EXHIBIT A

SCOPE OF WORK

☒ Contract ☐ Grant

Does this project include Research (as defined in the UTC)? ☒ Yes ☐ No

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Project Title: Quantifying Greenspace Impacts on Human Health and Ecosystem Services in California

Project Summary/Abstract

As California confronts various pressing challenges—from health disparities and mental health crises to the escalating impacts of climate change—we increasingly recognize how greenspaces drive health and other related ecosystem services. Trees, shrubs, parks, and other greenspaces offer numerous benefits. They mitigate exposure to air pollution, noise, and extreme heat, offer a setting for physical activity, encourage social interaction, reduce stress, and restore cognition. However, there are still important gaps in the current understanding of how nature affects human health and wellbeing. Working with local communities and large spatial datasets on greenspaces and human health, we will quantify how changing the quantity, distribution, and quality of, as well as access to, greenspaces will impact health, as well as ecosystem services, for all Californians, including those in underserved communities, and we will model the downstream costs or savings of these changes. Ultimately, our innovative and integrated approaches will provide insights and methods for driving science-based investment and management of greenspaces to ensure that the benefits of greenspaces reach people equitably, improve human health and well-being, and bolster ecosystem services to face the immense challenge of climate change.

Scope of Work

Statement of Significance

Research increasingly indicates that greenspaces, including street trees, forests, gardens, parks, and other natural vegetation, may benefit health by reducing exposures to air pollution, noise, and extreme heat and mitigating the impacts of these exposures on health. Additionally, greenspaces promote physical activity, encourage social interaction, reduce stress, and restore cognition. Substantial evidence suggests that greenspaces provide ecosystem services benefits, including cooling urban environments and reducing air pollution exposure. Collectively, these health and ecosystem benefits may have massive economic impacts on the state—at least $1.4 billion per year according to a partial accounting of four services provided by urban tree cover in California. However, there are still large knowledge gaps in quantifying how changing the quantity, distribution, and quality of, as well as access to, greenspaces is related to changes in both human health and ecosystem services, as well as the economic impacts of these changes. Moreover, greenspace is not equally distributed, and underserved and overburdened communities may obtain greater benefits from greenspaces.

Prior research from CARB has estimated that increasing greenspace statewide could lead to large benefits for health; however, these analyses were limited using non-specific satellite vegetation indices. More work is required to quantify urban greenspaces based on typologies, numbers of trees, access, location, and tree canopy cover metrics. These future analyses are fundamental to meet CARB's urban greenspace modeling needs. Furthermore, linking these novel greenspace metrics to underserved communities will aid CARB in estimating health equity concerns related to greenspace.

Greenspace may also have major benefits for ecosystem services, including through carbon sequestration, cooling of urban heat islands, impacting water usage, and filtering air pollutants. CARB's significant investments in community-driven air quality protection through AB 617 includes several urban greening strategies in Community Emission Reduction Plans (CERPs) around the state. While the CARB California Climate Investment (CCI) program has funded a number of urban greening projects and has calculated the future potential ecosystem service benefits for the projects, there is still a need for a comprehensive statewide monitoring and assessment of the many real benefits from California's urban green spaces that capitalizes on novel high resolution land cover and tree canopy data to estimate the value of CARB programs increasing urban greening, particularly in underserved communities through time and in response to climate and climate action.

With leadership from a team of environmental epidemiologists, plant scientists, environmental economists, environmental geographers, and community engagement experts, and working in concert with a statewide community advisory group and in consultation with CARB, this proposal aims to develop methodologies to fill these gaps in quantifying the human health and ecosystem service benefits of greenspaces and to support CARB's Nature-Based Solution programs to equitably increase greenspace in California communities. The objectives of this proposal are to create a repeatable and transferable process using remotely sensed data that will 1) quantify the health benefits of greenspaces, including downstream economic impacts; 2) quantify the ecosystem services benefits of greenspaces, including downstream economic impacts; 3) estimate how the benefits of greenspace impact underserved communities. This work will be informed by engagement with a Community Advisory Group as well as in consultation with CARB. The study will develop methodologies that can be applied to both current levels of urban greenness and future projections of urban greening under climate change to assess the health benefits and ecosystem service benefits at the state, regional, and local level. We will also consider the distribution of underserved communities in California and will model how future projections of urban greening efforts will impact these communities. The models will be responsive and adaptable to CARB needs and alternative greening scenarios that CARB develops. We will produce a model that CARB can modify and run to examine future scenarios after the contract ends.

This study will support CARB's Nature-Based Solution programs to increase green space in California communities, including through street, neighborhood, and schoolyard greening efforts, including those related to AB 1757 which is designed to increase nature-based solutions and "would require the state board, no later than January 1, 2025, to develop standard methods for state agencies to consistently track greenhouse gas emissions and reductions, carbon sequestration, and, where feasible and in consultation with the Natural Resources Agency and the Department of Food and Agriculture, additional benefits from natural and working lands over time." Through this proposed study, we will provide valuable evidence to target and guide the implementation of nature-based solutions to make equitable improvements in health across California, including in underserved communities. California's stunning greenspaces offer more than scenic beauty; this study will quantify how they actively promote human health and support the ecosystems that we rely upon.

Introduction

Research increasingly indicates that greenspaces, including street trees, forests, gardens, parks, and other natural vegetation, may benefit health by reducing exposures to air pollution, noise, and extreme heat and mitigating the impacts of these exposures on health. Additionally, greenspaces promote physical activity, encourage social interaction, reduce stress, and restore cognition.[1] Substantial evidence suggests that greenspaces provide ecosystem services benefits, including cooling urban environments, and reducing air pollution exposures. Collectively, these health and ecosystem benefits may have massive economic impacts on the state—at least $1.4 billion per year according to a partial accounting of four services provided by urban tree cover in California.[2] However, there are still large knowledge gaps in quantifying how changing the quantity, distribution, and quality of, as well as access to, greenspaces are related to changes in both human health and ecosystem services, as well as the potential economic benefits of these changes. Moreover, greenspace is not equally distributed, and underserved and overburdened communities may obtain greater benefits from greenspaces.

With leadership from a team of environmental epidemiologists, plant scientists, environmental economists, environmental geographers, and community engagement experts, and working in concert with a statewide community advisory group and in consultation with CARB, this proposal aims to develop methodologies to fill this gap in quantifying the human health and ecosystem service benefits of greenspaces and to support CARB's Nature-Based Solution programs to equitably increase greenspace in California communities. Specifically, this study will support CARB's Nature- Based Solution programs to increase green space in California communities, including through street, neighborhood, and schoolyard greening efforts, including those related to AB 1757 which is designed to increase nature-based solutions and "would require the state board, no later than January 1, 2025, to develop standard methods for state agencies to consistently track greenhouse gas emissions and reductions, carbon sequestration, and, where feasible and in consultation with the Natural Resources Agency and the Department of Food and Agriculture, additional benefits from natural and working lands over time." Through this proposed study, we will provide valuable evidence to target and guide the implementation of nature-based solutions to make equitable improvements in health across California, including in underserved communities. California's stunning greenspaces offer more than scenic beauty; this study will quantify how they actively promote human health and support the ecosystems that we rely upon.

Proposed Method

Task 1: Develop an Overall Workplan

We will work to develop an overall workplan for the analysis for the project. The PI will work with both CARB and the advisory group to develop this workplan. The final workplan will contain a clear description of deliverables for each task and a timeline for deliverables including interim milestones.

Deliverable: We will complete an overall workplan for the analysis for the project. This will contain detailed guidelines on how we tackle each task.

Task 2: Literature Review of the Health Impacts of Greenness and the Methods used to Quantify Health Benefits

Our study team has extensive experience in research on greenness and health, having published multiple prior reviews in the area,[1,3–7] and we have pioneered methods in exposure assessment in greenspace epidemiology.[8–10] Building on this expertise, we will conduct a systematic search of the greenspace and health literature. We will also examine studies that have evaluated the health-related economic costs and benefits due to greenspace. We will summarize study findings, including but not limited to those from CARB-funded projects, and will annotate the methodologies applied across studies. In our review, we will pay close attention to exposure assessment, to ensure that we have identified the most accurate and specific metrics of greenspace exposure. We will also assess bias, for instance to whether the authors have adequately controlled for important confounders, such as neighborhood socioeconomic status. We will also summarize findings for important vulnerable subgroups, including age groups, race/ethnicity, neighborhood socioeconomic status (SES), linguistic isolation, and urbanicity/population density.

Deliverable: We will provide CARB with a report on the findings of the literature review of health impacts of greenspace and the methods used to quantify health benefits. This will include a table summarizing major findings, methodological approaches, and potential biases and limitations in the literature.

Task 3: Data Collection for Exposure and Health Impact Analysis

We will first design a data management plan to ensure high-quality data (and metadata) are collected, used, transformed, and reported following robust scientific standards and norms. At a minimum, all data collected and generated will undergo a preliminary validation to ensure their usability, quality, statistical structure, and assumptions that might affect analyses and interpretation. We have developed a Conceptual Diagram (**Figure 1**) which captures Tasks 2-5.

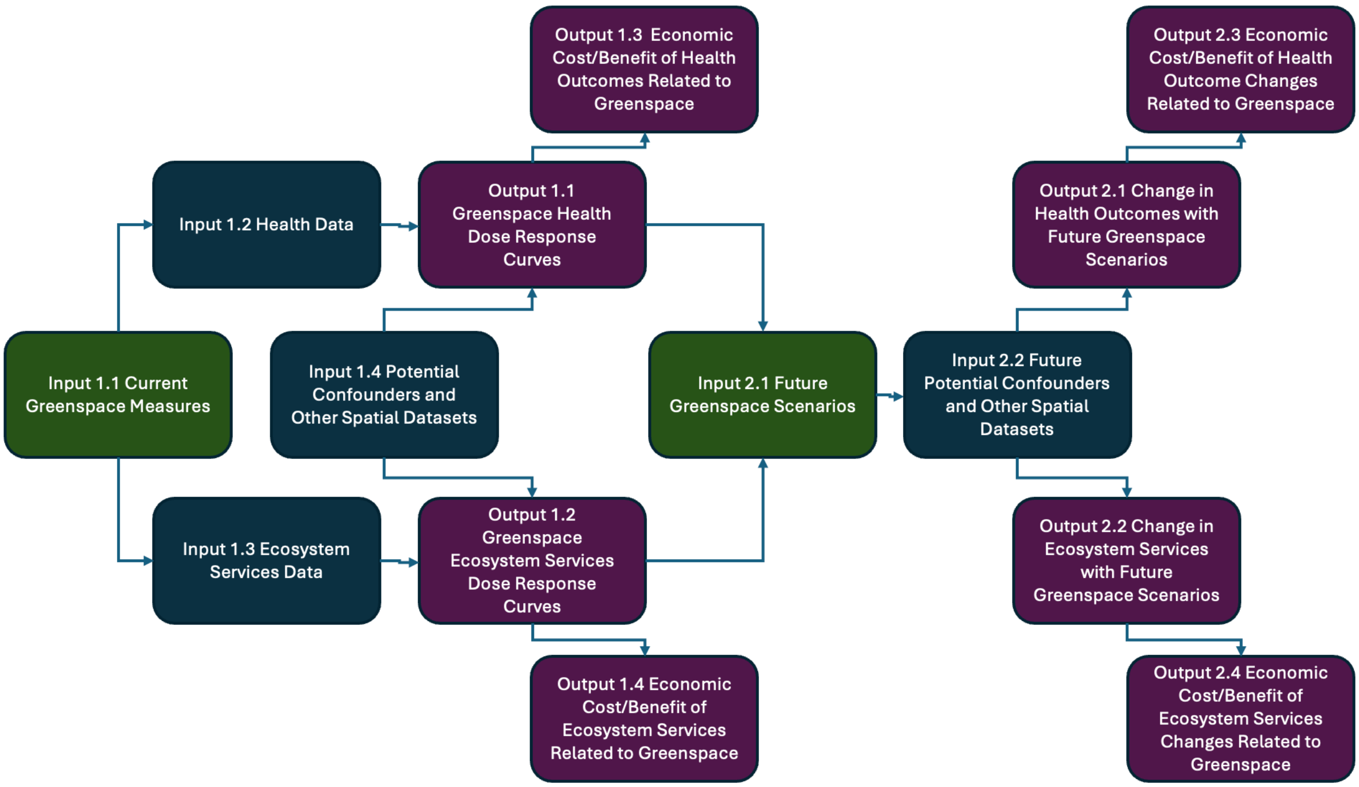

Figure 1. Conceptual Diagram

Greenspace Datasets

Our study team, including Drs. James, Ossola, and Brazil, has broad expertise in and has developed spatial analysis and remote sensing approaches to develop exposure metrics, as well as analytic pipelines and code, for greenspace, including satellite data (NDVI and EVI),[11] street-view based metrics, tree canopy cover data, high resolution tree canopy height data, tree species maps,[12] park datasets,[13] and biodiversity datasets. We will leverage our current research on multi-scalar approaches to integrate available greenspace data over time and match to longitudinal health datasets.[14,15] We will apply spatial analytic approaches to aggregate greenspace metrics up to any spatial scale needed for epidemiologic analyses, using, for example, zonal statistics or other approaches to examine the composition of greenspace within an administrative boundary. We have also added Dr. Noli Brazil, an expert in spatial analysis, to our study team. We have held prior symposia on developing greenspace exposure metrics,[16] and have received funding from REI to create a nationwide nature exposure repository. Together these data can provide both high-resolution accurate measures for landcover and tree cover as these datasets are available down to the 1m or smaller resolution, and most metrics are time-varying and collected consistently statewide. We will build on these datasets and dive deeper into datasets specific to California that might have increased specificity and resolution, including CARB-developed datasets on trees, shrubs, and grass. We will also focus on spatial datasets that are routinely collected and are open source, so that we can continue to monitor changes in greenspace over time (see **Table 1**).

We will capitalize on numerous spatial datasets on greenspace, with our main focus on tree cover. We have access to numerous datasets to estimate tree cover at high spatial resolution, but also at high temporal frequency to detect changes over time. For our primary tree cover metric, we will use available open-source urban tree canopy (UTC) cover maps that are routinely created by various federal and state agencies (please see the 2018 1 m resolution Urban Tree Canopy map of

California[17] in **Figure 2**) and the new high resolution (<1 m) urban tree canopy cover map for 2024 from CALFIRE soon to be released. These data are usually collected every 5-6 years for the entire state of California. UTC maps will be complemented by maps on greenspace derived from the National Agriculture Imagery Program – NAIP Program.[18] The last NAIP data were collected across the whole state in 2022 at 60 cm resolution, and collections are scheduled every 2-3 years by federal mandate to the USDA, guaranteeing a high-fidelity, high-frequency dataset. At larger resolution, we will completement UTC/greenness data with 30 m datasets related to urban land cover by using the National Land Cover Database (NLCD)[19] and the EVA Tool of the Multi-Resolution Land Characteristics (MRLC) Consortium that is able to detect year-by-year land cover change across the state.[20] To account for the fact that many Californians live in peri-agricultural areas, which may expose them to pesticides and allergens, we will include 30 m raster data from the Statewide Crop Mapping by the CA Natural Resources Agency, which is updated every 1-2 years.[21]

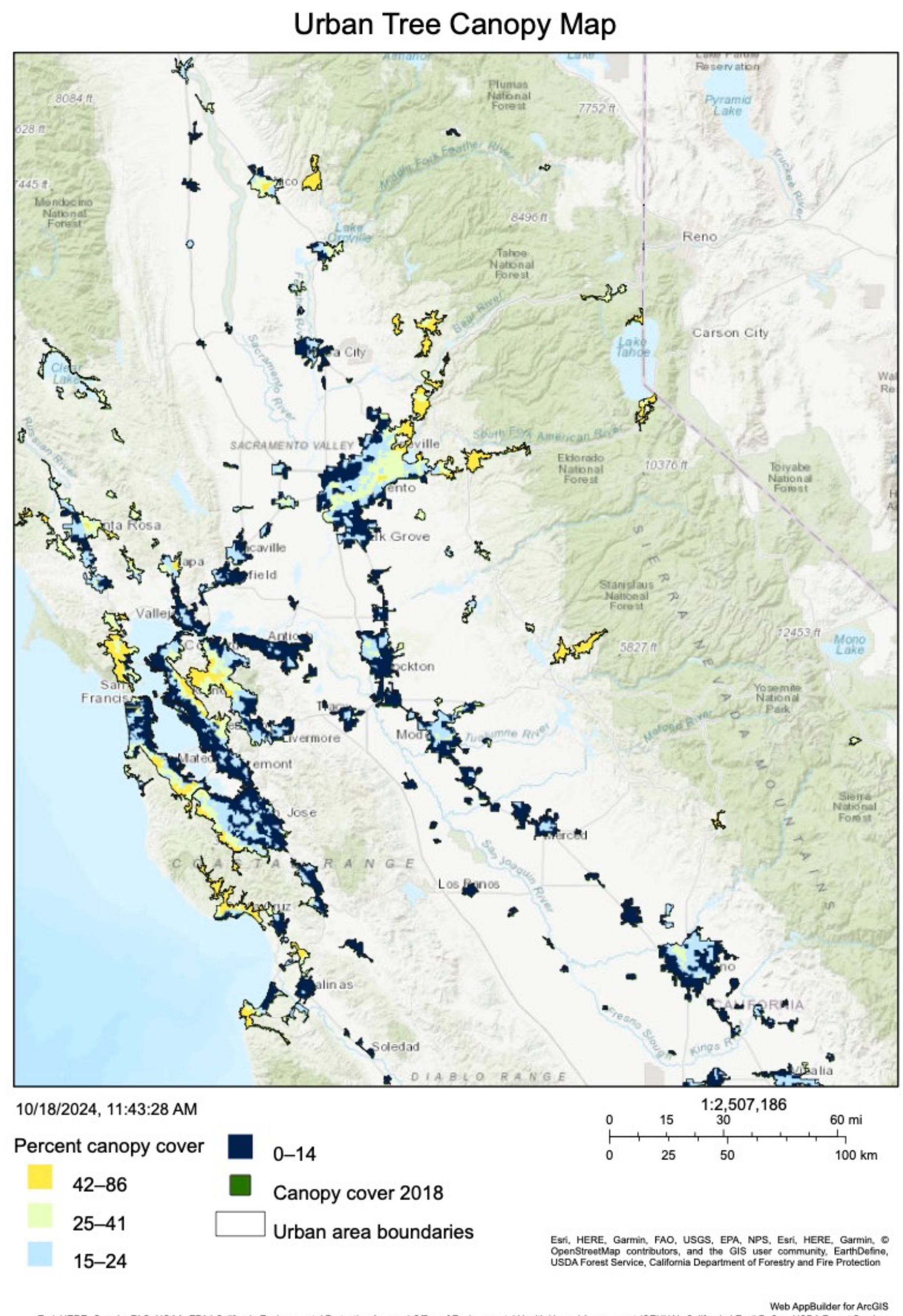

Figure 2. Percent Urban Tree Canopy Cover in Northern California

For street-level greenspace, we will examine Google Street View (GSV)- based metrics of greenspace based on ubiquitous street-level photographs that represent an on-the-ground perspective. We will leverage data from an NIH-funded R01 award (R01HL150119; PI: James) that used deep learning segmentation algorithms[22] applied to GSV imagery to derive computer vision measures of greenspace annually from 2007-present at a resolution of 100m for all Core-based Statistical Areas (CBSAs) in California. (CBSAs are combined metropolitan statistical areas and micropolitan statistical areas as defined by the US Census. CBSAs consist of the county or counties (or equivalent entities) associated with at least one core (urban area) of at least 10,000 population, plus adjacent counties having a high degree of social and economic integration with the core as measured through commuting ties.) For each image, the algorithm estimates the percentage of pixels from 150 pre-defined classes,[22] including natural features, such as trees, shrubs, grass, plants, and flowers. The algorithm has shown to have >90% accuracy to estimate what is in a given pixel. We then average across four images representing the four orientations to estimate the percentages of each class within a 360° view at a location (e.g., 30% trees in an image, see **Figure 3**). These GSV-based data are available at 100m resolution every year from 2007-present, and are updated annually. We will aggregate these metrics up to the Census tract or ZIP code level to enable linkage with health data and to deal with proprietary data issues. We plan to update these metrics periodically going forward.

For park access, we can use the US Geological Survey Protected Areas Database of the US version 2.1, which is a non-time varying dataset.[13] All land types likely to be used by the general public for outdoor recreation are included in this dataset. This dataset includes smaller parks within cities. It includes only parks accessible to the public and excludes non-accessible public land (e.g., Department of Defense land). It contains data on entrance fees. We will also examine the California Protected Areas Database, which contains lands that are owned in fee and protected for open space purposes by over 1,000 public agencies or non-profit organizations. For these park datasets, we can calculate distance to the closest park for every 100m across the state, or can create metrics of park density per Census tract or ZIP code.

To account for the effects that urban biodiversity can have on human health, as well as ecosystem services (see **Tasks 6-9**), we will create a robust set of biodiversity metrics that can be updated regularly over the years (see **Table 1**). These metrics will be calculated at the appropriate resolution to match the spatial extent of public health and ecosystem service datasets and outcomes (e.g., ZIP code, census tract, or finer resolution). We will create an updated list of endangered, rare and protected species by reviewing records from the IUCN Red Lists,[23] the US Endangered Species Act[24] and the California Endangered Species Act (CESA)[25] focused on trees and plants. In doing so, we assume that the proximity of humans to these species of conservation interest is a robust proxy for people exposure to wild and functional nature. Similarly we will compile a list of key invasive species from the Global Register of Introduced and Invasive Species (Global Invasive Alien Species Information Partnership (GIASI Partnership)),[26] that, conversely, are known to have detrimental effects on ecosystems and human wellbeing. For both selected endangered and exotic/invasive species we will obtain occurrence records from a vast variety of sources that are regularly updated to ensure longitudinal coverage over the years. These sources include data regularly collected at the individual (plant) level such as the Global Biodiversity Information Facility (GBIF),[27] eBIRD,[28] and the habitat/home- range level (~30 m to zip code level), such as the California Wildlife Habitat Relationships dataset,[29] the Biogeographic Information Observation System,[30] the California Natural Diversity Database (CNDDB).[31] For vascular plants, we will collect open-source data for native species, alongside their market availability in nurseries (Calflora[32] and Calscape[33] from the California Native Plant Society, both updated every 1-2 years). For trees will make use for the California Urban Forest Inventory as primary data at the ZIP code level, complemented by secondary data from the Falling Fruit Database[34] and Global Urban Tree Inventory.[12] Evidence suggests that greenspaces with high biodiversity have often the greatest quality, and thus higher use from local communities (e.g., for recreation, play, etc.). Key taxa that could be modelled could include non-allergenic plants, trees with high growth rates, and any other species with plant traits that could be beneficial for health outcomes. For instance, taxa could be selected to contrast evergreen versus deciduous species. It is known that some deciduous species could provide greater ecosystem services to people due to their ability to shade buildings/surfaces over summer and reduce energy costs for air conditioning, while allowing greater sun radiation during winter, thus also reducing energy consumption for warming. From a public health perspective, deciduous trees could similarly provide much-needed shade and cooling benefits to vulnerable people in summertime, while allowing greater light penetration in buildings during wintertime and thus a healthier indoor environment for people (e.g., greater light might reduce seasonal affective disorders (SAD)).

Trees

Grass

Other Green

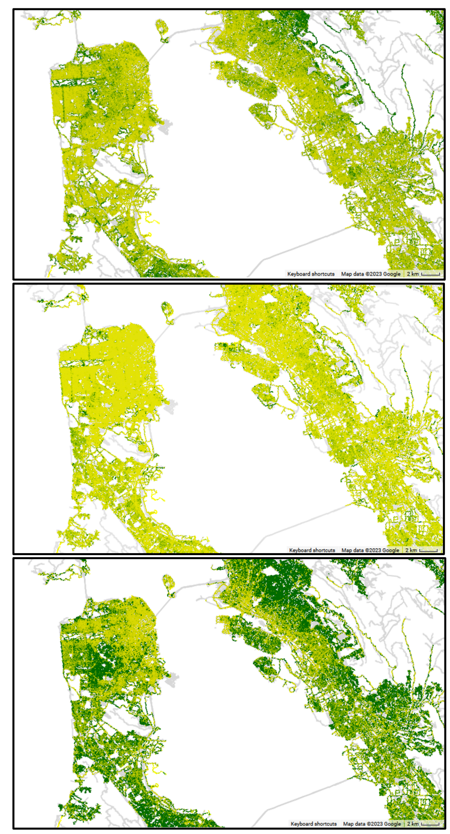

Figure 3. Map of 100m rasters of Google street-view derived metrics of trees, grass, and other green (plants, flowers, fields) in San Francisco, CA
For trees, min = 0.0%, max = 48.0%;
for grass: min = 0.0%, max = 18.0%;
for other green: min = 0.0%, max = 3.0%

To ensure our analyses are comparable to prior greenspace-health analyses in the published literature, we will also link Landsat satellite-based Enhanced Vegetation Index (EVI) and Normalized Difference Vegetation Index (NDVI) data. EVI is a

Landsat satellite- based metric of the quantity of ground vegetation which corrects atmospheric conditions and canopy background noise and is sensitive in areas with dense vegetation. EVI is available for every surface of the globe from 1984 to the present at 30m resolution every 16 days. We will also examine NDVI, another Landsat satellite-based measure of vegetation that has been widely used in previous studies of greenness and health.[1,5,6] NDVI is also available globally from 1984-present at 30m resolution every 16 days.

Table 1. Spatial Datasets on Greenspace

Dataset	Construct	Resolution / Scale	Temporal Frequency
Urban Tree Canopy Map of California from USDA Forest Service	Tree canopy cover	1m statewide	Every 5-6 years
CALFIRE high resolution urban tree canopy cover	Tree canopy cover	<1m statewide	Every 5-6 years
National Agriculture Imagery Program	Tree canopy cover	60cm statewide	Every 2-3 years
National Land Cover Dataset	Tree canopy cover	30m statewide	Every 5 years
EVA Tool of Multi-Resolution Land Characteristics	Tree canopy cover change	30m statewide	Every 1-2 years
Statewide Crop Mapping	Agriculture	30m statewide	Every 1-2 years
Google Street View	Greenspace viewable at the street-level	100m across all Core-based Statistical Areas statewide	Annual
US Geological Survey Protected Areas Database	Park access	Statewide polygons	Not Time-Varying
California Protected Areas Database	Park lands that are owned in fee and protected for open space purposes by over 1,000 public agencies or non- profit organizations	Statewide polygons	Every 1-2 years
IUCN Red Lists, the US Endangered Species Act, the California Endangered Species Act (CESA), Global Invasive Alien Species Information Partnership	Biodiversity	Varying scales	Every 10 years or more
Global Biodiversity Information Facility	Biodiversity	Varying scales	Every 1-2 years
eBIRD	Biodiversity	Varying scales	Every 1-2 years
California Wildlife Habitat Relationships dataset, the Biogeographic Information Observation System, the California Natural Diversity Database (CNDDB)	Biodiversity	Varying scales	Every 10 years or more
Calflora and Calscape	Biodiversity	Varying scales	Every 1-2 years
California Urban Forest Inventory	Biodiversity	ZIP code statewide	Every 2-3 years
Landsat Enhanced Vegetation Index	Vegetation	30m statewide	Every 16 days
Landsat Normalized Difference Vegetation Index	Vegetation	30m statewide	Every 16 days

Health Datasets

Co-I Hertz-Picciotto has substantial experience with publicly available health datasets in California. We will lean heavily on Dr. Hertz-Picciotto to identify and connect our team to health datasets that can be spatially linked to greenspace metrics.

Specifically, California Department of Health Care Access and Information (HCAI) data documents all hospitalizations and emergency department visits throughout the state, and these data are also linked to the ZIP- code of the patient's residence. For each visit, the dataset includes the ICD codes for discharge diagnoses, the dates admitted and released, as well as all treatments received and whether they were in the ICU or NICU (neonatal ICU), which can serve as proxies for severity of the condition. Of particular concern with respect to greenspace are cardiovascular, respiratory, renal, cerebrovascular, heat-related, neurologic, and mental health conditions, as well as injuries. HCAI also contains data on pregnancy outcomes (preterm delivery, birthweight-for-gestational age). The California Department of Public Health (CDPH), Center for Health Statistics and Informatics, Health Information and Research Section provides ZIP code level data on death certificate datafiles and ICD codes for cause of death. California Birth Data through the Department of Public Health contain exact address information, as well as information about complications of labor and delivery, APGAR scores (an indicator of neonatal stress immediately after delivery), and results of newborn screening tests that include thyroid levels and a large list of inborn errors of metabolism or other mutations. Maternal smoking is obtained usually through self-report. These data also contain Death and Fetal Death files can be obtained with exact addresses, which include date and causes of death, age, and primary occupation for parents. The California Birth Defects Registry includes all congenital malformations, and can be obtained with linkage to birth files at the address level. The California Department of Developmental Services shares residential address info and contains information on both children and adults (all ages) with disabilities that range from autism and intellectual disability to cerebral palsy and other verified conditions, as well as their age at assessment, periodic confirmation of diagnoses, and services or treatments that the person received or is eligible to receive. The California Cancer Registry data contains residential addresses and includes all diagnosed cases of cancer, affected organ, stage, grade, and locations of metastases. CalEnviroScreen (besides environmental data such as air pollution) includes health outcomes such as asthma, cardiovascular disease, and birth weight at census block group or tract resolution. According to the CARB priorities, we propose to also incorporate Medicare datasets available at the zip code level. Similarly, with specific relevance to greening schoolyards, we are able to access the California Assessment of Student Performance and Progress (CAASPP) data at the school-level and will build upon current tree canopy / green space cover assessments of California's schoolyards that Co-I Ossola is already creating for USDA-Forest Service.[35]

We will also work with our Community Advisory Group (CAG) to identify further high-quality datasets that might provide health data on important underserved subgroups. Health outcomes will be selected from those observed in the literature (**Task 2**) and will cover some of the following: perinatal (e.g., birth weight for gestational age, pre-term birth, early growth), cancer, cardiovascular disease, mental health (e.g., depression, anxiety), well-being (e.g., happiness), physical activity, sleep, obesity, diabetes, asthma, Alzheimer's Disease, and mortality. We will focus on the priorities of CARB to select health outcomes. Analyses can be performed for specific subgroups, e.g., by race or ethnicity, which might include Latinx, Black, Native Americans, and multi-racial, or by neighborhood SES. As multiple approvals are needed (from the California Committee for the Protection of Human Subjects for CDPH, the Vital Statistics Advisory Committee, and HCAI), we anticipate setting up the accounts for this project in advance and initiating these requests as early as feasible upon receipt of notification that we are selected to work with CARB on this project. Similar to the above greenspace metrics, we will work to identify health datasets that are routinely collected and are publicly available, so that we can monitor how changes in greenspace exposures impact health outcomes.

Table 2. Health Datasets with Geographic Data

Health Dataset	Outcomes Collected	Resolution / Scale
California Department of Health Care Access and Information (HCAI)	All hospitalizations and emergency department visits, including ICD codes for discharge diagnoses	ZIP code
The California Department of Public Health (CDPH), Center for Health Statistics and Informatics, Health Information and Research Section	Death certificate datafiles and ICD codes for cause of death	ZIP code
California Department of Public Health Birth Data	Complications of labor and delivery, APGAR scores (an indicator of neonatal stress immediately after delivery), and results of newborn screening tests that include thyroid levels and a large list of inborn errors of metabolism or other mutations, fetal death	Residential address
California Birth Defects Registry	Congenital malformations	Residential address
California Department of Developmental Services	Disabilities that range from autism and intellectual disability to cerebral palsy and other verified conditions	Residential address
California Cancer Registry	All diagnosed cases of cancer, affected organ, stage, grade, and locations	Residential

Health Dataset	Outcomes Collected	Resolution / Scale
	of metastases, as well as mortality following diagnosis	address
CalEnviroScreen	Asthma, cardiovascular disease, birth weight	Census tract
Medicare	Multiple outcomes	ZIP code
California Assessment of Student Performance and Progress (CAASPP)	Test scores	School-level

Potential Confounders and Other Spatial Datasets

In analyses, we will adjust for the following datasets, which might be correlated with greenspace and may drive health outcomes and therefore could confound the relationship between greenspace and health outcomes. Our group also has access to other spatial datasets that might confound greenspace-health associations, including climate, built environment, air pollution, wildfires, noise, and Census data on SES and segregation.[36] Climate: We will use the Parameter-elevation Relationships on Independent Slopes Model (PRISM) data,[37] which provide estimates of seven primary climate elements: minimum temperature, maximum temperature, precipitation, mean dew point, minimum vapor pressure deficit, maximum vapor pressure deficit, and total global shortwave solar radiation on a horizontal surface. Data are available at 800m resolution nationwide at monthly and annual resolutions from 1981 to the present. These data provide a more spatially explicit representation of climate exposure than observations from weather stations. Built Environment: We have access to time-varying walkability index at the Census tract level from 1990 to the present defined as the sum of Z scores of intersection density calculated from Tiger/Line shapefiles of all roads with interstates removed, population density from decennial Census data and American Community Survey data with a linear interpolation for intercensal years, and business density data from commercially available historical business data.[38] To incorporate the building density, we will include the new 2019-2020 Microsoft Building Footprints dataset,[39] which collect individual building shapes for the entire state. Air Pollution, specifically particulate matter, can be estimated at 1km scale annually from 2000-2016 using existing models,[40] or using CARB models. Wildfire exposure will be modeled based on daily 10 km gridded estimates of smoke pollution over the contiguous US.[41] Primary data from the Fire and Resource Assessment Program (FRAP) and the Fire Hazard Severity Zones from CALFIRE will allow to quantify relationships within recently burnt fires, the wild urban interface (WUI), and Fire Hazard Severity Zones. These data[42,43] are updated every year, or 1-2 years by CALFIRE mandate at a resolution ranging from 1-30 m. Noise will be estimated using a spatial sound model developed using a tree-based machine learning algorithm by the National Park Service which relies on acoustical data from 1.5 million hours of measurements from 492 urban and rural sites across the US during 2000-2014.[44–46] The resulting non-time-varying model maps sound levels at 270m resolution nationwide. Area-level Socioeconomic Status (SES) will be measured based on an index derived from a principal component analysis of Census tract variables, including summed Z scores of: median household income, median home value, % with a college degree, % non-Hispanic White, % non-Hispanic Black, % of foreign-born residents, % of families receiving interest or dividends, % of occupied housing units, and % unemployed.[36] We will also conduct analyses examining median household income, % foreign born residents, and % of each Census race category separately as potential confounders as well as effect modifiers. Area-level Segregation will be estimated using the Index of Concentration at Extremes (ICE) applied to any Census year,[47,47] which captures homogeneity of a given Census tract with respect to, for example, income and race.[48] We will work closely with CARB to ensure that our work builds on and is complementary to existing efforts, and appropriately advances the field.

Deliverables: In coordination with CARB, we will provide a catalog of greenspace and health datasets that are updated regularly, are open-source or made open-source, and can be linked to conduct epidemiologic analyses. We will also provide CARB with estimates for secondary datasets, including area-level SES and climate data, that can be used in analyses going forward.

Task 4: Development of Methodology to Quantify Health Benefits of Current and Future Urban Green Space Levels in California

Building from our literature review in **Task 2** and data compiled in **Task 3**, and in consultation with CARB staff, we will develop robust and replicable methodologies to estimate dose-response curves to quantify how current and future urban greenspace metrics are associated with differences in health outcomes. Analyses will be developed for application at a stateweide, regional, or local level. These methods will build on prior work modeling health effects of greenspace from our team,[49] but will also build upon and update the U.S. EPA Environmental Benefits Mapping and Analysis Program-Community Edition (BenMAP-CE)[50] platform. Thus, our approach is informed by but will update the existing approaches by developing high resolution models at the ZIP code, Census tract, or address level to estimate the changes in health outcomes from different urban greenspace scenarios in California.

Specifically, we will conduct analyses examining current greenspace conditions using the datasets listed in **Table 1** above as our exposures and the datasets listed in **Table 2** as our outcomes. First, we will take each exposure listed in **Table 1** and will create metrics of current greenspace conditions aggregated up to an appropriate scale for epidemiologic analyses when paired with the datasets in **Table 2**. This will likely be ZIP code or Census tract. We will also attempt to examine the spatial distribution of greenspace within this scale (e.g., whether greenspace is distributed equally across a ZIP code). We will then spatially and temporally link these exposure metrics with the health datasets in **Table 2**. We will then analyze data using the appropriate statistical approach for each outcome (e.g., Poisson for count outcomes such as hospitalizations, linear regression for continuous outcomes such as birth weight). For each outcome, we will examine each exposure in individual models, as well as in models with multiple exposures in the same model. We will use dimension reduction approaches, such as principal components analysis, or mixture models, such as Bayesian Kernal Machine Regression, to identify which exposure metrics seem to drive the variability in health outcomes. We will take an exposomic approach[59] to account for other correlated exposures that might confound greenspace associations, including air pollution, climate, noise, built environments, and population density. An exposomic framing entails estimating the impact of the totality of environmental exposures across the lifecourse. As such, analyses will be adjusted for factors in the **Potential Confounders and Other Spatial Datasets Section** above, as well as individual-level factors where available given the health dataset. For each outcome, we will provide the strength of each dose-response curve with 95% confidence intervals, as well as explore nonlinear relationships. We will also explore effect modification by area-level age, SES, racial/ethnic composition, segregation, and population density (as explained in the **Potential Confounders and Other Spatial Datasets Section** above) to identify if relationships between greenspace and health outcomes differ in underserved communities. We will also explore effect modification by climate and wildfire exposures to identify if relationships between greenspace and health outcomes differ by these environmental factors. Models will gauge how different factors might affect the statistical estimates and interpretation of the various scenarios. Factors will include climate zones (e.g., coast vs inland), climate change velocity, and population growth scenarios, among others. If we identify effect modification, we will provide stratum-specific dose response curves. These dose response relationships for each exposure-outcome relationship under current greenspace conditions will then serve as our model to use in future greenspace projections.

We will also develop methodologies to quantify the economic impact of differences in health outcomes related to greenspace-health dose response curves. A key initial step will be to review published efforts to estimate and collate greenspace values to identify methods or initial values suitable for our context. Notable examples include Center for Neighborhood Technology and American Rivers,[51] and Watts and Wolf[52] and Nowak and Greenfield.[2] Initially we will also explore the possibility of adapting BenMAP,[50] which is free and open-source, specifically for the economic valuation of health impacts. In California this tool has been used by the South Coast Air Quality Management District for their Socioeconomic Analysis of air quality improvements.[53] This will entail drawing on a mix of figures specific to California as well as other national figures adjusted for California as illustrated in the valuation of illnesses in California.[54]

Initial work will focus on a select set of values more precisely and robustly estimated as a core to build on in the medium- to long-term. We will provide annual estimates where possible, and where data exist, will quantify economic impact of differences in health outcomes, for instance, valuing mortality using the value of a statistical life (VSL) and morbidity using cost-of-illness (COI), e.g., including health care expenses (e.g., costs of avoided hospitalizations), and productivity losses.[2,55] Metrics that reflect a population's willingness-to-pay (WTP) for a given benefit—like VSL, which reflects WTP for mortality risk reductions—will be favored when available; however, when not available we will employ alternative measures of costs (like COI) which capture some direct costs but not all impacts to welfare, e.g., "pain and suffering, loss of satisfaction and leisure time."[50] For avoided mortality, valuation parameters used to convert outcomes into dollar values (VSL) are well-established in the literature (using hedonic and stated preference methods) and typically not tailored to specific applications. The value of morbidity reduction (avoided COI), will rely at least in part on estimates from other contexts using the approach of benefits transfer (BT). BT is used when it is "not feasible…to conduct original research for all necessary inputs"[53] and facilitates valuing a range of outcomes relatively quickly but at the expense of specificity to a given locale. We will seek to hone COI estimates to reflect California- or county-specific levels for health care expenses and/or loss of earnings.

To estimate future greenspace scenarios, we will consult with CARB to develop scenarios with exposure data that is consistent to the exposure metrics we identified in **Task 3**. We will also consider using data from partnerships with groups like Ten Strands,[56] Green Schoolyards America,[57] and other members of the Community Advisory Group (**Task 10**) to account for upcoming for urban greening interventions, including Urban and Community Forestry Projects funded by the Inflation Reduction Act.[58] Additional datasets currently used in our labs (CHELSA Global Climatologies 1km resolution to 2041-2060 and 2061-2080,[59] Swiss Federal Institute for Forest, Snow and Landscape Research WSL, updated every 2-3 years) will complement open data in **Task 3** to create more realistic and robust projections of health impacts in relation to green space change. Co-I Ossola's lab can predict future climate for any location/green space/etc. on earth based on an ensemble of climate model and greenhouse gas emission scenarios. The lab has already produced climate models for all 10,000+ schools across California, as well as projections for all community gardens in the US. Our analyses and projects confirm that several regions across California will face much greater climate impacts compared to others (e.g., inland versus coast). Thus, it is imperative to account for these climate projections to 1) assess the current relationship between greenspace and health, as well as their economic cost/benefit, and 2) find and prioritize opportunities for future allocations of greenspace at multiple scales across California.

Once we have projections for future greenspace scenarios, we will plug these greenspace scenarios, along with our best estimates for the other factors listed in the **Potential Confounders and Other Spatial Datasets Section** into our models developed for current greenspace. Will build a model that incorporates interaction terms for any effect modification that was identified above. We will also model economic impacts of changes in greenspace and subsequent changes in health outcomes into our economic models described above to estimate a cost or savings for predicted changes in health outcomes.

Deliverables: We will provide a model methodology to estimate impacts of current and future greenspace scenarios on health, as well as the economic benefits. This model will be transferable and reusable over time.

Task 5: Quantification of Health Benefits for Current and Future Projected Levels of Greenness in California

Using data from **Task 3** and the methodologies developed in **Task 4**, we will run the models to quantify health benefits of current and future greenspace levels in California, leveraging the expertise in greenspace epidemiology from PI James. Again, throughout the project we will identify greenspace and health datasets that are routinely updated so that we can evaluate changes over time in a longer-term monitoring framework. Building on associations observed in **Task 2**, data from **Task 3**, and methodology developed in **Task 4**, we will create stratum-specific estimates that account for potential effect modification by area-level age, SES, racial/ethnic composition, segregation, and population density, as well as climate scenarios. Using the models developed in **Task 4**, we can run analyses to provide statewide estimates for expected effect of overall differences in greenspace on differences in health outcomes, as well as regional and local levels. This will provide us with an estimate for the health outcomes that are affected by greenspace under current greenspace scenarios in California. We will also use the methodologies above to quantify the economic impacts of the difference in these health outcomes observed by level of greenspace.

Next, we will take estimates for projections of greenspace scenarios and add those estimates into our models to quantify how changes in greenspace might lead to changes in health outcomes. We will also incorporate changes in estimates for the factors listed in the **Potential Confounders and Other Spatial Datasets Section** into our models to quantify how the interaction between these factors might impact projected health benefits of greenspace. Again, we will run analyses to provide statewide estimates, as well as regional and local estimates, for the expected effect of changes in greenspace on changes in health outcomes based on predicted greenspace scenarios. This will provide us with an estimate for the health outcomes that would be affected by greenspace under future greenspace scenarios in California. We will also use the methodologies above to quantify the expected economic impacts of the expected changes in these health outcomes by applying similar methodologies to those explained in **Task 4**.

Deliverables: We will provide quantitative estimates of the health benefits, and downstream economic benefits, of greenspace under current and future greenspace scenarios. Estimates will be provided at the state, region, and local level, and will account for current and projected changes in other spatial factors, including underserved populations and climate changes.

Task 6: Literature Review on Ecosystem Service Benefits for Greenness and the Methods Used to Evaluate Them

We will conduct a systematic review of the literature on ecosystem services for greenspace and various outcomes related to greenspace, including cooling of urban environments and reducing air pollution exposures, in addition to other ecosystem services that might advance CARB's mission and goals. While this review will primarily focus on California, we will include key literature from other similar contexts to assess novel ways to further promote, integrate, and scale up the benefits that California's current and future greenspaces can provide to human and environmental health.[64] Particular emphasis will be given to the interplay and interaction of the 'greenspace—health' nexus with the impacts from extreme events and climate change and their implications for decision- and policy-making.[60]

Deliverables: We will provide CARB with a report on the findings of the literature review of ecosystem service impacts of greenspace and the methods used to quantify ecosystem service benefits. This will include a table summarizing major findings, methodological approaches, and potential biases and limitations in the literature.

Task 7: Collection and Analysis of Data for Ecosystem Service Benefits

We will first design a data management plan to ensure high-quality data (and metadata) are collected, used, transformed, and reported following robust scientific standards and norms. At a minimum, all data collected and generated will undergo a preliminary validation to ensure their usability, quality, statistical structure, and assumptions that might affect analyses and interpretation. We will compile current and historical data related to ecosystem services from a variety of state, regional, and federal sources and published in all formats available (e.g., geospatial, tabular, text). In collaboration with CARB staff, stakeholders, and the Advisory Board, we will rank and prioritize data collection and effort to complement the human health and greenspace data collected and generated in **Task 3**. We anticipate the final dataset will include key factors most likely to affect the 'greenspace—health' nexus, as described in **Task 3 Section on Potential Confounders and Other Spatial Datasets.** Urban heat and human exposure in urban settings will be quantified by mining the Landsat Collection 2 Surface Temperature from Landsat 8-9,[61] PRISM,[37] and gridMET.[62] These primary data will be complemented by atmospheric data on temperature, humidity and other covariates from several networks of weather stations from the National Weather Service (NWR California Stations),[63] CARB, and the California Irrigation Management Information System (CIMIS) currently manages over 145 active weather stations throughout the state (CA Dept Water Resources). Air pollution data will be quantified using CARB models, as well as 1km gridded $PM_{2.5}$ data.[40] Ultimately, our priority will be to identify ecosystem service datasets that are routinely collected and are open source so that these analyses will fit into a monitoring framework to be repeatedly evaluated over time.

Deliverables: In coordination with CARB, we will provide a catalog of ecosystem service datasets that are updated regularly, are open-source or made open-source, and can be linked to conduct analyses. We will also provide CARB with estimates for secondary datasets, including climate data, that can be used in analyses going forward.

Task 8: Development of Ecosystem Services Analysis Methods

We will design a multi-pronged, flexible, and scalable approach to data analysis to account for the variability of data available, the type of statistical data structures, statistical assumptions and power, the ecosystem service types to be modelled, and the varying quality of available data collected in **Task 7**. At a minimum, we will set up models to examine dose response curves between current greenspace levels and 1) differences in temperatures and 2) differences in air pollution levels. For heat, we will primarily focus on summertime temperatures and extreme heat events and will examine how greenspace metrics described in **Table 1** are associated with differences in these heat metrics. For air pollution, we will focus on average air pollution levels, as well as peak air pollution events and will examine how greenspace metrics described in **Table 1** are associated with differences in these air pollution metrics. For both ecosystem services, we will build out greenspace and ecosystem service metrics at the Census tract-level, and will create population-weighted estimates to better approximate true human exposure to each metric. We will spatially and temporally link greenspace and ecosystem service datasets. We will adjust for correlated exposures that might confound greenspace ecosystem service relationships, including many of the variables listed in the **Potential Confounders and Other Spatial Datasets Section.** We will also explore effect modification by area-level age, SES, racial/ethnic composition, segregation, and population density (as explained in the **Potential Confounders and Other Spatial Datasets Section** above) to identify if relationships between greenspace and ecosystem services differ in underserved communities, as well as in different climate scenarios. If we identify effect modification, we will provide stratum-specific dose response curves. These dose response relationships for each exposure-outcome relationship under current greenspace conditions will then serve as our model to use in future greenspace projections.

To create these models, we will test a set of traditional and new analytical approaches based on the diverse and complex data stream, comprising Artificial Intelligence and Machine Learning algorithms,[64] and where possible, the use of statistical tools able to make causal inferences in complex (big) data structures (e.g., Structural Equation Modelling, Path Analysis). To speed up analyses, we will make use of high-capacity computing located in our labs that can be seamlessly interfaced with the UC Davis Farm Cluster High-Performance Computing (HPC) system and other cloud-based tools for geospatial analysis and validation (e.g., Google Earth Engine, H_20.ai). All statistical and programming code and analytical pipelines will undergo strict QA/QC validation to ensure robust versioning, replicability, and accuracy of analyses. Preliminary and final data generated will be delivered with dedicated metadata and reported through current protocols and best-practice for long-term storage and ADA-compliant accessibility standards. All data will be published under open access licenses and in data portals that will ensure the maximum availability and usability well after the project ends.

We will also develop methodologies to quantify the economic impact of differences in ecosystem services, and their downstream impacts, related to greenspace-ecosystem service dose response curves. Similar to what we propose in **Task 4**, we will leverage existing frameworks to provide economic valuation to ecosystem services. For heat, we will leverage approaches that account for the cost of health-related outcomes (e.g., heat-related deaths), decreased productivity in workers, and potentially energy impacts. For air pollution, we will lean on BENMAP,[50] which was originally created to estimate the economic effects of air pollution. At a minimum, we will use approaches that factor in health outcomes (e.g., mortality, ER visits, hospital admissions, cardiovascular events), doctor visits, school absences, decreased productivity in workers, respiratory symptoms, medication use, asthma attacks, lung function changes, inflammation, and cardiac effects.

To estimate future greenspace scenarios, we will consult with CARB to develop scenarios with exposure data that is consistent to the exposure metrics we identified in **Task 3**. We will also consider using data the Community Advisory Group (**Task 10**) to account for upcoming for urban greening interventions, including Urban and Community Forestry Projects funded by the Inflation Reduction Act.[58] Once we have projections for future greenspace scenarios, we will plug these greenspace scenarios, along with our best estimates for the other factors listed in the **Potential Confounders and Other Spatial Datasets Section** into our ecosystem service models developed for current greenspace. Will build a model that incorporates interaction terms for any effect modification that was identified above. We will also model economic impacts of changes in greenspace and subsequent changes in ecosystem service outcomes into our economic models described above to estimate a cost or savings for predicted changes in ecosystem service outcomes.

Deliverables: We will provide a model methodology to estimate impacts of current and future greenspace scenarios on ecosystem services, as well as the economic benefits. This model will be transferable and reusable over time.

Task 9: Assessment of Ecosystem Service Benefits

Using data from **Task 7** and the methodologies developed in **Task 8**, we will run the models to quantify ecosystem service benefits of current and future greenspace levels in California. Throughout the project we will identify ecosystem service datasets that are routinely updated so that we can evaluate changes over time in a longer-term monitoring framework. Building on associations observed in **Task 6**, data from **Task 7**, and methodology developed in **Task 8**, we will create stratum-specific estimates that account for potential effect modification by area-level age, SES, racial/ethnic composition, segregation, and population density, as well as climate scenarios. Using the models developed in **Task 7**, we can run analyses to provide statewide estimates for expected effect of overall differences in greenspace on differences in ecosystem service outcomes, as well as regional and local levels. This will provide us with an estimate for the ecosystem services that are affected by greenspace under current greenspace scenarios in California. We will also use the methodologies above to quantify the economic impacts of the difference in these ecosystem services observed by level of greenspace.

Next, we will take estimates for projections of greenspace scenarios and add those estimates into our models to quantify how changes in greenspace might lead to changes in ecosystem services. We will also incorporate changes in estimates for the factors listed in the **Potential Confounders and Other Spatial Datasets Section** into our models to quantify how the interaction between these factors might impact projected ecosystem service benefits of greenspace. Again, we will run analyses to provide statewide estimates, as well as regional and local estimates, for the expected effect of changes in greenspace on changes in ecosystem services based on predicted greenspace scenarios. This will provide us with an estimate for the ecosystem services that would be affected by greenspace under future greenspace scenarios in California. We will also use the methodologies above to quantify the expected economic impacts of the expected changes in ecosystem services by applying similar methodologies to those explained in **Task 8**.

Deliverables: We will provide quantitative estimates of the ecosystem services benefits, and downstream economic benefits, of greenspace under current and future greenspace scenarios, specifically from reduced heat and air pollution exposures. Estimates will be provided at the state, region, and local level, and will account for current and projected changes in other spatial factors, including underserved populations and climate changes.

Task 10: Community Focused Advisory Group

A Community Advisory Group (CAG) will be recruited and facilitated in collaboration with the UC Davis Center ***T***owards

Health, ***R***esilience and ***E***nvironmental ***E***quity (THREE)[65] Community Engagement Core to supplement and expand the expertise of the research team, in particular in the areas of equity-oriented research methodologies, ground truthing of health and ecosystems services modeling, modeling for equitable benefits distribution, and research-to-policy and translation of research into community action. We anticipate the CAG will be made up of the following: 4-6 representatives from AB617 communities with urban greening strategies in their Community Emission Reduction Plans (this currently includes confirmed partners in South Central Fresno, Stockton, and Shafter with invitations to groups in El Centro-Heber-Calexico Corridor, and Southeast LA), and 2-4 representatives from community-based organizations with a focus on urban greening at either a local or statewide level. We have confirmed partnerships with TreePeople, Ten Strands, Green Schoolyards America, Central California Environmental Justice Network, Little Manila Rising, and the West Modesto Community Collaborative. We will also benefit from technical advice from the USDA's Urban Forestry Program. The project will also benefit feedback from Center THREE's larger and highly-engaged Community Advisory Committee (CAC), the co-chairs of which are members of the Center's executive Leadership Group, and which includes both community- based organizations and relevant state agencies. CARB is represented on CAC, as is the CA Department of Public Health, Department of Pesticide Regulation, Department of Toxic Substances Control, Office of Environmental Health Hazard Assessment, and the State Water Board. Following best practices in Community-Engaged Research, they will advise and support both the academic and community team members as needed, facilitate CAG meetings with an emphasis on open communication, mutual benefit, and accountability, and help ensure that both the outcomes and process components of the research are accessible, equitable, and culturally appropriate.

We will hold five virtual CAG meetings over the two-year funding period. The first (Year 1, Quarter 1) will focus on relationship building, discussion of methodology and priorities, and the development of an MOU documenting the collective agreements of academic and community team members in areas such as decision-making, communication, timelines, roles and responsibilities, data ownership, and authorship of publications and communications. This initial meeting will be followed by three 90-minute working meetings held virtually in Year 1, Quarter 3; and Year 2, Quarters 2 and 4. These meetings will provide opportunities for committee feedback and revision at each stage of the project. At each of these touch points, the committee will provide input and feedback on ways to make the research more reflective of local knowledge, relevant to local conditions and useful to inform community and policy action. For example, at the model development stage, the committee will contribute to the selection of priority exposures and health outcomes, as well as the economic outputs of focus. They will also provide feedback on projections for changes in greenspace and help ground truth model outputs, particularly in terms of whether there may be different dynamics at play in underserved communities. They will also provide feedback on the ways in which the research team interprets and communicates its data and contribute to mid-course design modifications if needed. At dissemination stage, they will provide guidance on the strategic communication and translation process into policy and community action, and the development of next steps for research and policy. The process design will draw on promising practices on the role of community research advisory boards that center community-based expertise and integrate this into the design and function of the research process, outputs, and outcomes.[66]

These meetings will be planned and conducted in collaboration with Center THREE's Community Engagement Core and CARB staff, and CAG contributions (feedback, comments, revisions) will be documented thoroughly in the final report. In addition, at the end of the project the team will host a virtual meeting open to the general public to share the results of the study and receive feedback that can be used to inform future research, policies and programs by the research team, CARB and other public agencies. CAG members will be compensated for their expertise in working and preparation time in parity with the compensation of academic team members. This equity in compensation is necessary both to ensure that the project has access to critical area of expertise and community connections as well as to align with environmental justice values that the communities most affected by an issue must play leadership roles in any research or policy designed to address it. As the Environmental Justice movement motto goes: "We speak for ourselves!"[67]

In the context of this proposal, in addition to the overall institutional support that will be provided by Center THREE, our Community Engagement Core Co-Directors will lead in the recruitment and facilitation of the CAG, leveraging decades- long relationships with key organizations in California's Central Valley and beyond. Center THREE's Community Engagement Core has a strong track record of successfully facilitating mutually-beneficial community-university collaborations, and will bring their considerable expertise to ensuring that this project's CAG is integrated as a full partner at every stage of the research process, from methodology development, to ground truthing modeling, to interpreting and communicating results.[68–70]

Deliverables: Meeting minutes from all CAG meetings, along with steps we have taken to incorporate guidance from the

CAG into our approach.

Task 11: Meeting, Reporting, Methods Transfer, and Preparation of Draft and Final Report

We will work closely with CARB staff on all Tasks, meeting regularly with them and providing appropriate deliverables before moving onto the next Task. We will share all code, documentation, and analyses with CARB staff and we will ensure successful execution of the methods developed during this contract on CARB IT systems. Additionally, all data and code necessary to update these procedures will be provided to CARB staff in clean, understandable, and well documented formats with the appropriate tutorials and meta-data. We will produce a draft final report six months before project ends. We plan to release both a complex technical report and a version for lay audiences.

Deliverables: We will provide CARB with code, documentation, and the final models. We will provide a draft final report six months before the project ends, as well as a final report with a complex technical version and a version for lay audiences.

Conclusion

Our proposed study will work closely with CARB to develop evidence-based methodologies to quantify the health and ecosystem service benefits of both current and projected levels of greenspace at the state, regional, and local level, and we will also develop approaches to estimate potential economic impacts of greenspaces. We will employ cutting-edge greenspace datasets to estimate exposure and will integrate important correlated spatial data into analyses to reduce confounding bias. This work will focus on underserved communities at every stage of analysis to ensure the equitable benefits of access to greenspace, and the eventual reduction of health and ecosystem service disparities. This project will provide fundamental evidence for CARB’s Nature-Based Solution programs to increase greenspace across California communities and will help to drive decision-making on which nature-based approaches (e.g., planting and maintaining trees) will be most effective, and where to implement them for the largest impact. Ultimately, this essential project will create vital tools to improve human health, to benefit ecosystems, to reduce health disparities, promote environmental justice, and to confront the climate crisis.

DELIVERABLES

As listed in Task 11 and as outlined in our Project Schedule, we will work closely with CARB staff on all Tasks, meeting regularly with them and providing appropriate deliverables before moving onto the next Task. We will share all code, documentation, and analyses with CARB staff, and we will ensure successful execution of the methods developed during this contract on CARB IT systems. We will produce quarterly progress reports, and we will produce a draft final report six months before project ends. We will release a Final Report at the end of the project, which will incorporate a one-page Public Outreach Document that will be widely used to communicate, in clear and direct terms, the key research findings from the study to the public. The Final Report will also include an Equity Implications Section that will summarize how the research results inform disparate impacts of greenspace policies, regulations, or programs on underserved communities. The Final Report will be copy-edited before being sent to CARB for review and the Principal Investigator shall attest that the Final Report has been reviewed and approved.

DATA MANAGEMENT PLAN

All datasets will be downloaded and hosted on UC Davis servers. In particular, we will use the Farm Computing Node to process large spatial datasets and to conduct analyses linking greenspace metrics to health and ecosystem services datasets. We will work with CARB to ensure that all data and algorithms for this project are either open source or have been developed by our team in such a way that we can transfer the data to CARB. For instance, we can process greenspace metrics at the Census tract or ZIP code level to enable transfer to CARB for their maintenance, manipulation, and redistribution. We will also provide CARB with workflow documentation so that they can understand our process and replicate it if need be.

PROJECT SCHEDULE

Task 1: Develop an Overall Workplan
Task 2: Literature Review of the Health Impacts of Greenness and the Methods used to Quantify Health Benefits
Task 3: Data Collection for Exposure and Health Impact Analysis
Task 4: Development of Methodology to Quantify Health Benefits of Current and Future Urban Green Space Levels in California
Task 5: Quantification of Health Benefits for Current and Future Projected Levels of Greenness in California
Task 6: Literature Review on Ecosystem Service Benefits for Greenness and the Methods Used to Evaluate Them
Task 7: Collection and Analysis of Data for Ecosystem Service Benefits
Task 8: Development of Ecosystem Services Analysis Methods
Task 9: Assessment of Ecosystem Service Benefits
Task 10: Community Focused Advisory Group
Task 11: Meeting, Reporting, Methods Transfer, and Preparation of Draft and Final Report

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p = Quarterly progress report
dr = Deliver draft final report (to be submitted six months prior to contract expiration)
fr = Deliver final report
m = Meeting with CARB staff
c = Community Advisory Group Meetings
d = Deliverable for Task

PROJECT MANAGEMENT PLAN

Our multidisciplinary team with expertise in environmental epidemiology, plant science, environmental economics, and community engagement is ideally suited for this proposal. The team will work closely with biweekly meetings to ensure that we accomplish all Tasks and provide Deliverables on time. We have a strong community engagement component, with strong prior ties to many community organizations across the state. Detail on our relevant experience is listed below:

<u>Peter James (PI)</u> has substantial expertise in greenspace epidemiology, including developing spatial metrics of greenspace and linking these data to large prospective cohorts to study associations with health outcomes. He has led multidisciplinary research teams developing novel metrics of greenspace, including applying deep learning to 350 million Google Street View images across all US cities to derive views of trees, grass, and other greenspaces, and has modeled how these exposures are associated with health outcomes. Dr. James has published widely on greenspaces and health, including primary research articles and multiple review articles, as well as on inequities in access to greenspace by race and socioeconomic status. He has also worked with communities to model how changes in greenspaces might impact changes in health and ecosystem service-related outcomes. He is working to develop nationwide repositories of greenspace datasets to accelerate research on greenspaces and health. Dr. James is also a Chapter Author for Human Health and Well-being Chapter in the first ever National Nature Assessment, sponsored by the US Global Change Research Program. As the Principal Investigator for this project, Dr. James will be responsible for the scientific direction and overall conduct of the project. He will contribute to all phases of the project, but will specifically play the lead on Tasks 2-5. He will also coordinate across all investigators on this project to ensure we meet all deliverables on time.

<u>Alessandro Ossola (Co-I)</u> is the lead of the Urban Science Lab at UC Davis. He is a former US National Academy of Science, Engineering and Medicine NRC Associate where he spearheaded research aimed at quantifying the fine-scale distribution and change of urban green spaces and tree canopy cover in several US cities. Recently Dr. Ossola received a New Innovator Award from the Foundation for Food and Agriculture Research to measure the nutritional values of over 500 trees species planted across 700+ US cities and 17,000+ towns. He is the lead of a large UCDA-funded project aimed at measuring school microclimates in several school districts across California, working with the Forest Service, CalFire and Green Schoolyard America. Dr. Ossola is the inventor of the Global Urban Tree Inventory, the first global assessment of the 4,700+ tree species in the world's cities and towns based on analysis of over 13 million records. He serves on the Oversight Committee of the USDA's Los Angeles Center for Urban Natural Resources Sustainability, and in 2023 he provided a testimony in a hearing of the AB 1757 NWL Expert Advisory Committee related to greenspace, ecosystem services and urban nature. Dr. Ossola will contribute across all Tasks, but will play a major role in Tasks 6-9.

<u>Michael Springborn (Co-I)</u> co-leads the Natural Resource Economics (NatuRE) and Policy Lab at UC Davis. He has extensive experience conducting research at the intersection of public health, economics and ecosystems. He has >15 years experience working with interdisciplinary research teams, including six different working groups supported by various NSF-funded research centers. This includes extensive collaboration with resource agency personnel such as a 2018-2022 group supported by National Socio-Environmental Synthesis Center, which he co-led. Dr. Springborn will contribute to all Tasks, but his expertise will be especially important in Tasks 4-5 and 8-9.

<u>Irva Hertz-Picciotto (Co-I)</u> is Director of the UCD Environmental Health Sciences Center (EHSC) THREE: <u>***T***</u>owards <u>***H***</u>ealth, <u>***R***</u>esilience and <u>***E***</u>nvironmental <u>***E***</u>quity which brings together faculty from multiple Schools and Colleges for collaborative research to advance understanding of environmental contributors to health, and translation of results into policies or practices to improve public health. She has published widely, led large multidisciplinary research teams, and works with community organizations in her research. Key EHSC THREE resources are a Pilot Projects Program and the Community Engagement Core (CEC); major focus areas are climate change and the Central Valley. Dr. Hertz-Picciotto's expertise will specifically be important for Tasks 3-5. In her role as the Director of the EHSC, where she has supported extensive community engagement, Dr. Hertz-Picciotto will also contribute her expertise to Task 10.

<u>Noli Brazil (Co-I)</u> is an Associate Professor and Vice Chair in the Department of Human Ecology at UC Davis. He is a spatial scientist with extensive expertise on applying spatial data to solve problems in human health and ecology. Dr. Brazil will contribute his expertise to Tasks 3-4 and Tasks 7-9.

Jonathan K. London (Co-I) co-directs the Community Engagement Core (CEC) of the UCD EHSC THREE and is a nationally recognized expert in Community-Based Participatory Action Research (CPBAR) in environmental health and justice with over 30 years of experience designing, implementing, and evaluating CBPAR projects around the world. He has published widely in environmental science and, health journals as well as policy-relevant reports. Dr. London was Founding Director of the UCD Center for Regional Change, which has led the field of university-community partnerships in the contexts of environmental justice, regional equity, and public health. He has led seminal policy-relevant interdisciplinary research on issues of water justice, air quality, cumulative risks and healthy and sustainable land use, transportation, and housing. Dr. London will lead Task 10, the Community Focused Advisory Group work on this project.

Shosha Capps (Co-I) brings more than a decade of experience facilitating university-community collaborations, with a focus on action-oriented, policy relevant research addressing health, access, and exposure disparities experienced by low-income communities and communities of color in California's Central Valley. She has served as the Co-Director of EHSC THREE's Community Engagement Core since 2021. Ms. Capps will play a major role in Task 10 and will call on her experience and relationships to support the Community Focused Advisory Group.

Staff:

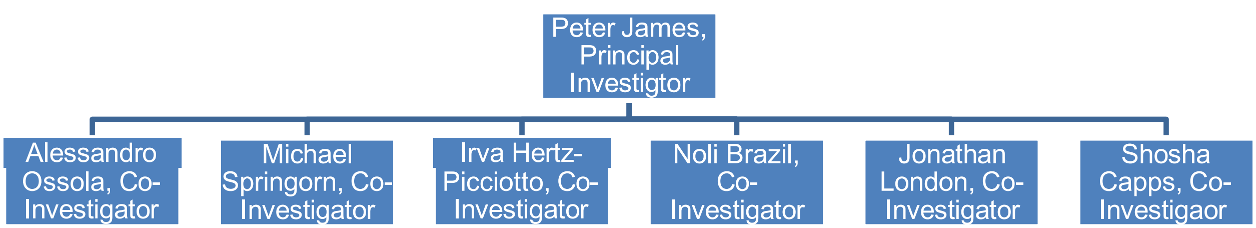
Mariela Alaniz is a Research Data Analyst within the EHSC. She will assist with analyzing data across all Tasks in the project.

To be appointed – Graduate Student Researcher (GSR), who will assist with literature reviews and analyzing data across all Tasks in the project.

To be appointed – Graduate Student Researcher (GSR), who will assist with literature reviews and analyzing data across all Tasks in the project.

To be appointed – Postdoc, who will assist with literature reviews and analyzing data across all Tasks in the project. They will also provide support in the Community Focused Advisory Group.

Organizational Chart



HUMAN SUBJECTS

We will utilize publicly available data for all analyses. Where applicable, we will obtain the appropriate Institutional Review Board approval to analyze human health data, particularly when using data that is potentially identifiable (e.g., participant address data).

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