, particularly in the Santa Clara Valley, surrounded by more urban land cover (within 2 km), have higher average and maximum temperatures than those surrounded by more vegetation [32]. Gardens in Melbourne surrounded by more urban land cover (1 km) in the Victorian Volcanic Plain also have more stable temperatures (i.e., lower variation) than those surrounded by more vegetation in the Gippsland Plain, meaning hotter temperatures for longer in those gardens [33]. In our regional comparison here, fine-scale urban heat effects are reflected in the high daily minimum temperatures and high maximum temperatures exhibited in gardens in ecoregions with more urban land cover—the Santa Clara Valley and Victorian Volcanic Plain. Interestingly, although the gardens in Melbourne span a smaller spatial extent, they exhibit higher temperature variation than the gardens across the California Central Coast, which covers a larger spatial extent across the landscape. This may also be due to the stabilizing effect of the high amounts of urban land cover in the Santa Clara Valley on temperatures.

The differences in the variability of local temperatures can have ecological and social implications within gardens. Temperature variability at the plot-level may affect food crop productivity and survivorship, and the species diversity of crops that can grow. Plots that experience higher temperatures or greater variation in temperatures over time are exposed to more extreme heat. High temperatures may scorch leaves, desiccate the crop, affect the timing of flowering, or even damage pollen [53–55]. All such outcomes would lower fruit production and increase the likelihood of crop failure. Despite differences in temperature variability, counter to our predictions, gardeners across regions are reporting to grow relatively the same plants across the regions. The similarities could be explained by two related socioecological phenomena: (1) climate does not affect most gardeners' planting decisions and instead gardeners plant for high-yield rewards [33]; and (2) because temperature variability may nevertheless negatively affect crop species, gardeners may decide not to replant a species if no crop was produced due to weather-related mortality, and consequently the same plants may pervade within these habitats because gardeners know how to care and maintain them in a changing climate. This possible idea is reflected in one surveyed gardener's reported experience: "We've had very hot days and heavy rainfall as well. The tropical plants that I planted were killed after the heat. I think it was the combination of rain and sun that killed them." In our daily interactions with gardeners of various immigrant backgrounds in these regions, we heard similar experiences of struggles to grow plant varieties or species from their regions of origin that they are familiar with in a new climate context. Trial-and-error with growing crop species in a changing climate context or new climate context may be why tomatoes, squashes, and beans dominate the garden landscape as relatively hardy crops. Gardener management may be able to adapt to local weather patterns and climate changes by increasing plant care through watering, but human intervention may not be able to entirely overcome some negative effects of temperature variability and extremes on plants. Consequently, gardeners may default to plants that they know best, observe others' success with, feel comfortable growing, and produce high yield rewards. Future work is needed to test these hypotheses to improve resource sustainability and maintain high plant diversity in gardens as climates change.

Local management of vegetation and ground cover can also affect local temperatures within gardens [32], although, in these sites, microclimate effects are smaller than regional effects. In regards to research application, management factors in gardens including vegetation complexity (vegetation height and cover) and ground cover (grass, mulch, and straw cover) can help reduce ambient temperatures at the garden scale and combat heating factors with low albedo such as impervious ground cover (pavement and stone) that drive maximum temperatures and their duration [32]. These factors are more useful in gardens for managing climate than tree canopy cover, which provides significant cooling effects to city temperatures [6,56], but could hinder crop production in gardens. Thus, gardens and plots can be managed in vegetation and ground cover to reduce temperature extremes and variability at the microhabitat (plot) scale given their regional context.

4.2. Looking beyond Averages to Examine Variability in Temperatures

When placed in the broader context of long-term temperatures in the region, the short-term fine-scale temperatures, and their variation can yield meaningful insight into the lived experience of biodiversity and human populations to changes in local weather patterns. Thus, local-scale, short-term temperatures are important measurement scales because these gardeners can be very responsive to local weather patterns and change (see Section 4.3). Long-term data provide good insight into global change assessments, while short-term temperature data may illuminate temperature variation and temperature extremes that plants experience and people perceive day-to-day in these habitats. In the case of temperature variation in our system, interday variation is likely driven by the punctuated extreme heat events across the summer in both regions. During the monitoring period, Melbourne experienced two short extreme heat events (two days each) while the California Central Coast experienced one longer extreme heat event (four days). The temporality of extreme heat events influences plant survival, human behavior, and decision making as is reflected by the surveyed gardeners reported perceptions in these regions and elsewhere [33,42]. Although these forms of data are very different, only focusing on long-term climate data may hide spatiotemporal variation to assume that regional climates are more similar than they are.

4.3. Implications of Temperatures on Human Behavior and Environmental Management

It is essential to understand how regional climate affects biodiversity and resource use and management. Our results highlight that the gardeners managing these systems experience and perceive temperature variability, and this can impact their management practices. Further, many gardeners are aware of weather patterns and cycles in their environment. Gardeners are highly responsive and adapt to perceived temperature and climate-related changes, as discussed previously [33,42]. In the questionnaires distributed to understand the impact of climate on gardeners' decision making around garden management, including watering and plant selection, gardeners reported that fluctuations in temperatures and precipitation elicit concern and affect their watering behavior [33,42]. Many gardeners employ more frequent watering or change how much water used per event in response to perceived changes in climate, thus adapting their watering behavior to perceived temperature variability. The similarity of plant species maintained in these gardens across regions, despite differences in temperature extremes, does suggest that gardeners' adaptive watering behavior facilitates the persistence of (similar) plant species.

However, plot-level local microclimates may still affect the diversity of crop species that survive, with extreme climate conditions such as extended periods of high heat or drought severely affecting the productivity and survivorship of food crops [57,58]. Although gardeners are less likely to change the plants that they grow in response to weather, more extreme heat and projected declines in water availability will call for more proactive adaptation strategies. Interestingly, climate change may also change the plant species able to grow in cities; in the case of our study region, bananas can grow and ripen for the first time in Melbourne due to higher mean temperatures (17 °C; the authors, pers. obs.). Future research should work with gardeners to study motivation to adapt, perceived ability to adapt, and proactive adaptation strategies to promote the resiliency of urban agriculture under climate change. Studies could collect information on gardener awareness building, planning and implementation, and monitoring and evaluation [59]. Education programs and dialogue can also focus on increasing perceived adaptive capacity to overcome socio-cognitive barriers that may hinder adaptation and may even elicit maladaptive responses (e.g., overwatering).

5. Conclusions

Climate affects natural and social systems and their coupling across urban and agricultural landscapes. In agroecosystems, temperatures impact crop survival and ecosystem functions including soil water conservation and nutrient cycling. Urban gardens designed for food production are popular urban green spaces across the world's cities but are similarly vulnerable to temperature and extremes for crop production that prompt adaptive behavioral responses by gardeners. As gardening is an outdoor activity, gardeners can gain an acute awareness of weather patterns occurring around them and knowledge of climate cycles [60]. In this study, we identified that there are strong regional differences in short-term microclimate temperature variability in urban agroecosystems, despite similarities in long-term climate averages. Across regions, we found that this actual and perceived variability in regional climate is affecting some gardeners' plant management and water use behavior, but most gardeners have similar plant species within their plots. Because temperatures influence the lived experience of both plants and people managing gardens, we suggest that temperature variability becomes the mechanism for human-plant interactions and natural resource use. For urban gardeners working to grow food under climate change, where temperature extremes and high heat may become more normal, habitat management and resource use suggestions should be tailored to interregional-scale variability to complement gardeners' knowledge and sensibilities acquired through their experiences. Regional assessments across similar and different climate regimes should incorporate fine-scale microclimate studies paired with studies on human behavior, perceptions, and decision making.

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References

1. UN-Habitat. *World Cities Report 2016: Urbanization and Development: Emerging Futures*; United Nations Human Settlements Programme (UN-Habitat): Nairobi, Kenya, 2016; ISBN 9789211333954.
2. Taha, H. Urban climates and heat islands: Albedo, evapotranspiration, and anthropogenic heat. *Energy Build.* **1997**, *25*, 99–103. [CrossRef]
3. Luber, G.; McGeehin, M. Climate change and extreme heat events. *Am. J. Prev. Med.* **2008**, *35*, 429–435. [CrossRef]
4. Güneralp, B.; Güneralp, İ.; Liu, Y. Changing global patterns of urban exposure to flood and drought hazards. *Glob. Environ. Chang.* **2015**, *31*, 217–225. [CrossRef]
5. Demuzere, M.; Orru, K.; Heidrich, O.; Olazabal, E.; Geneletti, D.; Orru, H.; Bhave, A.G.; Mittal, N.; Feliu, E.; Faehnle, M. Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *J. Environ. Manag.* **2014**, *146*, 107–115. [CrossRef] [PubMed]
6. Kendal, D.; Williams, N.S.G.; Williams, K.J.H. A cultivated environment: Exploring the global distribution of plants in gardens, parks and streetscapes. *Urban Ecosyst.* **2012**, *15*, 637–652. [CrossRef]
7. City of Melbourne. *Urban Forest Strategy: Making a Great City Greener 2012–2032*; City of Melbourne: Melbourne, Australia, 2012.

8. Tubby, K.V.; Webber, J.F. Pests and diseases threatening urban trees under a changing climate. *For. An Int. J. For. Res.* **2010**, *83*, 451–459. [CrossRef]
9. Kendal, D.; Dobbs, C.; Gallagher, R.V.; Beaumont, L.J.; Baumann, J.; Williams, N.S.G.; Livesley, S.J. A global comparison of the climatic niches of urban and native tree populations. *Glob. Ecol. Biogeogr.* **2018**, *27*, 629–637. [CrossRef]
10. Bowler, D.E.; Buyung-ali, L.; Knight, T.M.; Pullin, A.S. Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landsc. Urban Plan.* **2010**, *97*, 147–155. [CrossRef]
11. Rosenzweig, C.; Solecki, W.; Hammer, S.A.; Mehrotra, S. Cities lead the way in climate–change action. *Nature* **2010**, *467*, 909–911. [CrossRef] [PubMed]
12. Kong, L.; La Lun-Lau, K.; Yuan, C.; Ren, C.; Ng, E. Regulation of outdoor thermal comfort by trees in Hong Kong. *Sustain. Cities Soc.* **2017**, *31*, 12–25. [CrossRef]
13. Gonçalves, A.; Castro Ribeiro, A.; Maia, F.; Nunes, L.; Feliciano, M. Influence of Green Spaces on Outdoors Thermal Comfort—Structured Experiment in a Mediterranean Climate. *Climate* **2019**, *7*, 20. [CrossRef]
14. Kovats, R.S.; Hajat, S. Heat stress and public health: A critical review. *Annu. Rev. Public Health* **2008**, *29*, 41–55. [CrossRef] [PubMed]
15. Thorsson, S.; Lindqvist, M.; Lindqvist, S. Thermal bioclimatic conditions and patterns of behaviour in an urban park in Goteborg, Sweden. *Int. J. Biometeorol.* **2004**, *48*, 149–156. [CrossRef]
16. Nikolopoulou, M.; Steemers, K. Thermal comfort and psychological adaptation as a guide for designing urban spaces. *Energy Build.* **2003**, *35*, 95–101. [CrossRef]
17. Frumkin, H.; Hess, J.; Luber, G.; Malilay, J.; McGeehin, M. Climate change: The public health response. *Am. J. Public Health* **2008**, *98*, 435–455. [CrossRef]
18. Grothmann, T.; Patt, A. Adaptive capacity and human cognition: The process of individual adaptation to climate change. *Glob. Environ. Chang.* **2005**, *15*, 199–213. [CrossRef]
19. Neil Adger, W.; Arnell, N.W.; Tompkins, E.L. Successful adaptation to climate change across scales. *Glob. Environ. Chang.* **2005**, *15*, 77–86. [CrossRef]
20. Kasperson, R.E.; Renn, O.; Slovic, P.; Brown, H.S.; Emel, J.; Goble, R.; Kasperson, J.X.; Ratick, S. The social amplification of risk: A conceptual framework. *Risk Anal.* **1988**, *8*, 177–187. [CrossRef]
21. Kleerekoper, L.; Van Esch, M.; Salcedo, T.B. How to make a city climate-proof, addressing the urban heat island effect. *Resour. Conserv. Recycl.* **2012**, *64*, 30–38. [CrossRef]
22. Cabral, I.; Costa, S.; Weiland, U.; Bonn, A. *Nature-Based Solutions to Climate Change Adaptation in Urban Areas*; Springer: Berlin/Heidelberg, Germany, 2017; pp. 237–253. [CrossRef]
23. Dobbs, C.; Nitschke, C.R.; Kendal, D. Global drivers and tradeoffs of three urban vegetation ecosystem services. *PLoS ONE* **2014**, *9*. [CrossRef] [PubMed]
24. Ossola, A.; Hopton, M.E. Climate differentiates forest structure across a residential macrosystem. *Sci. Total Environ.* **2018**, *639*, 1164–1174. [CrossRef]
25. Stewart, I.D. A systematic review and scientific critique of methodology in modern urban heat island literature. *Int. J. Climatol.* **2011**, *31*, 200–217. [CrossRef]
26. Oke, T.R. Initial Guidance to Obtain Representative Meteorological Observations at Urban Sites. In *Instruments and Observing Methods*; WHO, Ed.; World Health Organization: Geneva, Switzerland, 2006.
27. Araos, M.; Austin, S.E.; Berrang-Ford, L.; Ford, J.D. Public health adaptation to climate change in large cities: A global baseline. *Int. J. Heal. Serv.* **2016**, *46*, 53–78. [CrossRef] [PubMed]
28. Hulme, M. Reducing the Future to Climate: A Story of Climate Determinism and Reductionism. *Osiris* **2011**, *26*, 245–266. [CrossRef]
29. WorldClim—Global Climate Data Bioclimatic Variables. Available online: http://www.worldclim.org/bioclim (accessed on 18 December 2018).
30. Gill, S.E.; Handley, J.F.; Ennos, A.R.; Pauleit, S. Adapting cities for climate change: The role of green infrastructure. *Built. Environ.* **2007**, *33*, 115–133. [CrossRef]
31. Huang, L.; Li, J.; Zhao, D.; Zhu, J. A fieldwork study on the diurnal changes of urban microclimate in four types of ground cover and urban heat island of Nanjing, China. *Build. Environ.* **2008**, *43*, 7–17. [CrossRef]
32. Lin, B.B.; Egerer, M.H.; Liere, H.; Jha, S.; Bichier, P.; Philpott, S.M. Local- and landscape-scale land cover affects microclimate and water use in urban gardens. *Sci. Total Environ.* **2018**, *610–611*, 570–575. [CrossRef]

33. Egerer, M.H.; Lin, B.B.; Threlfall, C.G.; Kendal, D. Temperature variability influences urban garden plant richness and gardener water use behavior, but not planting decisions. *Sci. Total Environ.* **2019**, *646*, 111–120. [CrossRef]
34. City of Melbourne. City of Melbourne Melbourne Facts and Figures. 2019. Available online: https://www.melbourne.vic.gov.au/about-melbourne/melbourne-profile/Pages/facts-about-melbourne.aspx (accessed on 20 December 2018).
35. Bureau of Meteorology Climate Statistics for Australian Locations (Melbourne). Available online: http://www.bom.gov.au/climate/averages/tables/ca_vic_names.shtml (accessed on 15 December 2018).
36. Victorian Environmental Assessment. *Findings by Bioregion*; Victorian Environmental Assessment: Melbourne, Australia, 2010.
37. Royal Botanic Gardens Victoria Victorian Volcanic Plain Bioregion. Available online: https://vicflora.rbg.vic.gov.au/flora/bioregions/victorian-volcanic-plain (accessed on 15 December 2018).
38. Google Inc Google Earth 2017. Available online: https://earth.google.com/web/ (accessed on 15 January 2019).
39. Climate-Data.org Santa Clara Climate: Average Temperature, Weather by Month, Santa Clara Weather Averages. Available online: https://en.climate-data.org/north-america/united-states-of-america/california/santa-clara-1431/ (accessed on 16 December 2018).
40. Climate-Data.org Santa Cruz Climate: Average Temperature, Weather by Month, Santa Cruz Weather Averages. Available online: https://en.climate-data.org/north-america/united-states-of-america/california/santa-cruz-6305/ (accessed on 16 December 2018).
41. Abdi, H. Coefficient of Variation. In *Encyclopedia of Research Design*; Salkind, N., Ed.; Sage: Thousand Oaks, CA, USA, 2010; pp. 1–5.
42. Egerer, M.H.; Lin, B.B.; Philpott, S.M. Water use behavior, learning, and adaptation to future change in urban gardens. *Front. Sustain. Food Syst.* **2018**, *2*, 1–14. [CrossRef]
43. Bolker, B.M.; Brooks, M.E.; Clark, C.J.; Geange, S.W.; Poulsen, J.R.; Stevens, M.H.H.; White, J.-S. Generalized linear mixed models: A practical guide for ecology and evolution. *Trends Ecol. Evol.* **2009**, *24*, 127–135. [CrossRef]
44. Bates, D.; Maechler, M.; Bolker, B.; Walker, S.; Christensen, R.H.B.; Singmann, H. lme4: Linear mixed-effects models using Eigen and S4. *R Packag.* **2015**, 1. Available online: https://cran.r-project.org/web/packages/lme4/lme4.pdf (accessed on 16 December 2018).
45. R Development Core Team R Development Core Team. *R: A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2016; Volume 55, pp. 275–286.
46. Fox, J.; Weisberg, S. *Companion to applied regression*, 2nd ed.; Sage: Thousand Oaks, CA, USA, 2011; Available online: http://socserv.socsci.mcmaster.ca/jfox/Books/Companion (accessed on 20 December 2018).
47. Hothorn, T.; Bretz, F.; Westfall, P. Simultaneous inference in general parametric models. *Biom. J.* **2008**, *50*, 346–363. [CrossRef]
48. McDaniel, M.D.; Tiemann, L.K.; Grandy, A.S. Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? A meta-analysis. *Ecol. Appl.* **2014**, *24*, 560–570. [CrossRef]
49. Lin, B.B.; Flynn, D.F.B.; Bunker, D.E.; Uriarte, M. The effect of agricultural diversity and crop choice on functional capacity change in grassland conversions. *J. Appl. Ecol.* **2011**, 609–618. [CrossRef]
50. Hijmans, R.J.; Cameron, S.E.; Parra, J.L.; Jones, P.G.; Jarvis, A. Very high resolution interpolated climate surfaces for global land areas. *Int. J. Climatol.* **2005**, *25*, 1965–1978. [CrossRef]
51. Watkins, R.; Palmer, J.; Kolokotroni, M. Increased temperature and intensification of the Urban Heat Island: Implications for human comfort and urban design. *Built Environ.* **2007**, *33*, 85–96. [CrossRef]
52. Stone, B.; Hess, J.J.; Frumkin, H. Urban form and extreme heat events: Are sprawling cities more vulnerable to climate change than compact cities? *Environ. Health Perspect.* **2010**, *118*, 1425–1428. [CrossRef]
53. Teixeira, E.I.; Fischer, G.; van Velthuizen, H.; Walter, C.; Ewert, F. Global hot-spots of heat stress on agricultural crops due to climate change. *Agric. For. Meteorol.* **2013**, *170*, 206–215. [CrossRef]
54. Barlow, K.M.; Christy, B.P.; O'Leary, G.J.; Riffkin, P.A.; Nuttall, J.G. Simulating the impact of extreme heat and frost events on wheat crop production: A review. *Field Crop. Res.* **2015**, *171*, 109–119. [CrossRef]
55. Battisti, D.S.; Naylor, R.L. Historical Warnings of Future Food Insecurity with Unprecedented Seasonal Heat. *Science* **2009**, *323*, 240–244. [CrossRef] [PubMed]
56. Armson, D.; Stringer, P.; Ennos, A.R. The effect of tree shade and grass on surface and globe temperatures in an urban area. *Urban For. Urban Green.* **2012**, *11*, 245–255. [CrossRef]

57. Gourdji, S.M.; Sibley, A.M.; Lobell, D.B. Global crop exposure to critical high temperatures in the reproductive period: Historical trends and future projections. *Environ. Res. Lett.* **2013**, *8*. [CrossRef]
58. Lobell, D.B.; Schlenker, W.; Costa-Roberts, J. Climate trends and global crop production since 1980. *Science* **2011**, *333*, 616–620. [CrossRef] [PubMed]
59. Klein, R.J.T.; Nicholls, R.J.; Mimura, N. Coastal adaptation to climate change: Can the IPCC Technical Guidelines be applied? *Mitig. Adapt. Strateg. Glob. Chang.* **1999**, *4*, 239–252. [CrossRef]
60. Lin, B.B.; Egerer, M.H.; Ossola, A. Urban gardens as a space to engender biophilia: Evidence and ways forward. *Front. Built Environ.* **2018**, *4*, 1–10. [CrossRef]