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Where and Why Do Ecosystem-Based Adaption Projects Take Place in California?

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WHERE AND WHY DO ECOSYSTEM-BASED ADAPTATION PROJECTS TAKE PLACE IN CALIFORNIA?

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Daniel K. Jacobson

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WHERE AND WHY DO ECOSYSTEM-BASED ADAPTATION PROJECTS TAKE PLACE IN CALIFORNIA?

by

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APPROVED FOR THE DEPARTMENT OF ENVIRONMENTAL STUDIES

SAN JOSÉ STATE UNIVERSITY

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ABSTRACT

WHERE AND WHY DO ECOSYSTEM-BASED ADAPTATION PROJECTS TAKE PLACE IN CALIFORNIA?

by Daniel K. Jacobson

California is experiencing the harmful impacts of climate change and will continue to do so for generations. As a result, municipalities have been forced to turn to adaptation solutions to help local residents adjust to inevitable impacts such as sea level rise, extreme heat, and extreme weather. Ecosystem-based adaptation (EbA), the use of nature and ecosystem services to help human systems adapt to climate change impacts, is an increasingly popular, cost-effective, and multi-benefit adaptation strategy. While prior research has shown that other forms of adaptation, often referred to as ‘hard’ and ‘soft’ strategies, disproportionately benefit whiter and wealthier populations, there has been little research on the equitability of EbAs and their outcomes. This study examines the distribution and characteristics of EbAs in Santa Clara County (SCC) and San Mateo County (SMC) through a climate justice lens. It uses content analysis of EbA project documents and GIS mapping to answer the question “where and why do EbA projects take place in California?” The results show that EbAs are not equitably distributed in SCC and SMC, and that predominantly White areas are home to nearly half of the EbAs. At the same time, EbAs located within low-income and minority communities, especially predominantly Hispanic ones, have longer construction times, potentially causing harm to people residing near these projects. Also, many EbAs are located in areas that have been gentrified, or are at risk of gentrification, raising the question of whether EbA projects contribute to green gentrification. This study ends with suggestions for municipal agencies, planners, and future researchers interested in equitable EbA strategies.

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Introduction

Global climate change is today's defining issue and will continue to be for generations to come (J. B. R. Matthews, 2018). As the Earth's climate continues to change into the 21st century, communities across the world are facing its impacts with increasing severity. Extreme temperatures, heavy precipitation, exacerbated storm surge, and occurrence of agricultural and ecological drought are a few of the many impacts of climate change. Santa Clara and San Mateo Counties are no exception as their residents are experiencing with increasing severity and frequency. In response to these developments, these two counties have created climate actions plans that to-date, have yet to prove on-the-ground action (Boswell & Jacobson, 2019; County of Santa Clara, 2023). Ever-improving evidence indicates an urgent and widespread need to address the current and future impacts of climate change (Arneth et al., 2019).

Mitigation and adaptation are the two main approaches to address the impacts of climate change on human, biological, and physical environments (Sciortino, 2011). Mitigation aims to minimize climate change impacts by reducing anthropogenic greenhouse gas emissions and deforestation. Adaptation, on the other hand, aims to anticipate and respond to climate change impacts by taking steps to reduce vulnerability of human systems. There is now consensus among leading climate organizations including the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC) that even with best-case scenario mitigation efforts, future climate change impacts are unlikely to be prevented, and climate change impacts will likely be felt for centuries (IPCC, 2014; Paris Agreement to the UNFCCC, 2015). This consensus stipulates a dire need to shift climate change efforts towards adaptation strategies, especially in vulnerable communities that are already experiencing life altering and life-threatening impacts.

As climate change adaptation has become a priority in climate policy within the last twenty-five years, it is unclear whether on-the-ground implementation of adaptation projects are being prioritized for the most climate-vulnerable communities, or whether they are primarily benefiting wealthier communities that can afford to pay for them (Lisa & Schipper, 2006). More traditional adaptation strategies like hard structures including levees, sea walls, and water desalination plants are known to be capital intensive, inflexible, and inequitably distributed (Jones et al., 2012; Kithiia & Lyth, 2011). Similarly, ‘soft adaptation’ strategies, such as insurance policies and managed retreat have often shown to benefit well-to-do citizens over underserved and highly vulnerable citizens (Scipioni, 2017; Talus, 2020; Reckdahl, 2014). Ecosystem-based adaptation (EbA), the use of nature and ecosystem services to help human systems adapt to climate change impacts, offers a promising, cost-effective, flexible, and potentially more equitable adaptation alternative (Brink et al., 2016; Hummel et al., 2020). Examples of EbA include urban forestry, green spaces, green stormwater infrastructure, riparian restoration, wetland restoration, and agroforestry, to name a few.

The concept of EbA was brought to prominence in the late 2000s and was primarily used in the global south because of the low cost, and the greater reliance their inhabitants and economies have on ecosystem services (Vignola et al., 2009). Since then, EbA has become a popular adaptation solution for the global south and the global north alike. Even the Bay

Area, one of the wealthiest locations in the world, is implementing EbAs on a large scale. In fact, the South Bay Salt Pond Restoration Project, which is within this study's research sample, is the largest tidal wetland restoration project on the west coast and is an EbA to address sea level rise, coastal erosion, and flooding impacts.

The increased popularity of EbAs in locations such as the San Francisco Bay Area is likely due to their relatively low cost compared to hard and soft adaptive alternatives, but also for the multiple side benefits that they provide such as community beautification, public health benefits, and cultural benefits. Currently, the distribution of benefits and burdens of EbA solutions is poorly understood, despite the promising rhetoric around EbA as an equitable practice (Brink et al., 2016). Further research is needed to understand whether the most climate vulnerable populations are actually benefiting from EbAs, or if they are simply bearing their burdens. This study aims to contribute to climate justice and EbA literature to encourage equitable implementation of EbAs. Accessibility to effective and affordable climate change adaptation practices, in which EbA may be able to provide, is of paramount importance for the protection of vulnerable communities and for the prevention of further exacerbation of climate and social injustices.

This research asks the following questions:

1. Where are EbA projects located and what are the predominant ecosystems at the project sites?
2. What are the sociodemographic and socioeconomic characteristics of the populations where EbA projects are located?

3. How do EbA projects vary in funding, and size based on location population characteristics?
4. Who is implementing EbA projects and where are they implementing them?

Literature Review

Introduction

I created this study because I wanted to know (a) The location of EbA projects (b) The predominant ecosystems, habitats, or land-use patterns at the sites; (c) The sociodemographic and socioeconomic characteristics of the site's population; and (d) How the characteristics of the residents at the site affected funding and project size; and (e) What agencies implemented EbAs and where they implemented them.

To prepare for the study, I reviewed research on climate justice, climate change adaption, and ecosystem-based adaption. To locate relevant research, I consulted a variety of sources, including academic journals, textbooks, and census data of the study site's population.

Climate Justice

The IPCC (2018) defines climate justice as "justice that links development and human rights to achieve a human-centered approach to addressing climate change, safeguarding the rights of the most vulnerable people and sharing the burdens and benefits of climate change and its impacts equitably and fairly." Amidst the progression of anthropogenic climate change, it is apparent that climate change stems from, and contributes to systemic injustices, making it not only an environmental issue, but a social issue (Slocum, 2018). Injustices are found within all aspects of the climate crisis from the unequal impacts of the fossil fuel industry on communities, to the unequal distributions of climate change impacts on different places and people, to the solutions implemented to address the climate crisis and their outcomes. From this general understanding, climate justice has emerged as an important subset of environmental justice. The following discusses important literature along four dimensions of climate justice: (a) the unequal impacts of the fossil fuel industry on people of color, low-income communities, and indigenous groups; (b) the concept of common but differentiated responsibilities; (c) the unequal distribution of climate change impacts and vulnerability; and (d) the inequity in who benefits and who bears the burdens of climate change solutions.

Unequal Impacts of the Fossil Fuel Industry on People of Color, Low Income Communities, and Indigenous Groups

History and Impacts of the Fossil Fuel Industry

The history of the fossil fuel industry is coterminous with that of the industrial revolution starting in England in the 18th Century (Williams, 2023). Fossil fuel is ancient, decomposed organic matter found beneath Earth's surface that comes in the form of coal, oil, and natural gas, which can be burned to produce energy (National Geographic Society, 2023). As industrialization spread, fossil fuel became in high demand to fuel the transition from rural to industrial economies. The rapid expansion of the fossil fuel industry and industrial revolution around the world ignited a number of social issues, largely due to the capitalist nature of the industry. Kendall (2015), states that [industrial] workers were seen as productive capital just as much as looms and furnaces were and they had to be exploited for the maximum gain. Harmful work environments, poor health outcomes, and segregation as a result from the fossil fuel industry continue to this day.

Fossil fuels are extracted through a number of methods including mining, drilling and hydraulic fracturing or "fracking" (Denchak, 2022). Fossil fuel extraction, burning, transport and industrial use negatively impact local communities residing or working in close proximity to these practices resulting in significant negative environmental, health, and social impacts (White, 2013). For example, fossil fuel activity has been found to significantly impact local air quality due to the burning of natural gas waste and truck traffic required for these operations (Government Accountability Office, 2012; Macey et al., 2014; Schmidt, 2013). Exposure to poor air quality results in increased incidence of cardiovascular disease, pulmonary disease, and premature mortality, therefore highlighting the detrimental effects the fossil fuel industry has on human health and wellbeing (Brook et al., 2010; Cohen et al., 2017). In fact, a recent study shows that globally, around 8.7 million people die every year due to particulate air pollution resulting from fossil fuel extraction and processing (Vohra et al., 2021). In order to assess the justice implications of the fossil fuel industry, it is important to distinguish the variability and extent of these impacts on different sociodemographic populations.

Fossil Fuels and Environmental Racism

The burden of the fossil fuel industry and the localized pollution it produces in the United States are disproportionately experienced by people of color (Ash & Fetter, 2004; Chakraborty & Zandbergen, 2007; Cushing et al., 2021). Interestingly, Crowder and Downey (2010) found that Black and Latino homes were more exposed to industrial pollution than White homes with similar economic and levels of education, indicating that race alone influences exposure levels to the harms of air pollution from fossil fuels. A landmark example of racial injustice is Cancer Alley, a 200-mile corridor between the cities of New Orleans and Baton Rouge, Louisiana, that is home to over 130 plants, factories, refineries and landfills, encompassing about 25% of the total United States' petrochemical production (Simonsen et al., 2010). Studies have shown that within Cancer Alley, Black people and lower socioeconomic populations were highly affected by toxic air pollution from these petrochemical plants and found that cancer risk in low-income and predominantly Black census tracts of Cancer Alley was 12 to 16% higher than in higher-income, predominantly White tracts (James et al., 2012; Terrell & St Julien, 2022).

Another well-known example of the racial disparities in exposure to the harmful effects of the fossil fuel industry is found in Richmond, California, home to the largest oil refinery on the West Coast (Chevron, 2018). The demographic makeup of Richmond is 20% White nearly 20% Black, and 40% Hispanic, making this one of the most ethnically diverse cities in California (U.S. Census Bureau, 2021; Corburn et al., 2014).

A 2010 community health assessment found that 22% of Black children in the city of Richmond were hospitalized at some point for asthma, compared to 9% of White children (Casanova et al., 2010). The Chevron refinery, similar to many others across the country, put minority communities at risk of place-based hazards, such as poor air quality, poor water quality and poor health outcomes. The refinery also puts residents at greater risk for potential disasters (O'Rourke & Connolly, 2003; Parfomak et al., 2013). For example, in 2015, an explosion at the Chevron refinery sent more than 15,000 local residents to the hospital with respiratory illness that was triggered by the accident (Cagle, 2013). There is mounting evidence that communities of color are disproportionately burdened by the fossil fuel industry; Indigenous communities are also disproportionately impacted.

Fossil Fuel Impacts on Indigenous Communities

Indigenous and native communities in the United States and across the world, have historically been invaded, exploited, and displaced in the interest of the fossil fuel industry

(LeQuesne, 2019; O'Rourke & Connolly, 2003; Shelton & Eakin, 2022). Despite the United Nations Declaration on the Rights of Indigenous People (United Nations General Assembly, 2007), these rightly sovereign communities and their lands continue to be exploited for political, natural resource, and fossil fuel interests (Spiegel et al., 2020; Temper, 2018). Watts (1999), coined the term "petro-violence," citing the direct violence suffered by Indigenous peoples who stand in the way of development, as well as the international conflicts incited by the extraction of petro-chemicals. The Amazon Rainforest provides many examples of petro-violence against Indigenous peoples. Home to Indigenous communities that are estimated to have settled in the Amazon between 10,000 and 39,000 years ago, European and non-indigenous populations have dramatically altered its socioecological landscape within the last few hundred years (Amazon Aid, 2023; Mann, 2005; World Wildlife Fund, n.d.). Extractive and fossil fuel industries, in particular, have devastated Indigenous Amazonian peoples through the pollution of life-providing rivers and ecosystems, deforestation, epidemics, and even violence (Finer et al., 2008; Kimerling, 2013; M. Sanchez, 2007; Vallejos et al., 2020; Walker et al., 2015). In fact, in the year 2020, 37% of those attacked and killed for defending against deforestation and extractive practices, including fossil fuel extraction and development, were Indigenous (Global Witness, 2021).

Indigenous women are threatened with petro-violence from the formation of "man-camps," temporary housing for out of area non-Native workers, on indigenous lands for exploration and extractive purposes. In fact, these camps markedly contribute to the Missing and Murdered Indigenous Women, Girls, and Two-Spirited People epidemic, in which four of five Native American women have experienced violence at some point in their life (Patil et al., 2022; Rosay, 2016). Indigenous men, on the other hand, are often forced to assimilate and work for fossil fuel projects, are notoriously harmful to workers' physical and mental health, subjecting them to the negative effects of the industry (Clay, 2014; Harris et al., 2021; Vohra et al., 2021; Wu et al., 2019).

Proponents of fossil fuel extraction, transport, and processing endeavors argue that these projects are of "national interest" to energy independence and national security (Energy Policy Research Foundation, 2010; U.S. Chamber of Commerce, n.d.), therefore are justified, however this completely disregards the negative health, socioeconomic and cultural impacts they has on Indigenous people (Hall, 2018; LeQuesne, 2019; Weinhold, 2011). A prime example of this disregard and injustice towards Indigenous peoples in the United States, is the case of the Dakota Access Pipeline, a "1,172-mile pipeline for transporting crude oil from North Dakota to refineries and terminals in Illinois" (Whyte, 2017, p. 155). Originally, the proposed Dakota Access Pipeline route was drawn closer to the urban center of Bismarck, whose population is nearly 90% white (U.S. Census Bureau, 2022a). Bismarck residents opposed this siting, due to concerns that the project would pollute their drinking water sources (Whyte, 2017). In response to these concerns, the proposed project was redrawn along a more rural route through the Standing Rock Sioux Tribal reservation (Whyte, 2017). While some argue that the redirection was justified, because the rural reservation has a lower population density than the city of Bismarck and therefore a pipeline there would impact fewer people, this shows a clear negligence for the health, economic and social well-being of the local Indigenous and rural communities (Emanuel et al., 2021). The construction of the Dakota Access Pipeline led to protests in 2017 that drew large crowds of people from many different regions and backgrounds to support the demands made by the Standing Rock Sioux and Cheyenne River Sioux tribes (Hersher, 2017).

Evidence shows that fossil fuel extraction and transport projects continue to be practiced and proposed near Indigenous communities, negatively impacting their health and traditional ways of life (Jonasson et al., 2019; Liddell & Kington, 2021). The recently approved Willow Project in Alaska, for example, has sparked justice concerns amidst Indigenous Alaskan communities. The Willow Project is an oil drilling project in one of the largest oil fields in the world (Brockbank, 2023). Charlie Sollie Hugo (2023), President of the Naqsragmut Tribal Council, wrote in a public letter to the U.S. Department of the Interior and U.S. Bureau of Land Management, explaining the local indigenous Anaktuvuc Pass residents' fear of the project's harmful impacts on the caribou, their primary source of food and a key figure in their cultural beliefs and traditions. Cases like this highlight the lack of cultural consideration when implementing fossil fuel projects, particularly in and nearby Indigenous communities and communities of color. While the negative impacts of the fossil fuel industry have been shown to fall upon communities of color and Indigenous communities, the injustices of the industry can also be viewed through a socioeconomic lens, in part because of significant parallels between race, indigeneity and socioeconomic status.

Differential Fossil Fuel Industry Impacts Based on Socioeconomic Status

As a capitalist society, socioeconomic status plays a large role in nearly all facets of life. In the context of justice, socioeconomic status is a multidimensional issue, in which income levels are highly related to other societal qualities such as race, health status, access to healthcare, lifestyle and exposure to place-based hazards (Hardaway & McLoyd, 2009;

Samari et al., 2019; Zimmer et al., 2016). In the United States, the percentage of Black and Native Americans below the poverty rate over two times the percentage of White, non-Hispanic Americans below the poverty rate (Creamer et al., 2022). It is, in part, due to poverty that ethnic minorities and Indigenous individuals are often more likely to reside within undesirable and unsafe areas near industrial and hazardous activity (Commission for Racial Justice, 1987; Jiang & Yang, 2022), further exacerbating economic and racial disparities, and contributing to a vicious cycle of injustices (Doubeni et al., 2012).

Despite this relationship between race, indigeneity and socioeconomic status, socioeconomic status by itself is also a strong indicator of exposure to environmental and health hazards linked to the fossil fuel industry. Mayfield et al. (2019) found in Appalachia, that mortality risk associated with natural gas activity increased as socioeconomic status decreased. Similarly, Perera (2017) found that, across the globe, children living in poverty are disproportionately impacted by the harms of fossil fuel combustion, with greater incidence of low birth weight, neurodevelopment disorders, asthma, cancer and infant mortality. In the same way that the fossil fuel industry disproportionately harms marginalized, underserved and lower socioeconomic populations, so do the climate change impacts that have resulted from the decades of irresponsible fossil fuel use.

Unequal Distribution of Climate Change Impacts and Vulnerability

In the context of climate change impacts, vulnerability can be defined as the susceptibility of human systems to experience adverse effects of natural or human-induced disasters or conditions (Cardona et al., 2012). There is mounting evidence that vulnerability to climate change impacts is not equally distributed across racial, social, economic and geographical spectrums (Environmental Protection Agency [EPA], 2021; Pörtner et al., 2022; Odeku, 2022). Vulnerability does not solely depend on the extent of climatic changes occurring globally. Several non-climatic stressors increase vulnerability to environmental and climatic changes, such as population growth, urbanization, socioeconomic and racial inequality (Pielke et al., 2007). Preston et al. (2014) calls these social vulnerabilities the 'roots of climate injustice'. In their book, Wisner et al. (2003) highlight the ways in which social, political and economic systems cause natural processes and environmental changes to become human disasters. The idea of addressing these non-climatic social vulnerabilities has been gaining traction amongst policymakers and activists and was the topic of interest during the COP26 People's Summit for Climate Justice (Odeku, 2022).

Hurricane Katrina has become a tragic example of climate disaster injustices and vulnerabilities. Racist and classist policies in New Orleans, Louisiana pushed low-income and minority populations to live in locations more vulnerable to storms and hurricanes and led them to have fewer resources to rebuild post-disaster (Elliott & Pais, 2006; Finch et al., 2010). As a result, low-lying and geographically vulnerable neighborhoods like the Lower 9th Ward, home to predominantly low-income Black families, were disproportionately impacted by Hurricane Katrina (Rusca et al., 2021). In fact, Black residents made up 66% of Hurricane Katrina deaths, as compared to White residents who made up 31% (Campanella, 2007). Hurricane Katrina is not an anomaly. Other climatic events have caused similar differential impacts across different groups of people, including Hurricane Harvey and Superstorm Sandy, in both those cases the worst damages were felt by marginalized, minority and low-income neighborhoods (Chakraborty et al., 2019; Faber, 2015; Shultz et al., 2020). While climate change impacts such as extreme heat and the urban heat island (UHI) are less acutely disastrous than hurricanes, they also disproportionately harm minority and lower socioeconomic populations in a significant way. In fact, Hsu et al. (2021) found that "the average person of color lives in a census tract with higher [UHI] intensity than non-Hispanic whites in all but 6 of the 175 largest urbanized areas in the continental United States" (p. 1).

Vulnerability: The Product of Exposure, Sensitivity and Adaptive Capacity

The extent to which climate change affects an individual or a population is largely attributed to their vulnerability levels. Gamble and Balbus (2016) conceptualize climate change vulnerability levels as the inter-relationship between a population's sensitivity to risks, exposure to risks, and adaptive capacity. Human sensitivity to climate change is the extent that a party is affected by variability in climate conditions or a party's "susceptibility to harm" (Gamble & Balbus, 2016). Exposure to climate change, in a human context, is defined as "the presence of people; livelihoods; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected" (J. B. R. Matthews, 2018, p. 549). Lastly, adaptive capacity is defined as "the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (J. B. R. Matthews, 2018, p. 542). As sensitivity, exposure, and adaptive capacity vary across populations as a result of age, health status, gender, socioeconomic status, and race, so does vulnerability.

Age is a significant indicator of climate change vulnerability, in which older populations have shown to be more sensitive to extreme heat, with greater incidence of heat-related morbidities (Arsad et al., 2022; Gamble et al., 2013; S. Lin et al., 2012; Liss & Naumova, 2019; Toloo et al., 2014; Q. Zhao et al., 2019). Children, on the other hand, have been found to be more sensitive to flooding-related mortality and morbidities (Han & Sharif, 2021; Paul et al., 2018).

An individuals' health status and pre-existing conditions like respiratory illness, diabetes, and cardiovascular conditions are also indicators of climate change vulnerability as poor health increases sensitivity (Federal Interagency Forum on Aging-Related Statistics, 2020; Filiberto et al., 2009; L. Wang et al., 2010). People with respiratory conditions such as asthma and chronic obstructive pulmonary disease (COPD), are more sensitive to extreme heat due to the positive correlation between temperature and poor air quality (Kalisa et al., 2018; Pearce et al., 2011). Xu et al. (2019), found that heatwaves lead to increased hospitalization for people with diabetes. Pre-existing cardiovascular conditions were also found to increase sensitivity to heat-related death and illness (Loughnan et al., 2010). Adaptive capacity is also greatly impacted by health status. An individual's mobility and cognitive function, whether in the case of evacuation or in the case of preparing one's home or community for climate change impacts, is essential for adaptive capacity building (Berry et al., 2011).

The impact of gender on climate change vulnerability is partly determined by differentiated biophysical markers such as body composition, and partly determined by social constructs. As there is limited research on transgender vulnerability to climate change (Bunce & Ford, 2015), binary genders will be assumed for the purpose of this paper. While women are generally more sensitive to extreme heat due to their higher body fat composition, men are generally more exposed to extreme heat conditions, likely due to their greater likelihood of working outdoors (Toloo et al., 2014). Traditional gender roles and socio-cultural norms for women, particularly in developing nations, such as the responsibility of fetching water, harvesting food and collecting fuel will become increasingly burdened with climate change impacts on water availability, extreme heat and extreme weather conditions (Sultana, 2018; United Nations Women, 2022). Compounding social inequities such as illiteracy and poverty, also contributes to differential vulnerability to climate change impacts between genders. In Africa, the percentage of illiterate women was greater than 55% as compared to 41% in men, making it more difficult for women to obtain climate change education, adaptative training and evacuation warnings (Rena & Nettimi, 2007). Also, of the 1.3 billion people living in poverty, 70% of them are women, indicating fewer resources to adapt to climate change therefore increasing their vulnerability (Osman-Elasha, 2009). These differential vulnerabilities by gender are not only present in developing nations. In their study in the Western U.S., J. C. Liu et al. (2017), found that the percentage of hospital admissions for wildfire smoke-related hospital admissions were 10.4% among women as opposed to 3.7% among men.

Low socioeconomic and poverty status is known to contribute to exacerbating some of the aforementioned conditions that increase vulnerability to climate change. For example, low- income families also generally live in low-income or subsidized housing, which has shown to be located in geographically undesirable and vulnerable locations, increasing the exposure of these families to climate change impacts such as extreme heat and flooding (Elliott & Pais, 2006; Finch et al., 2010; Gabbe & Pierce, 2020; Rosoff & Yager, 2017;

Voelkel et al., 2018). Poverty also reduces adaptive capacity, by means of lack of transportation in evacuation scenarios (Centers for Disease Control and Prevention, 2013), lack of electricity and air conditioning for extreme heat (Wilby et al., 2020), or inadequate school systems, impeding their ability to understand, prepare for and respond to climate change impacts (Yu et al., 2021). Interestingly, in their study in Eastern Uganda, Balikoowa et al. (2018) found that single male-headed households were the most vulnerable to climate change, therefore challenging the conjecture that female-headed households are generally more vulnerable.

Racial disparities in vulnerability to environmental hazards and climate change impacts are largely due to racial isolation and residential segregation or ‘redlining’ (Bravo et al., 2016; Gamble & Balbus, 2016). In their study of neighborhood factors associated with greatest heat risk in San José, California, Gabbe et al. (2022), found that neighborhoods with greater Hispanic and Asian populations had the greatest heat risks. Similarly, in Portland, Oregon, Voelkel et al. (2018) found that low-income and non-white communities are most susceptible to extreme heat related impacts. In a nationwide study, Manware et al. (2022), found that the most vulnerable race groups in the United States to extreme heat were non-Hispanic Black, Hispanic or Latino of any race and Asian in that order. In the aforementioned study in the Western U.S., J. C. Liu et al. (2017) found that Black populations had wildfire smoke-related hospitalization rates of 21.7% as compared to 6.9% in White populations. Following natural disasters, such as hurricanes and flooding events, Black individuals in the U.S. have been found to lose wealth while White individuals have been found to actually obtain more wealth indicating the prioritization of White communities in federal disaster relief (Howell & Elliott, 2018; Katz, 2021).

Common but Differentiated Responsibilities

Climate change is a global and transboundary issue, and hence requires collective action to reduce greenhouse gas emissions at the global scale (Baer, 2009; Hayward, 2012). The UNFCCC (1992)

> [acknowledges] that the global nature of climate change calls for the widest possible cooperation by all countries and their participation in an effective and appropriate international response, in accordance with their common but differentiated responsibilities and respective capabilities and their social and economic conditions. (p. 1)

In other words, while all parties are responsible for combatting climate change, a country's extent of responsibility should be dependent on their greenhouse gas emission levels and their ability to take action. However, it has proven difficult to discern the level of responsibility of different countries (Persson et al., 2021). Understanding differential responsibilities amongst countries and groups of people for causing climate change, for mitigating climate change and transitioning to renewable energy sources, and for facilitating adaptation to climate change impacts is of the utmost importance in the discussion of climate justice at both the international scale and domestic scale.

Who Is Responsible for Causing Climate Change? (Who Is to Blame?)

To determine who is to be held responsible for undertaking climate change solution efforts, it is essential to identify the parties most responsible for causing climate change in the first place. Responsibility has historically been assigned by placing the most responsibility on the nations with the greatest cumulative emissions since the Industrial

Revolution, as cumulative anthropogenic emissions is proportional to changes in global temperature (Hansen et al., 2007; H. D. Matthews et al., 2009; Persson et al., 2021). This is called the 'polluter pays' principle (Hayward, 2012). Based on the cumulative carbon dioxide emission totals from 1850 to 2021, the United States has caused 24% of the world's CO2 emissions, followed by the European Union with 17%, and China with 14% (Friedlingstein et al., 2022). This way of assessing a country's responsibility presents some intergenerational justice concerns, as the current generations that were born into highly GHG emitting societies reap the quality-of-life benefits of industrialization, but also bear the burden instead of their ancestors, who established these fossil fuel dependent societies (Hayward, 2012).

Similarly, by looking at modern day annual emissions, one could argue that parties with the greatest GHG annual emissions today are most to blame for causing changes in the global climate. In this case, China would be the most responsible, followed by the United States, India, Russia, and Brazil (Friedlingstein et al., 2022). However, many have argued that highly emitting countries with relatively low historical emissions, have the 'right to pollute' in order to catch up with developed nations that reaped the economic benefits of the industrial evolution early on (Streck, 2020; Torres, 2002). This argument follows the 'beneficiary pays' principle, since low- income countries may be high emitters today but have not fully benefited from the industrial revolution to the same extent as high-income nations (Hayward, 2012). Also, wealthier developed nations are outsourcing much of their natural resource-intensive production to developing nations (Roberts & Parks, 2007). China, for example, has become the 'world factory' in which much of developed world outsource much of their production, and the environmental damages to China (Liang & Zhang, 2011;

Ma et al., 2019). This introduces the idea of consumption-based emissions, which are more representative of a nation's lifestyles and behaviors, despite whether the emissions are emitted in their own country or abroad (L. Guo & Ma, 2021).

The discussion around allocation of responsibility for causing climate change is most often discussed in the context of international fora, such as at the yearly Conference of the Parties organized by the UNFCCC (Baer, 2009; Persson et al., 2021). However, many have argued that the nation-state is not the correct scale for assigning responsibilities, since not all groups of people within a country are equally responsible for that country's emissions based on their behaviors and lifestyles (Rosencranz & Jamwal, 2020; Vanderheiden, 2011). In fact, it was found that the wealthiest 10% of the global population accounts for 52% of the carbon emissions from 1990 to 2015, while the poorest 50% of the populations is accountable for only 7% of emissions (T. Gore et al., 2020). This discrepancy in emissions based of socioeconomic status represents the need for a more holistic, fine scale method of accountability in which an individual's behaviors, not solely a nation's borders, are considered.

It is evident that there is a great disparity in responsibility for the causes of climate change both between countries and between groups of people within countries. This, in turn, presents a number of justice and sociopolitical issues regarding the world's response to climate change. The recognition of who is most responsible for the causes of climate change is an important step towards holding them accountable and responsible for climate change solutions and reparations. One of the most pressing developments of climate change is the issue of allocating responsibility for the burden of costly climate change solutions, including mitigation and adaptation (Gardiner, 2004; Hayward, 2012; Vanderheiden, 2011). As previously discussed, the responsibility for the causes of climate change varies greatly between countries, populations, and individuals. In a just world, those most responsible for causing climate change would be the ones responsible for financing and undertaking climate change solutions, however it has shown to not be so simple.

Who Should Be Responsible for Adaptation?

While the distribution of responsibility for climate change causing emissions varies across and within a country's borders, so does the distribution of climate change impacts and vulnerability. In fact, those least responsible for causes of climate change, such as individuals living in poverty, houseless populations, and small-island states are often the most vulnerable to climate change impacts (T. Gore et al., 2020; Timilsina, 2021). Shukla (1999) stated that "the distribution of impacts across the nations is independent of emissions profile of each nation," (p. 1) which can also be applied within nations. Similarly, Reckien and Petkova (2019) argued that those in need of effective adaptation to climate change should not the ones responsible for conducting or funding adaptation efforts. In other words, the level of responsibility a population has for the causes of climate change does not correlate with that populations' vulnerability levels to climate change impacts, and therefore it would be unjust for them to be responsible for adaptation efforts. This is where the argument for compensatory and reparative justice comes into play: High emitting countries should be responsible for supporting highly vulnerable populations in their efforts to adapt to climate change and for compensating them for climate-related damages or losses (Hattori, 2021; Vanderheiden, 2011).

Who Wins and Who Loses as a Result of Climate Change Mitigation Solutions?

Similar to the disproportionate distribution of climate change impacts and vulnerabilities, there are justice implications in regard to who actually benefits from climate change mitigation solutions. J. B. R. Matthews (2018) defines climate change mitigation as “a human intervention to reduce emissions or enhance the sinks of greenhouse gases.” There are two main international treaties regarding climate change mitigation efforts, the Kyoto Protocol and the Paris Agreement. The Kyoto Protocol legally bound only participating developed nations to reduce GHG emissions, while permitting developing nations their ‘right to pollute’ (Kyoto Protocol to the UNFCCC, 1998). The Paris Agreement, on the other hand, set a goal of limiting global temperatures from rising 1.5℃ above pre-industrial levels, while encouraging all nations, regardless of development status, to reduce their emissions (Paris Agreement to the UNFCCC, 2015). These treaties have set the guidelines for global climate change mitigation. However, inequities have arisen in who benefits most from mitigation solutions, and who is burdened by them.

Efforts to mitigate climate change are primarily focused on the electricity, transportation, and industrial economic sectors, which between the years 1990 to 2021, accounted for 76% of the worlds GHG emissions (EPA, 2023b). It is clear that a transition to cleaner, renewable, non-carbon-based energy sources is needed to mitigate the climate crisis, however doing so in a just manner has proven to be difficult. In order to undergo a “just transition” into a low-carbon global economy, Newell and Mulvaney (2013), stated that it is imperative to consider the environmental, climate, and energy justice implications.

Injustice of Renewable Energy Solutions

As the push towards a renewable energy economy is underway, renewable energy solutions sometimes reproduce some of the same systemic injustices caused by the fossil fuel economy. It is critical to understand injustices linked to renewable energy projects and policies in order to ensure a just transition.

Issues with Hydropower. Hydropower solutions, while offering renewable energy supply and contributing to climate change mitigation efforts, have also shown to directly harm communities who likely won't even benefit from them. In Northeast India, Rampini (2016) found that the development of hydropower along the Brahmaputra River harms downstream rural riverine communities' livelihoods and diminishes their capacity to adapt to climate change. Similarly, Blake and Barney (2018) concluded that the highly regarded 'best practice' Theun-Hinboun hydropower project in Laos, while showing promising energy outcomes, has shown "slow violence of ecosystem degradation, livelihood choice erosion, loss of local autonomy, cultural transformation and exposure to multiple new risk factors from development-induced displacement and resettlement" (p. 20). Similarly, X. Zhao et al. (2020), concluded that the development of two hydropower projects in China socially excluded 20,000 people who were forced to relocate, and were unable to afford the electricity produced. These examples show how communities that bear the least responsibility for anthropogenic climate change are asked to bear the burden of climate change solutions.

Issues with Lithium. Transitioning from fossil fuels to renewable forms of energy does not eliminate the need for natural resource extraction. One of the detriments of the 'just transition' is the environmental and social impacts of lithium mining, particularly on

Indigenous communities. With climate change mitigation efforts, there is increased demand of lithium for lithium-ion batteries for electric vehicles (EVs) and large-scale energy storage (Graham et al., 2021). While EVs and efficient energy storage are excellent climate change mitigation solutions, the extraction of the lithium mineral presents a number of environmental and social justice concerns (Agusdinata et al., 2018; Peters et al., 2016). Lithium is found in modest quantities and concentrations across a wide range of geographies and, similarly to fossil fuels, lithium mining causes significant environmental impacts (Prior et al., 2013). A prime example of injustice associated with lithium mining, is Thacker Pass, Nevada, home to one of the largest lithium deposits in the United States (Nevada Division of Environmental Protection, 2022). With the increasing demand for domestic sources of lithium in the United States, a new mine at Thacker Pass permit was unduly expedited by the Trump Organization in 2021, largely in the name of national energy security (Uji et al., 2023). However, a federal lawsuit pursued by Indigenous communities, environmental groups, and farmers citing the detrimental local impacts on their water (Wildbear, 2021), air (Protect Thacker Pass, 2022), and the sacred Indigenous history of the resident Northern Paiute Tribe (Wilbert et al., 2023). Not only are the extraction processes of lithium harmful, the disposal of lithium ion batteries impairs water quality, pollutes the air, and creates other environmental harms (Wan & Wang, 2022). As previously mentioned, toxic disposal sites are known to be most commonly found in low-income and communities of color potentially increasing these populations risks to the harms of lithium ion battery disposal (Commission for Racial Justice, 1987; Jiang & Yang, 2022).

Differential Benefits from Renewable Energy and Associated Technologies

Renewable energy technologies, such as residential rooftop solar panels, EVs and smart thermostats offer air quality, economic, and climate change resilience benefits. However, to date, the adoption of renewable and clean energy technologies is inequitably distributed (Borenstein & Davis, 2016). The adoption of rooftop solar panels is significantly less in disadvantaged, low socioeconomic, and ethnic minority communities. This is likely due to the high up-front cost of installation (Lukanov & Krieger, 2019; O'Shaughnessy et al., 2023). Similarly, accessibility to EVs is currently limited to well-to-do early adopters who can afford this new form of technology and reap the benefits of its innovations (Mo et al., 2022). EV and solar technologies also lower owners' energy burden, while increasing energy the burden of lower socioeconomic populations that are without access to the benefits of these technologies (Vega-Perkins et al., 2023).

In Denmark, tax breaks in the form of subsidies were offered to citizens who purchased EVs to speed up the transfer of this new technology, however mostly wealthy citizens found it financially beneficial to purchase EVs and benefit from these tax breaks, upsetting taxpayers who felt they were subsidizing the consumption habits of rich citizens (Østergaard, 2015). Similarly, Borenstein and Davis (2016) found that of the $18 billion in U.S. federal income tax credits for residential 'clean energy investments', the wealthiest 20% of Americans received 60% of the total subsidies, and 90% of the EV subsidies.

The production of renewable energy infrastructure and technologies also presents racial and economic injustice concerns. Lennon (2017) highlighted the fact that these technologies are generally perceived as equitable and injustice-remediating solutions. However, the very manufacturing of the products often involves harmful work environments and exploitative labor of poor and minority workers. There is evidence to support these claims. For example, researchers have found that solar manufacturing sector jobs can induce vulnerabilities and worsen inequity (Bickerstaff et al., 2013; Brock et al., 2023; Mulvaney, 2014; Sovacool, 2021).

Energy Poverty. Energy poverty is defined as “insufficient access to modern and cleaner energy resources at low prices” and is one of the main concerns about the transition to renewable and clean energy sources (Al-Tal et al., 2021; Iliopoulou et al., 2022). Arguably, two of the most influential variables that impact energy poverty are geographic location and socioeconomic status (Papada & Kaliampakos, 2019). Rural and mountainous communities are especially susceptible to energy poverty, likely due to the cost of transmission to more isolated areas and the lower income of rural populations (M. Song et al., 2023). Energy poverty is an issue of utmost importance in Sub-Saharan Africa, where the majority of households are still considered energy poor, in which only 43% have access to reliable electricity (Blimpo & Cosgrove-Davies, 2019; Moss, 2019). There are concerns that a global transition to clean energy before the attainment of global energy justice, in other words before attaining “a global energy system that fairly distributes both the benefits and burdens of energy services, and one that contributes to more representative and inclusive energy decision-making” (Sovacool et al., 2017, p. 677) will ‘lock-in’ communities in energy poverty (Moss, 2019). Because fossil fuels are often inexpensive compared to contemporary clean energy sources, the transition from energy poverty to energy security through clean energy can be unfeasible, highlighting the need for energy security before we can achieve a just energy transition towards more sustainable energy sources (Bradshaw, 2010; Newell & Mulvaney, 2013).

Fossil Fuel Livelihoods. A poorly executed transition from fossil fuels could cause detrimental economic harm to communities and families whose livelihoods depend on the fossil fuel industry (Barry & Healy, 2017; Carley et al., 2018). Communities like Campbell County, Wyoming, the largest producer of coal in the United States, are highly vulnerable to the energy transition, as their main source of income is being targeted (Raimi, 2021). The push towards decarbonization is also particularly problematic in these communities, because those with the greatest fossil fuel employment numbers also tend to have high rates of poverty, and low rates of educational attainment (Snyder, 2018). While a transition to a 100% renewable energy economy is expected to produce more than enough jobs to replace all current fossil fuel industry jobs, the renewable energy jobs will not necessarily be located where fossil fuel workers reside, resulting in their relocation or unemployment (Jacobson et al., 2017). Jolley et al. (2019), found that fossil fuel workers from the closure of two coal-fired power plants in Ohio, employees that are displaced for new employment are likely to experience pay cuts. Newell and Mulvaney (2013) argued that in order for a just transition to take place, compensation must be provided, and new jobs must be created to ensure fossil fuel workers are rightfully considered and supported. The fossil fuel industry has notably created an economic dependency of mining and industrial communities on the revenue from fossil fuel extraction and processing to fund their education systems, infrastructure, and other public works (Haggerty & Haggerty, 2021). As the world attempts to transition to renewable energy sources, however, many of these communities are at risk of mass unemployment and loss of revenue. Big Horn County, Montana, for example exported 60% of the state's coal between the years 2010 and 2019, but since, two of their four coal mines have been shut down. As a result, Big Horn County has experienced severe cuts from $4.5 million in federal mining royalty payments to $1.2 million, resulting in county government layoffs, benefits reduction, loss of public services and higher taxes for non-coal sector community members (Haggerty & Gentile, 2022; Montana Association of Counties, 2022; K. Smith, 2021). This economic chokehold that the fossil fuel industry has on communities that rely on its revenue, is one of the reasons that the 'just transition' has proven so difficult.

Climate Change Adaptation

J. B. R. Matthews (2018) defines climate change adaptation in human systems as "the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities." As climate change impacts are highly variable between communities, societal sectors (economy, infrastructure, public health, social, etc.), and time scales (response to past impacts, current impacts, or planning for future impacts), "on-the-ground" adaptation projects are most often executed at the city or community level (Smit & Wandel, 2006). However, larger national and international frameworks, such as the UNFCCC and the U.S. EPA's Climate Adaptation Action Plan, can help provide guidance and resources for localities to enact adaptation practices to reduce their unique vulnerabilities (EPA, 2021). Today, climate change adaptation has become an international priority, however, this was not always the case.

Initially, many climate advocates opposed the concept of adaptation, including Al Gore (1992), former U.S vice president, who described climate change adaptation as "laziness, an arrogant faith in our ability to react in time to save our skins." The narrative that adaptation is fatalistic, and that it is the acceptance of a failure to mitigate, has inhibited adaptive planning (Doss-Gollin et al., 2020). Also, the global benefits of climate mitigation have overshadowed the more local benefits of adaptation, resulting in a prioritization of mitigation solutions (Pielke et al., 2007). In recent years however, the narrative around climate change adaptation has become more legitimized and salient in the climate change discussion (Pielke et al., 2007; Schipper, 2020).

Why Has the Focus Shifted from Mitigation to Adaptation?

While mitigation efforts are crucial and not to be overlooked, adaptation is needed now, especially for the most vulnerable and underserved populations. Historically, climate change mitigation has been prioritized over adaptation efforts, with only 4%-20% of global climate funding going towards adaptation (Eisenstadt et al., 2021; European Bank for Reconstruction and Development, 2018; Timilsina, 2021). In the last two decades however, steps have been taken on the international, national, state, and city scales to encourage climate change adaptation. On the international scale, in 2002, the UNFCCC's Delhi Declaration brought awareness to the need for adaptation stating that "adaptation requires urgent attention and action on the part of all countries." As of 2021, 79% of all countries had a formal adaptation plan, strategy, policy or law (United Nations Environment Programme, 2021). At COP21 in 2015, the United States, under President Obama, committed to double the nation's public financing for climate change adaptation domestically and abroad by the year 2020 (The White House, 2015). At the state and city level, many local governments have adopted adaptation plans (Georgetown Law, 2023). It is clear that adaptation is now viewed as a legitimate climate change solution alongside mitigation, but why has this shift occurred?

If global GHG emissions were reduced to zero today, the human and ecological impacts of climate change would continue to be felt for decades, if not centuries (Pielke et al., 2007). This "climate change lag" happens because GHGs can remain in the atmosphere for hundreds of years (EPA, 2022; Ricke & Caldeira, 2014). In 2015, The Paris Agreement set the goal of limiting global average temperature from rising above 1.5℃ from pre-industrial levels. However, findings show that even if this goal is reached, significant and potentially irreversible impacts on environmental and human systems would still occur (Allen et al., 2018; Paris Agreement to the UNFCCC, 2015).

Amidst slow moving mitigation efforts, climate change is now here. As of 2022, the Earth's average temperature had risen by 1.06℃ as compared to pre-industrial levels, and since 1981 the rate of warming has doubled (Lindsey & Dahlman, 2023). In fact, July 2023 was the hottest month on Earth in the last 125,000 years (Livingston, 2023). Under SSP2-4.5 (a moderate GHG emissions scenario), global surface temperature is expected to reach about 2.0℃ above pre-industrial levels by 2050, and nearly 3.0℃ by 2100, well over the Paris Agreement's goal of 1.5℃ (Allan et al., 2021; Paris Agreement to the UNFCCC, 2015). With rising seas, extreme heat, increased and intensified storm activity, floods, drought and wildfire the world is already observing the impacts of climate change on economies and infrastructure, as well as human health and wellbeing (Pörtner et al., 2022; Watkiss et al., 2015; World Economic Forum, 2022). Between the years 2000 and 2019 there were more than 11,000 climate change-induced extreme weather events impacting 94.9 million people, resulting in 475,000 deaths, and causing an estimated $2.56 trillion in economic losses (Eckstein et al., 2021). In 2012, Hurricane Sandy caused $62.5 billion in physical and economic damages and 117 deaths (Centers for Disease Control and Prevention, 2013; Henry et al., 2013). Although the cause of the storm itself cannot be directly attributed to climate change, the extent of the damages was assuredly attributed to sea level rise (Strauss et al., 2021).

The need for effective adaptation is particularly urgent in developing countries and poorer parts of the world, as climate change impacts are more consequential for them than in other parts of the world. Dell et al. (2008), discovered that in poor nations, an increase of 1℃ diminished economic output by 1.1%, exacerbating their economic and developmental disadvantages as compared to wealthier nations. Similarly, Hsiang (2010) found that in Caribbean and Central American nations, an increase of 1℃, reduced non-agricultural production by 2.4% and significantly increased political instability.

Small-island nations, many of which are low-income and infinitesimally responsible for climate change, are already at the mercy of SLR, as they are experiencing severe coastal erosion, extreme weather, saltwater intrusion, and degraded ecosystems. Some small island-states, such as those in Micronesia, are experiencing SLR at a rate three to four times faster than the global average and are being forced to respond despite their limited ability (Perkins & Krause, 2018). Under the slogan “1.5 To Stay Alive,” the Alliance of Small Island States called on the UNFCCC to incorporate the goal of keeping global temperatures below 1.5℃ above pre-industrial levels, as the original goal of 2.0℃ would prove catastrophic to small island states (Alliance of Small Island States, 2015; Paris Agreement to the UNFCCC, 2015).

However, despite this goal of 1.5°C, small island nations are currently on the frontlines of climate change and are being pummeled by tropical storms, hurricanes, and SLR. In 2017, Prime Minister Roosevelt Skeritt of Dominica, a small-island nation in the Caribbean, addressed the United Nations following a devastating year of hurricanes, stating that “Eden is broken,” implying that the time for mitigation has passed, and the time for adaptation is now (United Nations, 2017). Adaptation is needed most in the most vulnerable nations such as developing, poor and small-island nations that unfortunately have the least adaptive capacity to do so.

Adaptive Capacity

The ability of a nation, group, or individual to adapt to climate change is referred to as adaptive capacity. More formally, adaptive capacity is “the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences” (J. B. R. Matthews, 2018, p. 542). Adaptive capacity is one of the three components of climate change vulnerability, and an increase in adaptive capacity theoretically decreases the other two components, sensitivity, and exposure, therefore reducing overall vulnerability (Engle, 2011). The determinants of adaptive capacity include economic resources, technology, information and skills, infrastructure, institutions, and equity (Smit & Pilifosova, 2001). Similar to vulnerability levels, differential adaptive capacities can be observed at multiple scales, between countries, between groups of people within a country, and between individuals.

Sarkodie and Strezov (2019) found that nations in sub-Saharan Africa such as Mali, Chad, Niger, and Sudan were the most vulnerable to climate change, in part due to the fact that they have some of the lowest adaptive capacities in the world. Their low adaptive capacity can be attributed to their lack of economic resources to enact adaptive practices, their lack of adaptive technologies such as climate stress-tolerant crops and irrigation systems, and their lack of institutions for sustainable development, land-use planning, and disaster response (Sarkodie & Strezov, 2019).

Considering the great vulnerability of small island states, their adaptive capacity to climate change in general is severely low. Small island states, such as those in in Micronesia, have practiced traditional adaptive capacity building for centuries through the use of stone masonry. However, amidst anthropogenic climate change, these solutions have proven ineffective, forcing them to adopt more contemporary adaptive capacity building strategies (Nunn et al., 2017). These contemporary strategies, unfortunately, disrupt the traditional and cultural sense of place in small island states and developing countries, and even result in relocation from these areas completely (Hay, 2013; Nunn, 2009; Santha, 2015).

While adaptive capacity varies between countries, there is also variability between populations within individual nations. Hurricane Katrina is a great example of differential adaptive capacities between populations at a city scale. Masozera et al. (2006) found that not only did lower socioeconomic and Black populations face greater impacts from Hurricane Katrina than their White and wealthier neighbors, but they also had significantly less adaptive capacity to respond to the storm. A few factors contributed to this lack of adaptive capacity. One of which is that a disproportionate number of this population did not own vehicles, making it more difficult to effectively evacuate and return to the city afterwards (Bullard & Wright, 2009; Byrnes, 2014). Another factor that influenced this lack of adaptive capacity in Black and poor neighborhoods, was the inability to afford the costs of rebuilding and a deficiency of city services provided to these neighborhoods such as clean water, energy, and sanitation services (Harden, 2006; Byrnes, 2014). In fact, five years following the storm, the percentage of Black residents in New Orleans dropped from 67% to 60%, largely attributed to their lack of adaptive capacity (Mildenberg, 2011).

Phan et al. (2019) found that women in Vietnam may have less adaptive capacity than men since men traditionally have more institutional power, whether political, economic, or social. Also, the formal nature of male-dominant institutions provides them with more information (one of the adaptive capacity determinants) regarding climate change impacts and vulnerabilities, therefore increasing male adaptive capacity (Phan et al., 2019). Reed et al. (2014) argues that gender differences in adaptive capacity are not only present in developing nations, such as Vietnam, but also found in post-industrial nations like Canada.

Types of Climate Change Adaptation Strategies: Who Benefits and Who Bears the Burden from Them?

Climate mitigation is often discussed at the global scale, as it requires collective action to achieve a global reduction in anthropogenic greenhouse gas emissions. Adaptation, on the other hand, is often discussed at the state, city, local and individual scales (Adger, 2001). As climate change impacts are felt differently in different parts of the world, location-specific adaptation practices are required. There are currently three types of climate change adaptation pathways which will be discussed, including hard and soft adaptation pathways and the novel EbAs, which is the focus of this thesis.

Hard Adaptation Strategies

Hard or “grey” adaptation strategies are technology-based, artificial, and man-made structures that are used to reduce community exposure to climate change impacts (Brink et al., 2016). These structures include levees, seawalls, jetties, house stilts for SLR, water desalination and recycling plants, freshwater storage tanks, irrigation technology, crops genetically modified to better resist droughts, and air conditioning for extreme heat. Hard adaptation strategies are often capital and labor intensive, making these solutions less sustainable and less accessible, particularly to lower income populations (Brink et al., 2016; Jones et al., 2012).

Historically, hard adaptation efforts have been implemented mostly in marine, estuarine and freshwater shoreline communities in response to non-anthropogenic climate variability damages such as coastal erosion and seasonal storm surge (Patrick et al., 2016). While coastal armoring structures have shown to be effective in protecting property directly behind them, they are known to be inflexible to climate variability and to cause harm to adjacent coastlines and communities through the relocation of erosion, also known as “shifting vulnerability” (Griggs & Patsch, 2019; Schipper, 2020). This is a common finding in studies on coastal armoring structures, especially for foreshore structures, which are structures that extend into open water, such as groynes, jetties, and breakwaters.

Schoonees et al. (2019) explained that, although foreshore structures are designed to mitigate erosion and coastal destruction from the intensification of tides and sea level rise, they actually exacerbate coastal erosion in adjacent beaches, which stimulates environmental justice concerns. For example, in Fiji, a seawall built to protect a particular community increased the vulnerability of another community further down the coast (Piggott-McKellar et al., 2020). Similarly, Sultana (2010) found that hard flood control measures along rivers throughout Bangladesh led to the inundation and elimination of floodplains that provided food and income sources. This significantly increased the vulnerability of local poor women who relied on these floodplains for their well-being and livelihoods. In Charleston, South Carolina, a proposed nine storm surge seawall project was designed to end right before reaching predominantly Black and historically underserved neighborhoods. Despite residents' concerns regarding the redirection of storm surge towards them, community displacement, and gentrification, the project is still on track and will be implemented (Taylor et al., 2022).

There are also environmental justice concerns with hard coastal adaptation structures as they are known to compromise or completely eliminate public access to sandy beaches in which many community identities, economies, and cultures are dependent on (Hoegh-Guldberg, 2015; Sekich, 2021).

Soft Adaptation Strategies

It is increasingly understood that the concept of climate change adaptation is not only one of structural fortification, but also of social and behavioral modifications. Soft adaptation measures include information dissemination, policy, and adoption of adaptive behaviors among individuals and communities (Sovacool, 2011). Soft adaptation strategies include of large-scale strategies including land-use planning to avoid development in vulnerable areas, as well as the implementation of warning systems and evacuation plans (Jones et al., 2012). These policies have been criticized for prioritizing emergency response instead of the systemic roots of climate change vulnerability, largely due to procedural injustices (Preston et al., 2014).

Soft adaptation also includes planned retreat from vulnerable locations, purchasing insurance, and making individual or family evacuation plans (Black et al., 2011; Carman & Zint, 2020). Planned retreat is “a coordinated effort to permanently move people and assets away from hazardous places,” largely discussed in the context of coastal communities (Siders et al., 2021, p. 272). Often perceived as a last resort option, it is becoming increasingly more salient as climate change’s impacts on coastlines are intensifying (Zurich, 2023). Planned retreat has the potential to have beneficial transformative outcomes for development patterns, particularly in coastal areas. However, there are concerns that, without adequate consideration of past injustices, in which marginalized communities live in the most hazardous locations, these injustices would simply be relocated (Siders et al., 2021).

The establishment of disaster evacuation plans has become a commonplace climate change adaptation practice for municipalities, households and individuals. Early warning systems and evacuation routes are developed to facilitate the evacuation of the masses in emergencies such as hurricanes, earthquakes, and wildfires. However, these plans often do not consider minority and underserved populations adequately. Up to 15% of the world’s population are people with physical or mental disabilities and face disproportionate mortality rates from disasters due to their lack of consideration, accommodation and inclusion in evacuation planning (Hashemi, 2018; United Nations Office for Disaster Risk Reduction, 2013). Evacuations are also costly, isolating and highly burdening lower socioeconomic populations. Some estimates say that the average family spends over $5,000 when evacuated for a hurricane, making it impossible for some lower socioeconomic families to evacuate without substantial government or community assistance (Scipioni, 2017; Talus, 2020). In the case of Hurricane Katrina, approximately 100,000 New Orleans residents did not evacuate because they could not afford a car or other modes of transportation (Reckdahl, 2014).

It is clear that the need for climate change adaptation has never been greater. To ensure effective and fair adaptation, it is important to consider the failures of previous efforts. From the shortcomings of the hard and soft pathways, EbA has emerged as a cost-effective and potentially equitable adaptation strategy with a wide range of environmental and social co-benefits.

Ecosystem-Based Adaptation: What Is It and Why Is It Needed?

Ecosystems, Ecosystem Services, and Nature-Based Solutions

To understand the concept of EbA, it is important to define the elements involved. An ecosystem "is a functional unit consisting of living organisms, their non-living environment and the interactions within and between them" (J. B. R. Matthews, 2018, p. 548). Ecosystems provide provisions and goods for humans such as food, materials for shelter, and medicines. They also provide ecosystem services, "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life" (Daily, 1997, p. 3). Ecosystem services include cleansing of air and water, mitigation of storm impacts, moderation of temperatures, aesthetics, and cultural benefits (Daily, 1997, p. 3).

Nature based solutions (NbS) is an umbrella term for the utilization of ecosystem services to address societal issues such as economic and social development, public health, food and water security, environmental degradation, climate change mitigation, and the focus of this paper, climate change adaptation (International Union for Conservation of Nature, 2020). Recently, the application of NbS as a climate change adaptation strategy, known as EbA, has been gaining popularity for the multiple benefits it offers (Secretariat of the Convention on Biological Diversity, 2009). EbA is the use of ecosystem services to reduce vulnerability, increase resilience, and increase adaptive capacity of human systems to climate change impacts (International Union for Conservation of Nature, 2020). Although recently formally recognized as a type of adaptation strategy, EbA has been used by local and indigenous communities throughout the world for centuries to adapt to natural environmental and climatic variability (Blinman, 2008; Jackson et al., 2018).

Why EbA is Needed: Ecosystem Degradation

As human civilization continues to expand, and global land-use patterns are altered, ecosystems are being degraded substantially, or eliminated entirely. From deforestation to urban soil sealing to pollution and degradation of wildlife habitats, ecosystem services have been dramatically degraded, impairing human health and wellbeing, and increasing vulnerability to climate change (Artmann & Brueste, 2014; Kabisch, 2014; Kabisch et al., 2016; X. P. Song et al., 2014). In fact, the valuation of global ecosystem service loss was estimated between $4.3 and $20.2 trillion annually from 1997 to 2011 (Costanza et al., 2014). This degradation of ecosystems comes at a time when their services are needed more than ever to help people adapt to anthropogenic climate change. Widespread ecosystem degradation and global climate change has sparked calls for EbA solutions, particularly in urban, coastal, and agricultural settings (Goddard et al., 2010; D. Haase et al., 2014; Kabisch et al., 2016).

EbA can remediate some of the ecosystem degradation that has taken place, while also avoiding some of the shortcomings of hard and soft strategies. While the latter do help people adapt to climate change, research has also shown them to be inequitable and even environmentally harmful. Hard strategies are capital intensive, inflexible to climate variability, and socially inequitable because their benefits and burdens are unequally distributed across communities (Brink et al., 2016). Soft adaptation strategies, on the other hand, have also shown unequal outcomes, as they are highly dependent on community-level social capital and institutional efficiency which varies greatly between communities (Jones et al., 2012; Sovacool, 2011). EbA has emerged as a solution to the shortcomings of the hard and soft adaptation pathways, as well as a more a cost-effective, flexible, and efficient approach to increase adaptive capacity; it also addresses other societal issues (Brink et al., 2016).

Types of EbAs

EbA is practiced differently based on geographical location and local needs. Urban EbA, coastal EbA, and agricultural EbA operate very differently from one another, but all have the same purpose to help human system adapt to climate change by restoring ecosystems and the services they provide.

Urban EbAs

The use of EbA to restore and reintroduce nature and ecosystems into urban settings has become a priority for urban planners and policymakers across the world (Brown et al., 2021;

Cole, 2012; Rall et al., 2015; X. Zhang et al., 2015). The (re)introduction of nature and ecosystems into urban settings is commonly referred to as “urban greening,” “green urban infrastructure” or “living infrastructure,” which can generally be defined as “hybrid infrastructure of green spaces and built systems” (Alexandra & Norman, 2020; Demuzere et al., 2014; Sanz et al., 2022). The use of urban nature and ecosystems for the purpose of climate change adaptation will be further referred to as ‘urban EbA’. The three types of urban EbA discussed in this paper are urban forestry, urban green space, and green stormwater infrastructure.

Urban Forestry. Urban forestry is the “planting, maintenance, care and protection of tree populations in urban settings” (American Forests, 2019). With the exacerbation of UHI effect from climate change, the need for urban forest canopy has never been more essential for urban residents. Urban forests, including street trees, trees on private property, and trees within parks and open spaces, provide significant air temperature-cooling through evapotranspiration and shading (Ouyang et al., 2019; Swae, 2015). Countless studies in a wide range of locations across the world show that the greater the percentage of urban forest canopy cover, the lower the ground surface and near-ground air temperature (Hamada & Ohta, 2010; Middel et al., 2014; Sanusi et al., 2016; Shashua-Bar et al., 2010; Vailshery et al., 2013; Ziter et al., 2019). Studies show that, although urban forestry EbA is most often used to adapt to increased temperatures and UHI, these systems also provide adaptive stormwater management and mitigate urban flooding (Langenheim & White, 2022). For example, Berland and Hopton (2014) found that communities with street tree programs benefited significantly from stormwater interception and flood reduction, compared to communities without street tree programs.

Urban Green Space. Another EbA solution that is unique to urban settings is urban greenspace, which is loosely defined as "any vegetated land within or adjoining an urban area" (Greenspace Scotland, 2008, p. 2). This includes parks, community gardens, greenways, and nature trails. Similar to urban forestry practices, the need for greenspaces in cities is due to the loss of ecosystem services from development. The protection and introduction of greenspaces are effective in aiding human adaptation to climate change-induced heat by providing evapotranspirative cooling, solar reflectivity, and if forested, provides shade for people (Norton et al., 2015). Evidence of the effectiveness of urban greenspace at mitigating urban heat is reflected in the findings of many empirical and model simulation studies (Gallay et al., 2023; Maheng et al., 2019; Murtinová et al., 2022; J. Zhao et al., 2021). Urban green spaces (UGS) are effective in reducing urban heat and can also help address flooding and stormwater management issues by acting as flood plains. Evidence of the flood mitigation benefits of UGS shows that UGS intercept and retain significant levels of precipitation and runoff (Bai et al., 2018; Kadaverugu et al., 2021; H. Kim et al., 2016).

Green Stormwater Infrastructure. With the additional stress of climate change and its intensification of storms and flooding, traditional "grey" stormwater infrastructure, such as pipes, tunnels and gutters have proven insufficient, unaffordable, and unsustainable (Aerts et al., 2014; Brown et al., 2021). Green stormwater infrastructure (GSI) has become a popular EbA alternative to traditional stormwater management solutions to accommodate the precipitation changes driven by climate change (Mosleh et al., 2023). GSI are defined as "soil-water-plant systems that intercept stormwater, infiltrate a portion of it into the ground, evaporate a portion of it into the air, and in some cases release a portion of it slowly back into the sewer system" (PennFuture, 2023). Examples of GSI that fall within the scope of EbA include bioretention systems, green roofs, constructed wetlands, and land conservation (EPA, 2023d; Vijayaraghavan et al., 2021). Also commonly referred to as "rain gardens" or "bioswales," bioretention "is a terrestrial-based water quality and water quantity control process… [that] provides opportunity for runoff infiltration, filtration, storage and water uptake by vegetation" (Minnesota Department of Natural Resources, 2022). In essence, bioretention systems aim to mimic natural hydrological processes by using plants in developed areas to help manage storm water and mitigate pluvial flooding. Bioretention solutions have proven to be effective in both controlling urban stormwater runoff and mitigating flood risk (C. Guo et al., 2018; Hunt et al., 2008; Palermo et al., 2023; L. Zhang et al., 2019, 2020). Although the purpose of a bioretention system is stormwater management and flood mitigation, systems such as rain gardens and bioswales also help reduce UHI through evapotranspiration (Coutts et al., 2013; Humaida et al., 2023; Mitchell et al., 2018).

Another example of GSI are green roofs. A green roof is a form of GSI defined as "a vegetative layer grown on a rooftop" (EPA, 2023c). In cities across the world, building roof surfaces make up 40 to 50% of impermeable surfaces, and contribute to flash flood events which are becoming more common due to climate change (Mentens et al., 2006; Stovin et al., 2012). Green roofs are particularly applicable to address these issues in highly urbanized and densely populated areas with limited space to implement other types of EbA measures

(Humaida et al., 2023; Shafique et al., 2018). Green roofs have shown to be an effective stormwater management solution and flood mitigation strategy by retaining stormwater before it reaches the ground (Villarreal & Bengtsson, 2005). Studies have found that they retain between 10 to 75% of runoff, reducing the risk of urban floods by 28 to 82% (L. Liu et al., 2020; Shafique et al., 2018).

The effectiveness of green roofs for stormwater management and flood risk reduction is well established, so is their effectiveness in reducing the UHI effect. In their study, Li et al. (2014) concluded that, as the ratio of green roofs to non-green roofs increased, the surface and near-surface temperatures were reduced. Numerous other studies support this claim (Feyz et al., 2021; Lalošević et al., 2018; Shafique & Kim, 2017; Sharma et al., 2016). Green roofs can also help reduce indoor temperature and energy use for cooling (Jim & Peng, 2012).

Coastal EbAs

As coastal ecosystems are degraded, so are the services that they offer to humans. The importance of coastal ecosystems for the protection of coastal communities from storm surge and erosion is well understood (Fosberg & Chapman, 1971; Gedan et al., 2010; Shaler, 1886). Mangrove forests, coral reefs, tidal marshes, sand dunes among other coastal ecosystems are known to effectively buffer coastal populations from SLR and its hazards (Arkema et al., 2013). However, at the same time as climate change and SLR intensify extreme weather and flooding disasters, coastal ecosystems across the world are being degraded, disconnected, or lost entirely by human development, diminishing their natural capacity to address these impacts (Temmerman et al., 2013; Waltham et al., 2020). The conservation and preservation of coastal ecosystems such as coral reefs, mangroves, sand dunes, and coastal wetlands has become a popular EbA solution for coastal areas (United Nations Environment Programme, 2016).

As coastal ecosystems are highly diverse, coastal EbA solutions are not universally applicable and look very differently across different geographies. For example, coral reefs are only viable in tropical waters and therefore would not be an effective strategy in more polar latitudes. For this reason, coastal EbA restoration must be specific to the regions existing ecosystems.

Mangrove forests are coastal ecosystems found in tropical and subtropical latitudes and consist of mangrove trees which have densely intertwined and exposed roots that "stabilize the coastline, reducing erosion from storm surges, currents, waves, and tides" (National Oceanic and Atmospheric Administration, 2023b). Functioning mangrove forests have shown to greatly protect coastal communities from hurricane damages (Das & Vincent, 2009), and even protect against tsunamis (Cochard et al., 2008; Dahdouh-Guebas et al., 2005; Danielsen et al., 2005). K. Zhang et al. (2012) found that mangrove forests off of Florida's Gulf Coast lessened the amplitude and extent of land inundation from Hurricane Wilma, and that without the mangroves, inundation would reach at least 70% further inland.

Coral reefs are highly diverse marine ecosystems found in tropical and sub-tropical latitudes and are critical to protecting vulnerable coastlines from storms and erosion in these regions (National Oceanic and Atmospheric Administration, 2019; Sheppard et al., 2005; Wild et al., 2011). Wells et al. (2006) found that coral reefs are capable of mitigating wind induced wave activity by 70 to 90%. However, while coral reefs provide significant coastline protection, the reefs themselves are threatened and being lost by human-induced conditions including climate change, anthropogenic pollution, and ocean acidification (Freeman et al., 2013; National Oceanic and Atmospheric Administration, 2023a). In fact, between 2009 and 2018, 14% of living coral was lost due to these anthropogenic changes (Souter et al., 2021). As coral reefs are degraded, the importance of them for coastal climate change adaptation and resilience is becoming highlighted.

More relevant to this thesis, tidal marshes are defined as "wetlands frequently or continually inundated with water, characterized by emergent soft-stemmed vegetation adapted to saturated soil conditions," and are mostly found "along protected coastlines in middle and high latitudes worldwide" (EPA, 2023a). Tidal marshes have the natural capacity to attenuate wave height and storm surge (Wamsley et al., 2008), and have been found to reduce property damages (Rezaie et al., 2020). Hurricane Katrina and the damage it caused to the Gulf Coast brought awareness to the importance of tidal marshes for coastal communities for future storms and climate change impacts (Day et al., 2007; Shepard et al., 2011). Ali et al. (2020) found in a study on the southeastern coast of New Jersey that salt marshes reduced flood levels and damage to property by 14%, supporting the use of ecosystem services to respond to climate change-induced storm surge and flooding. Similarly, Silver et al. (2019), in a vulnerability study of the Bahamas, found by using sea level rise projection models that if current coastal habitats are maintained and protected, a quarter of Bahama's shoreline could be prevented from becoming highly vulnerable in future climate change scenarios. In a flood-prone region in Fiji, Daigneault et al. (2016) compared conventional hard adaptation, dredging, and EbA in the form of riparian buffer plantings, to determine cost-effectiveness of each. EbA was found to be more cost effective and resulted in fewer downstream adverse effects (Daigneault et al., 2016).

Agricultural EbAs

EbAs for agricultural ecosystems look quite different from EbAs for urban and coastal ecosystems. Agricultural systems are considered managed ecosystems and working landscapes (Antle & Capalbo, 2002). As climate change threatens agricultural production with drought, extreme precipitation, increased heat, and impacts on pests and pollinators, it is critical for the agricultural sector to adapt to these impacts (Easterling et al., 2007; Kurukulasuriya & Rosenthal, 2003).

Agroecology. Agroecology combines ecological theories and agricultural science with social and labor movements as a sustainable solution for agriculture’s climate adaptation, climate mitigation, and social equity needs (Gliessman, 2020). As current commercial agricultural and food systems are characterized by low biodiversity (monocultures) and environmental and soil degradation, they have become increasingly vulnerable to climatic changes (Easterling et al., 2007; Kurukulasuriya & Rosenthal, 2003). The practice of agroecology aims to reduce climate change vulnerability of food systems by reconnecting them with their surrounding ecosystems, while prioritizing economic and social needs. This is largely done by encouraging biodiversity through practices including organic soil amendments, polycultures, crop rotation, crop-livestock mixed systems, and agroforestry (Altieri et al., 2015).

Organic soil amendment practices include locally sourced compost, mulch, and natural pesticides, to promote healthy microbial soil ecosystems, and to ensure consistent soil nutrients. Bhusal et al. (2023) found that organic soil amendments by smallholder farmers in the highly vulnerable mountains of Nepal, not only increased crop yield, but also increased adaptive capacity of the farms.

Polyculture and crop diversification are important adaptation options to mitigate the risks of crop failure due to climate variability (Schroth et al., 2009). The practice of polyculture is “an agricultural method that aims to mimic nature in its design, planting species that complement each other in the same growing space” (Neglia, 2023). Similar to an individual’s investment portfolio, diversification of crops (or stocks) is critical insurance for the potential failure of one of those crops (or stocks). Mariani (2023) explains how polyculture systems with two or more types of crops are more profitable and less risky than monoculture systems, especially in the context of climate change.

Cover crops are “plant[s] that [are] used primarily to slow erosion, improve soil health, enhance water availability, smother weeds, help control pests and diseases, increase biodiversity and bring a host of other benefits” (Clark, 2015). Planting cover crops has become a popular climate change adaptation strategy for agricultural systems (Blanco-Canqui et al., 2015). The use of cover crops is particularly effective in increasing resilience to precipitation variability and warmer temperatures. In the case of drought, cover crops help retain ground water, reducing stress on farmer’s water needs and increasing resilience to high temperatures (Chou et al., 2015). For extreme weather events, and heavy rains, cover crops and their root systems add structural integrity to the soil, diminishing nutrient leeching and erosion (Shirriff et al., 2022).

Crop-livestock mixed systems are “a form of sustainable intensification of agriculture that rely on synergistic relationships between plant and animal system elements to bolster critical agroecosystem processes, with potential impacts on resilience to weather anomalies” (Peterson et al., 2020). This strategy offers a number of adaptive benefits. Brewer and Gaudin (2020), found that crop-livestock systems increase the stability of soils, resulting in less erosion from climate change-induced flooding, while also increasing the soil’s ability to sequester atmospheric carbon. Sraïri et al. (2021) found that the introduction of livestock into semi-arid agricultural systems increased water-use efficiency, therefore increasing resilience to drought conditions. Lechenet et al. (2017) found that crop-livestock mixed systems can diminish yield-threatening and invasive pests, which become more prominent as the climate changes.

Agroforestry. Agroforestry is a form of agroecology involving non-crop vegetation and plantings such as trees and shrubs, and the protection of natural forest ecosystems, to help reduce climate vulnerability of food systems. A couple prominent agroforestry practices that are utilized for climate change adaptation purposes include windbreaks and forest farming (United States Department of Agriculture, 2019).

Also referred to as shelterbelts, hedgerows, or vegetated environmental buffers, windbreaks are lines of trees or shrubs that are “strategically integrated into an agricultural landscape to simultaneously provide economic, environmental and social benefits” (M. M. Smith et al., 2021, p. 1). Primarily intended to protect crops from wind, windbreaks also provide a number of ecosystem services to help agricultural systems adapt to climate change. These services include increasing soil integrity to prevent erosion from extreme weather and rainfall, shade for livestock in cases of extreme heat, and habitat for climate change vulnerable pollinators essential for crop production (Bentrup et al., 2019; United States Department of Agriculture, 2023b).

Forest farming is "the cultivation of high-value crops under the protection of a managed tree canopy" (United States Department of Agriculture, 2023b). This practice has been informally practiced by Indigenous people for centuries, however within the last few decades it has become a systematized method for the protection of crops vulnerable to climate change impacts, particularly extreme heat (Chamberlain et al., 2009). For example, shade-grown coffee practices, in which coffee plants are intentionally planted beneath natural or planted trees, has shown to improve soil water retention and reducing crop evapotranspiration, increasing the crops' ability to adapt to drought conditions and extreme heat conditions (Esteban Lozano-Baez et al., 2021; Gerlach et al., 2023; B. B. Lin, 2010; Posthumus et al., 2013; P. Smith & Bustamante, 2014). Forest farming can also be applied to livestock, pastoral, and grazing practices to provide shade and shelter for animals in extreme weather and heat events (Eggers et al., 2023). In fact, cows with access to adequate shade have been found to produce two liters more of milk per day as compared to heat-stressed cows with low shade access (Groenevald, 2022).

Why is EbA Becoming More Popular?

EbA is becoming a popular climate change adaptation strategy for a number of reasons. As compared to traditional hard adaptation measures, EbA is cost-effective, it is flexible to changes in local climate and conditions, and it provides multiple co-benefits.

Cost-Effectiveness & Flexibility

Proponents of EbA highlight the cost-effectiveness of these practices. Compared to traditional hard adaptation strategies, EbAs are often found to be less expensive and more effective than hard adaptation measures (Baig et el., 2016; Bubeck et al., 2019; Rao et al., 2013; Reid et al., 2019). This can be particularly true in cases of ecosystem conservation and preservation which are effective in buffering nearby and downstream communities from climate change impacts, and require lesser upfront intervention costs, since there is generally very little or no need for construction, labor, plantings, or materials (Reid et al., 2019). In fact, Losada et al. (2018), found that the protection of mangroves is 1,000 times less expensive than building a sea wall to protect communities from the impacts of sea level rise and coastal flooding. It can be difficult to quantify the cost of ecosystem conservation, restoration, and creation of green infrastructure projects. However, experts believe that such methods are 50% less costly, on average, than hard infrastructure (Bassi et al., 2021; Brancalion et al., 2019; Holl & Howarth, 2000). In fact, Bassi et al. (2021) concluded that the replacement of hard adaptive infrastructure with EbA and green infrastructure globally, could save $248 billion annually, halwhile still providing effective adaptive and co-benefits.

As opposed to hard adaptation strategies, which have shown to be inflexible to climatic variability due to their permanence and static nature, EbAs are more flexible or “plastic” in different climate change scenarios (Brink et al., 2016; Jones et al., 2012). For example, there is abundant evidence that mangrove forests have migrated and re-established themselves along highly-volatile and changing coastlines for millions of years, something hard structures are clearly unable to mimic (Alongi, 2008; Duke, 1992). This ability of ecosystems to adjust and adapt to different environmental and climate stressors, is one of the keystone arguments for implementing EbAs (Munang et al., 2013; Ojea, 2015; Scarano, 2017).

Co-Benefits

It has been established that EbAs have adaptive benefits for urban, coastal and agricultural systems by addressing extreme heat, providing flood protection, and conserving water. However, EbAs provide additional non-adaptive co-benefits that hard and soft strategies do not. On top of increasing adaptive capacity, EbAs also provide climate change mitigation benefits, environmental benefits, public health benefits, and social benefits.

Mitigation Co-Benefits

Carbon sequestration is the “process of capturing and storing atmospheric carbon dioxide” (USGS, 2023). As urban development and deforestation have eliminated significant amounts of carbon sinks such as trees and vegetation, the reintroduction of greenery, particularly in urban and agricultural settings can provide these lost climate mitigation benefits. Urban trees and vegetation have shown to sequester significant amounts of atmospheric carbon (Nowak et al., 2000, 2006; Nowak & Crane, 2002; Velasco et al., 2015). Agroforestry, “the intentional integration of trees and shrubs into crop and animal farming systems to create environmental, economic, and social benefits” is another example of EbA that provides mitigation benefits through the sequestration of GHG (Critchley et al., 2023; United States Department of Agriculture, 2023a). Agroforestry is prioritized by most developing nations under the Paris Agreement to achieve their Nationally Determined Contribution (NDC) of GHG reductions, while also providing adaptative benefits to their agricultural systems (Duguma et al., 2023; Mulia et al., 2020).

Environmental Co-Benefits

Environmental co-benefits of EbA solutions include supporting biodiversity through habitat creation, improved water quality, and improved air quality. Urban forests, urban parks, green roofs, and bioretention systems have shown to provide habitat for birds, pollinators, and other species (Kazemi et al., 2009; Le et al., 2023; Lerman et al., 2014; Partridge & Clark, 2018). Similarly, coastal ecosystem restoration and conservation EbA projects such as those involving mangrove forests, coral reefs, and salt marshes, increase habitat availability for shorebirds and marine species (Gauthier et al., 2021; National Oceanic and Atmospheric Administration, 2023a). Conserving habitats and promoting biodiversity can provide many benefits to human systems. Native biodiversity, for example, are crucial for pollinator habitat that allow both urban gardens and large-scale agriculture to function and thrive (Theodorou et al., 2020). Human livelihoods, such as those in the aquaculture and tourism industries depend directly on biodiversity as well. Biodiversity in marine and freshwater coastal ecosystems is needed to ensure the health of the livestock, encourage breeding, and increase production of aquaculture practices (Convention on Biological Diversity, 2018). Tourism, more specifically ecotourism, is highly dependent on biodiversity and environmental health as an attraction for visitors, especially in developing nations whose economies rely on this industry (De Zoysa, 2022).

Public Health Co-Benefits

As the environmental justice movement largely stemmed from concerns around public health disparities between communities, the wide array public health co-benefits of EbA are a big reason why these practices are often favored by environmental and climate justice advocates (Brink et al., 2016).

An increase in green urban spaces, urban forestry, and urban vegetation is associated with improved air quality and positive public health outcomes such as decreased incidence of asthma, respiratory illness, and respiratory illness mortality (Jaafari et al., 2020; Lovasi et al., 2008; L. Wang et al., 2016; Wolf et al., 2020). Proximity to green space and natural surroundings also provide a number of psycho-somatic benefits including reduced blood pressure, reduced heart rate, and lower levels of anxiety (Aspinall et al., 2013; Hartig et al., 2014; Ottosson & Grahn, 2005). Healthy urban forests and green spaces have proven to dramatically improved air quality through filtration of harmful pollutants such as carbon monoxide, nitrogen dioxide, PM10, PM2.5, and sulfur dioxide (Kiss et al., 2015; Qui et al., 2018). Bioretention projects effectively improve stormwater runoff water quality, which results in cleaner oceans, lakes, rivers and streams for recreation, and also safer drinking water (Gaffield et al., 2003; Le et al., 2023; Trowsdale & Simcock, 2011).

Social Co-Benefits

Studies show that access to quality green space encourages social interaction and boosts neighborhood social capital, sense of community, and social cohesion (de Vries et al., 2013; J. Kim & Kaplan, 2004; Seeland et al., 2008). The introduction of green spaces has also reduced the prevalence of both non-violent and violent crime, particularly in underserved communities (Branas et al., 2011; Chong et al., 2013; Shepley et al., 2019). Green and natural spaces also have cultural benefits and services such as providing space for outdoor recreation and urban beautification (Jennings et al., 2016; Ponizy et al., 2017).

EbA policy and planning endeavors offer opportunities to rearrange social and political power dynamics for historically underserved groups. Woroniecki (2019) found that marginalized groups gained a general sense of empowerment among other social benefits following their involvement in the implementation of two EbA projects in Sri Lanka. Disadvantaged communities, particularly indigenous communities, rely most on their immediate environments and generally have greater understanding of their natural systems, therefore hold the knowledge to utilize ecosystems in an effective manner. In the wake of the discussion of EbAs, there has been increased interest in understanding these Indigenous knowledge systems (IKS), which puts Indigenous and vulnerable local populations in a position of power (Ramadani et al., 2023; Zvogbo et al., 2022). The application of such IKS is becoming a prominent topic in the discussion of EbA implementation and advocacy, because IKS provides location-specific methods to cope with natural surroundings and changes in local climate (Mbah et al., 2021). While the inclusion of Indigenous communities and IKS in the implementation of EbAs is promising, it doesn’t ensure that EbAs and their outcomes are equally distributed and benefit the most climate-vulnerable communities.

EbA and Justice

Hard and soft adaptation strategies have shown to produce inequitable outcomes in which underserved, lower income and ethnic minority populations have received the short end of the stick. For example, coastal armoring projects and river levees can put underserved populations at greater risk or displace them completely (Piggott-McKellar et al., 2020; Schoonees et al., 2019; Sultana, 2010). Soft adaptation efforts such as insurance policies and evacuation plans, on the other hand, have shown to be unaccommodating to low-income communities and people with disabilities (Hashemi, 2018; Scipioni, 2017; Talus, 2020; United Nations Office for Disaster Risk Reduction, 2013). Amidst the current heightened attention to social and racial inequity, EbAs have the potential to act as an equitable climate change adaptation practice and alleviate some of those injustices.

However, Triyanti and Chu (2018) discuss how EbAs, green, and nature-based solutions are most often implemented through a technocratic lens, prioritizing “scientific projections, engineering techniques, and their respective roles in shaping economic benefits” (p. 11), with the presumption that equitable social benefits will naturally follow. Warner and Wiegel (2021) argue that these presumptions are unjustified, citing a number of cases where well-intentioned climate change adaptation interventions actually increased the vulnerability of highly vulnerable and underserved communities (Eriksen et al., 2021; Klepp & Chavez-Rodriguez; 2018; Marino & Ribot, 2012). For example, in Vietnam, lowland forest protection policies protect lowland residents from riverine flooding. However, these same policies prohibit marginalized people living in these lowland mountain areas from harvesting forest products that they rely on (Beckman, 2011). Because of cases like this, there have been calls for a greater involvement of social scientists in EbA practices and policies to encourage their equitable implementation and establishment as a commonplace adaptation solution (Seddon et al., 2020; Warner & Wiegel, 2021).

To ensure that EbAs produce equitable adaptive outcomes, it is also crucial to consider the potential disservices, downsides, and injustices of EbA solutions. With any climate adaptation initiative, there are associated costs and benefits, and ‘winners’ and ‘losers’. EbAs are no exception. While EbAs show promising adaptive benefits and co-benefits to society, the costs and benefits of EbAs, as well as their distribution are, at this point, poorly understood (Brink et al., 2016; Richerzhagen et al., 2019). Ideally, the most vulnerable populations should receive the greatest benefits from adaptative solutions, including EbAs, however to-date, very little research has explored the equity implications of EbAs by looking at their distribution, outcomes, and associated labor practices. This study aims to contribute to the understanding of EbAs as just climate adaptation solutions by assessing who is implementing these projects, where they are located, and how much is being spent on them, all in relation to sociodemographic and vulnerability markers. The next discussion addresses some ways that EbA could potentially contribute to environmental, climate, and social injustices.

Unequal Distribution of EbAs

The cost-effective and multi-benefit nature of EbAs implies they could benefit a larger number of people; however, it is unclear if the outcomes of EbAs are distributed in an equitable manner. Research shows that hard and soft adaptation efforts prioritize wealthier and whiter communities and disregard ethnic-minority, underserved, and socioeconomically vulnerable communities (Ford et al., 2011; Remling & Persson, 2014; Sovacool et al., 2015). Further research is required to determine if EbAs minimize or exacerbate these disparities (Brink et al., 2016). Past research has looked at the distribution of nature-based systems and urban greening projects. However, the distribution of EbA projects from a climate justice perspective has not yet been studied. EbA differs from other forms of NbS, as EbAs are meant to boost adaptive capacity to climatic change. While minimal research has examined the distribution of EbA, Stanford et al. (2018) examined the locations of stream restoration projects in relation to sociodemographic and sociopolitical variables of census tracts in the California Central Coast over the span of 30 years. Interestingly, they discovered that human-oriented stream ecosystem restoration projects, of which include EbAs, were mostly located in wealthy, White, and highly educated areas. This study by Stanford et al. (2018) is the basis for this thesis, in which EbA project distribution will be assessed in relation racial, socioeconomic, and climate change vulnerability variables.

Urban forestry has long been seen as an inequitable practice, particularly in the United States. Grant et al. (2022) state “the distribution of trees and access to nature is rarely equitable across urban neighborhoods” and that that this inequity is “predominantly rooted in enduring procedural and recognitional injustices” (p. 1). A wide range of studies emphasize how racially marginalized and lower socioeconomic communities have less urban forest canopy than their counterparts (Foster et al., 2022; Gerrish & Watkins, 2018). Burghardt et al. (2022), discovered that historically “redlined” neighborhoods in Baltimore, Maryland regularly had lesser street tree diversity and were “nine times less likely to have large (old) trees occupying a viable planting site” (p. 1). This finding is echoed by other studies of historically redlined communities, urban green space and ecosystem health, in which redlined and historically marginalized communities have less green space and worse ecosystem health (Locke et al., 2020; Schell et al., 2020; Wolch et al., 2014). Interestingly, Burghardt et al. (2022) also found that these historically redlined neighborhoods were the sites of recent tree planting projects, indicating a local interest and investment in the remediation of previous racist environmental policies.

Green rooftops have also been found to be located mostly in areas with greater income as these projects are relatively high in cost (L. Sanchez & Reames, 2019). Versini et al. (2020) explains how individual green roofs have minimal to no community-scale benefit, unless widely practiced throughout an urban area, indicating that the cooling and energy-saving benefits of green roofs are only experienced by those residing or working within the green roof building, who are likely to be well-to-do.

Ecosystem restoration projects have historically prioritized ecological and biodiversity outcomes, while they have poorly considered the social outcomes of these projects. These projects can actually produce further injustices for marginalized and underserved populations (Löfqvist et al., 2023). As of late however, researchers are calling for heightened attention to social justice issues related to ecosystem restoration to ensure effective, sustainable, and just climate change, biodiversity, and livelihood solutions (Elias et al., 2021; Löfqvist et al., 2023; Osborne et al., 2021).

Negative and Unequal Outcomes of EbAs

It is important that EbA and NbS are distributed equitably between socio-spatial contexts to benefit a large group of people and especially the most climate-vulnerable ones; however, to preemptively mitigate the resultant injustices of these practices, it is also crucial to consider the potential social downsides. Ecosystem disservices and green gentrification are two commonly cited issues when discussing the equity of EbAs.

Ecosystem Disservices

Ecosystem disservices, as compared to ecosystem services, are generally overlooked and greatly understudied, often to the detriment of the people that environmental management projects, such as EbAs, are intended to benefit. Lyytimäki and Sipilä (2009) argue that ecosystem services “refers only to the ‘goods’ produced by biodiversity and ecosystems, ignoring the inevitable ‘bads’ that ecosystems produce for human well-being” (p. 309). von Döhren and Haase (2015) identify three types of ecosystem disservices for urban ecosystems: economic, environmental, and social disservices, all of which have their (in)justice implications.

Economic ecosystem disservices include infrastructural and home damages from urban street trees (Mullaney et al., 2015) and invasive species (Del Toro et al., 2012), or the cost of maintenance required for urban forests (Escobedo et al., 2011; X. Wang et al., 2018; Young & McPherson, 2013), GSI (Bak & Barjenbruch, 2022; Lekkerkerk, 2020; Tian, 2011; Wilbers et al., 2022), and the exclusion of livelihood practices (Ancrenaz et al., 2007; Dunlap & Fairhead, 2014; Reid et al., 2019; Work et al., 2018). These disservices are a form of injustice because of the disproportionate financial and labor burden that lower socioeconomic populations face to repair damages, maintain projects, and remove invasive species. Another example comes from Bangladesh, where an incentive-based fish habitat conservation program proved to benefit the economic interests of the government by preserving locations for ecotourism, but banned certain aquaculture practices to the detriment of fishermen who rely on said practices (Reid et al., 2019).

Ecosystem disservices linked to public health include the release of phosphorus and localized GHGs from restored wetlands (Aldous et al., 2005; Kinsman-Costello et al., 2014; Klimas et al., 2016; Pataki et al., 2011), the release of respiratory illness-inducing allergenic pollen from urban forests (Arnold et al., 2013; Lovasi et al., 2013), and the production of breeding and habitats for disease vectors such as mosquitos, ticks, and other animals in non-native vegetation (Temmerman et al., 2013). The risk of vector-borne diseases is especially problematic surrounding poorly managed and litter-filled urban forested ecosystems, which have been shown to act as a driver for the spread of vector-borne diseases (Obame-Nkoghe et al., 2023).

More relevant to the scope of this study, ecosystems and EbAs can also burden communities with a number of social disservices. There is evidence showing that green spaces, particularly in urban settings, can induce a sense of fear, danger, and discomfort in local residents by creating dark areas and obstructed views, especially in women and elderly populations (Baumeister et al., 2022; Huerta & Utomo, 2022; Jorgenson & Anthopoulou, 2007; Koskela & Pain, 2000; Plieninger et al., 2013). The conservation or preservation of some ecosystems can also result in the exclusion of certain populations from benefiting from its ecosystem services. For example, the Prey Lang Supporting Forests and Biodiversity project in Southeast Asia is an EbA and mitigation project that is a prime example of how some people experience disservices disproportionately. This ‘fortress conservation’ project barred free access to the Prey Lang Forest, which was used and relied on by local and indigenous residents for traditional purposes and their livelihoods, uprooting their lives for the interest of ecosystem health (Dunlap & Fairhead, 2014; Work et al., 2018). While the exclusion of underserved populations from green spaces and wilderness areas presents significant injustice issues, so does the ‘over-greening’ of underserved communities, where the addition of natural space acts as a driver of neighborhood gentrification.

Green Gentrification

The discourse around NbS often portrays these solutions as no-regret, win-win solutions; however, this is not always the case (T. W. Haase et al., 2017; Mees & Driessen, 2011). Green or "ecological" gentrification is one of the greatest concerns associated with NbSs and EbAs. Dooling (2009) defined green gentrification as the "implementation of an environmental planning agenda related to public green spaces that leads to the displacement or exclusion of the most economically vulnerable human population" (p. 621). While EbAs' role in green gentrification is not yet well understood, like many other greening and sustainability initiatives, it has the potential to be a driver of the displacement of lower socioeconomic and marginalized populations. For example, the cleaning up of hazardous waste along the Gowanus Canal in Brooklyn, New York, spurred the development of more green and sustainable housing and infrastructure marketed to and priced for local middle class and upper-class residents (Gould & Lewis, 2018). Gould and Lewis (2018) coined the term 'sustainability class', to refer to populations who can afford sustainability practices, without sacrificing their livelihoods, homes, and ways of life.

Anguelovski et al. (2019) discussed "green climate gentrification" to highlight the need for the prioritization of social justice in climate resilience and adaptation plans incorporating EbA solutions. In East Boston, Massachusetts, a shoreline, blue collar, primarily Latino and Italian community experienced green climate gentrification and is at risk to experience more. The 2018 Resilient Boston Harbor Plan, which uses EbAs and other forms of green infrastructure, includes rentals that start at $2,300, reserving this location for the exclusively wealthy (Anguelovski et al., 2019). Shokry et al. (2020) presented evidence of green climate gentrification in the Philadelphia, Pennsylvania and found that the locations of EbA projects, or “green resilient infrastructure,” resulted in neighborhood gentrification and the reduction of minority populations.

There is plenty of research illustrating how NbS and environmental restoration projects can result in green gentrification; there is also increased interest in finding ways to avoid these negative effects. The movement “just green enough”, calls for “the creation of small parks and nearby affordable housing, [that] can reduce the changes of [green gentrification]” (Rigolon & Németh, 2020, p. 402). The inclusion of local socially, economically, and physically vulnerable populations in the planning and implementation of urban greening and EbA initiatives is also crucial in determining the extent that neighborhoods can withstand greening with maximum benefits while minimizing gentrification. Hoover et al. (2021), echoed this sentiment and argued that prioritizing the needs of historically marginalized communities and explicitly addressing racist urban planning is key to avoiding green gentrification. While the discourse around this issue is gaining interest, more research is needed to understand the extent to which EbAs can act as drivers of green gentrification.

Unequal Labor Burden of EbA

As the location of EbAs can induce injustices through ecosystem disservices and green gentrification, the labor required for EbA implementation can also result in unjust outcomes. Manual labor workers, especially those who work outdoors, are particularly exposed and vulnerable to climate change impacts, especially extreme heat (Kjellstrom et al., 2016; Sahu et al., 2013; Spector et al., 2019). In fact, the International Labour Organization (ILO, 2018) predicts that from 2018 to 2030, the number of work-hours in G20 countries will be reduced by 1.9% due to heat stress alone. L. Johnson et al. (2022) highlighted how ‘just transition’ scholars and activists focus primarily on the labor conditions for workers transitioning out of carbon-based industries, while very little focus is spent on the conditions of workers that are ‘laboring for adaptation’. Similarly, Lambrou (2022), concludes that in the nine Resilient by Design adaptation project proposals in the San Francisco Bay Area (all of which include EbAs), the topic of labor conditions and equity was given minimal to no attention in all nine.

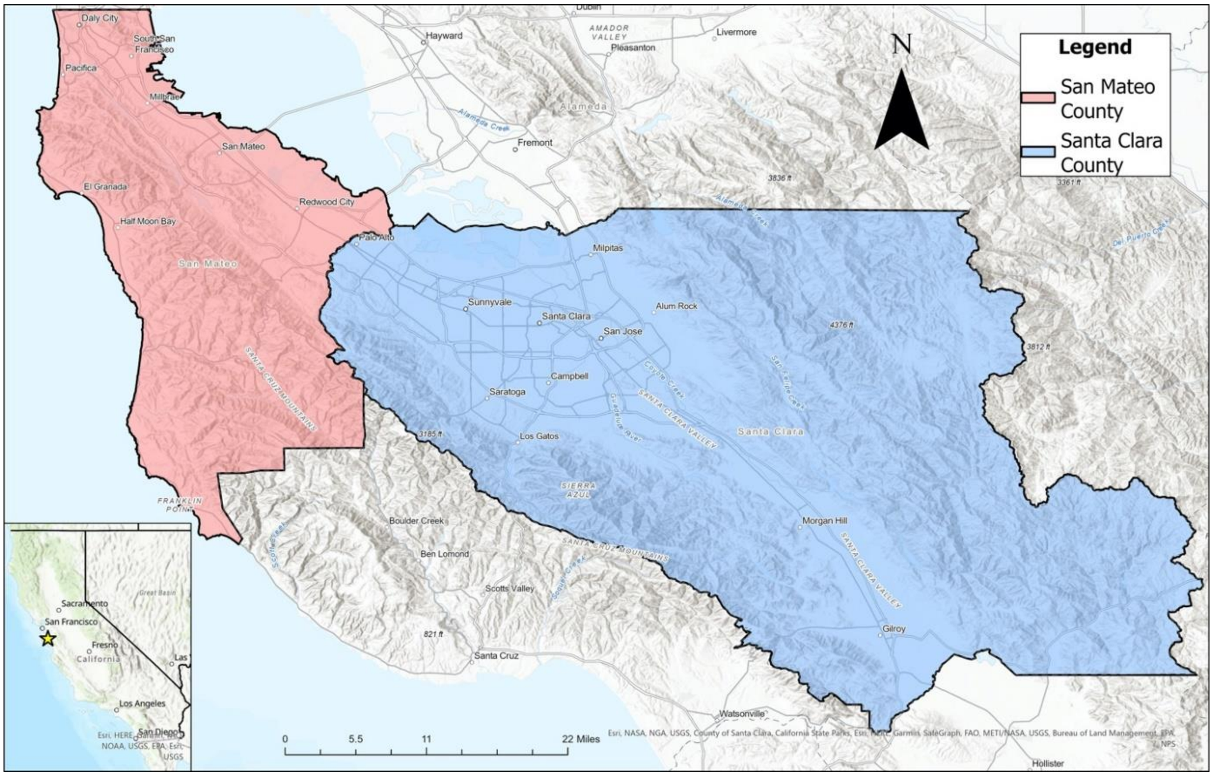
While greening and nature-based solutions, such as EbA, are often perceived as low-impact and low-maintenance projects, they actually require a significant amount of manual labor and maintenance which are time consuming and costly. Adaptation labor is needed to ensure effective and lasting EbA strategies. L. Johnson et al. (2022), defined adaptation labor as “human action to build or repair environments, infrastructures, production systems, and everyday productive and socially reproductive strategies to bear the actual or expected impacts of climate change” (p. 3). As the demand for climate change adaptation projects grows, the need for adaptation labor is massive, however these labor positions often exploit underpaid, undocumented, and socially vulnerable workers (L. Johnson et al., 2022; Nelson et al., 2022). On top of the financial exploitation of laborers, the working conditions of many of these jobs expose them to harmful climate change impacts directly. For example, climate change-induced extreme heat threatens outdoor adaptation laborers with heat stress, making them more susceptible to illness and injury, and also diminishing their productivity (Szewczyk et al., 2021).

Insufficient pay, poor & dangerous working conditions, and lack of government support not only limits the proliferation of EbAs, but also creates unjust working conditions for those implementing these projects. For this reason, it is clear that EbAs are not a silver bullet climate change adaptation solution. However, as compared to the more established hard and soft adaptive solutions, EbAs offer a promising opportunity to support climate change adaptation efforts, while also addressing social inequities if past, present, and potential future injustices are sufficiently prioritized.

Methodology

This thesis utilizes geospatial information systems (GIS) and secondary data such as EbA project reports and census tract data to understand whether some places and people in Santa Clara County (SCC) and San Mateo County (SMC) benefit from EbAs more than others. The study site for this study includes SCC and SMC, which are located within the San Francisco Bay Area region of California (Figure 1).

Figure 1
Santa Clara and San Mateo Counties



SCC is located within the South Santa Clara Valley and borders the southern portion of the San Francisco Bay (SF Bay), with a total area of 1,312 mi^2 (SCC, 2023). SMC is located on the San Francisco Peninsula with the SF Bay to the east and the Pacific Ocean to the west, with a total area of 455 mi^2, with 57.7 miles of coastline (County of San Mateo, 2023a). Both counties encompass a wide range of land cover types from highly dense urban areas, to coniferous and hardwood forests, to cultivated cropland, to marshlands (Santa Clara Valley Open Space Authority, 2014).

History of Study Site

The SF Bay Area has a long and complicated history regarding racial and ethnic identity. The area was originally home to the Ohlone people, an Indigenous group of tribes that were massacred or forced to assimilate, initially by Spanish explorers in the late 1700s and later by the State of California itself in the mid 1800s (Bay Area Equity Atlas, 2023). The African-American Great Migration between 1910 and 1970, brought great numbers of African-Americans to both SMC and SCC, in their attempt to escape the racist Jim Crow laws of the South (Simister, 2016). Since then, the percentage of Black residents in SCC and SMC have steadily been shrinking so drastically that some call it a 'Black exodus' as a result of redlining and inequitable policies (Kadah, 2023). Since 1769, SCC has undergone drastic land-use and social changes from native land management practices, to Spanish colonization, to American colonization, and to the recent Silicon Valley tech boom resulting in massive economic and urban development and widespread gentrification (Grossinger et al., 2008; Mujahid et al., 2019).

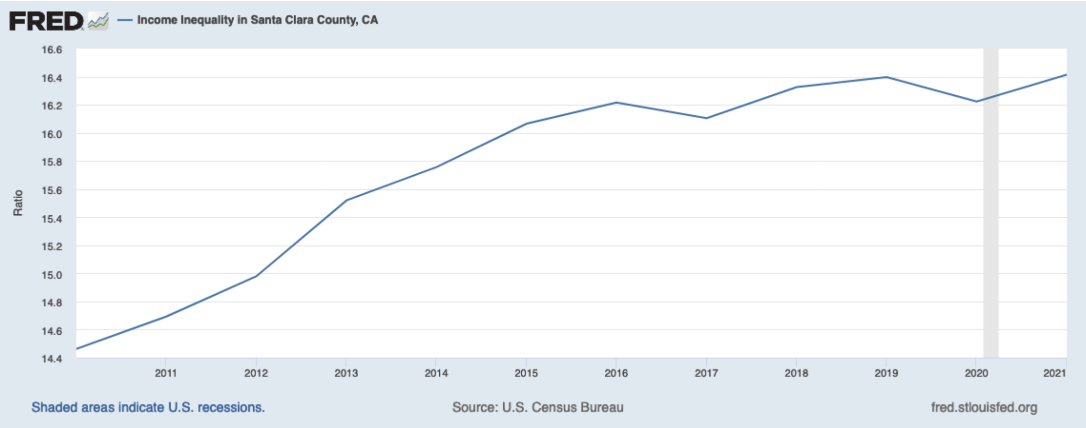
Demographics

Today, SCC and SMC have estimated populations of 1,870,945 and 729,181 residents, respectively (U.S. Census Bureau, 2022b, 2022c). SCC is the sixth most populous county in the State of California, with an estimated growth of 11.28% since 2010, while SMC is the 15th most populous county, with an estimated growth of 8.32% since 2010 (World Population

Review, 2023). Not only are SCC and SMC highly populated and steadily growing, they are also respectively the third and fourth wealthiest counties in the entire country (S. R. Johnson, 2022). In 2019 the average joint median income for SCC was $164,794, and was $159,894 for SMC (State of California Franchise Tax Board, 2021). This can be largely attributed to the technological and industrial development of the area. Both SCC and SMC are located within Silicon Valley, the center of the tech world and provides 11.6 percent of the jobs in the entire San Francisco Bay Area (Landes, 2023). Although there is great wealth within the study site, there is great income disparities as well (see Figure 2 and Figure 3).

Figure 2

Income Disparity by Year in Santa Clara County

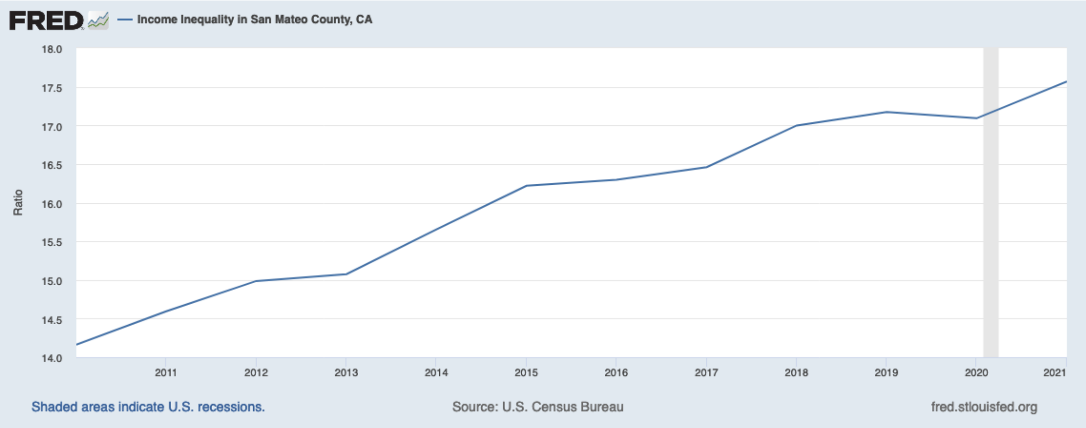


Note. From "Income Inequality in Santa Clara County, CA," by Federal Reserve Economic Data, 2021a (https://fred.stlouisfed.org/series/2020RATIO006085).

SCC has a majority Asian population, while SMC has a majority White population. Both counties have large Hispanic populations but have dwindling Black populations (see Table 3 in Results). The social, demographic, and economic makeup of these two counties differ greatly from the makeup of California and the United States, making this an interesting location to examine in this study.

Figure 3

Income Disparity by Year in San Mateo County



Note. From "Income inequality in San Mateo County, CA," by Federal Reserve Economic Data, 2021b (https://fred.stlouisfed.org/series/2020RATIO006081).

Climate Change Impacts

SCC and SMC have separate climate change vulnerability assessments that both highlight that SLR, extreme heat, and riverine flooding impacts are of grave concern for both counties (County of Santa Clara, 2015; ICLEI Local Governments for Sustainability, 2011). Average temperatures in the San Francisco Bay Area are predicted to increase by 2.7ºF by the year 2050, and between 3.6ºF to 10.8ºF by 2100 (Riordan et al., 2016). Local sea level for the San Francisco Bay Area is projected to rise up to one meter by the year 2100 under high-emissions scenario (Kopp et al., 2014), putting private properties, transportation infrastructure, public parks, beaches, and recreational areas at risk of inundation or loss altogether (Sea Change San Mateo County, 2018).

Climate Action

While SCC and SMC are highly vulnerable to climate change impacts, they are also frontrunners in climate change action and adaptation efforts. As of 2019, only 41% of California cities have completed climate action plans while 93% of SCC's cities, and 85% of

SMC's cities had a completed climate action plan, on top of their respective county-wide climate action plans (Boswell & Jacobson, 2019). SCC is also in the process of drafting a *Climate Roadmap 2030*, that intends to align the County's city climate action plans to encourage intercommunity climate action (County of Santa Clara, 2023).

The SMC Office of Sustainability also launched a Climate Resilience Program, to increase adaptive capacity of its public health, emergency preparedness, housing, transportation, stormwater management, and environmental sectors, while encouraging green infrastructure and EbA (County of San Mateo, 2023b). The commitment of these two counties to climate change adaptation, specifically EbA, makes it an ideal location for this study. All in all, the history, socio-demographics, climate change vulnerabilities, and climate change action in SCC and SMC make them a unique and interesting study site for this research.

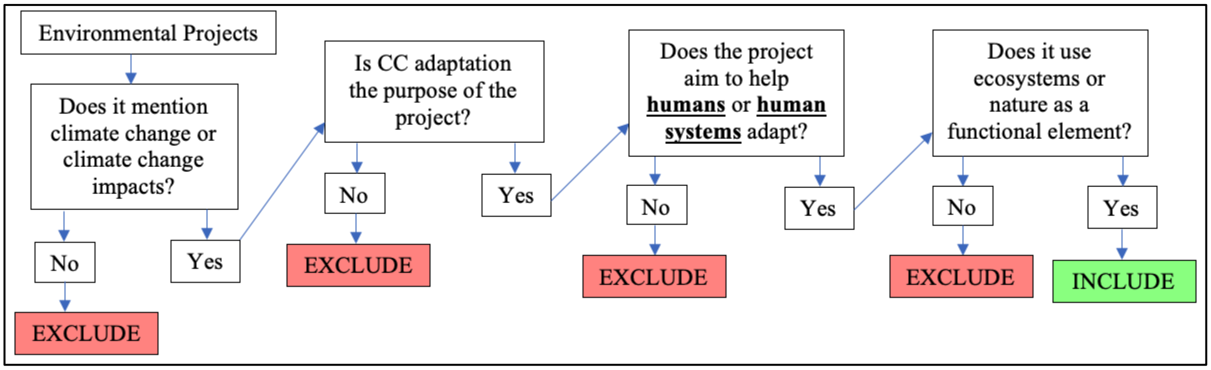
Not only are these two counties undertaking climate mitigation efforts, they are also prioritizing climate change adaptation. In 2015, SCC's Office of Sustainability launched *Silicon Valley 2.0,* a climate adaptation guidebook for public and stakeholder use, and it promotes the use of EbA as "part of an overall adaptation strategy to help people and communities adapt to the impacts of climate change" (County of Santa Clara, 2015).

Sampling

At the time of the study, very few projects were explicitly described using terms such as 'ecosystem-based adaptation' or 'nature-based adaptation solution' in their documentation. For this reason, content analysis and purposive sampling was used to identify projects that met the researcher's pre-set criteria of an EbA project. Through internet searches and the use of two online databases, EcoAtlas and Adaptation Clearinghouse, a compilation of general environmental projects was produced. All of the projects within this compilation were then put through a sampling procedure to identify the final EbA project sample. Figure 4 shows the EbA project inclusion criteria, and the sampling procedure of EbA projects for this study.

Figure 4

EbA Project Sampling Criteria and Procedure



Data Collection Methods & Limitations

Following the completion of the sampling process, further content analysis of all EbA project documents was conducted to obtain descriptive EbA project data, which was compiled into a database. This database was further developed into a geodatabase with geospatial data, to be functional in ArcGIS Pro. This study relied on secondary data in the form of project documents, geospatial coordinates, socioeconomic and sociodemographic data. This research faced some limitations including inconsistent project size data, inability to observe EbA project impacts on communities over time, and the lack of subjective community perceptions of EbAs. Project size data was inconsistent between EbA projects as some were measured in acres, some were measured in linear miles, and a few had no project size data at all. Ideally, each project would have geospatial vector or line data of the project's exact boundaries, however very few projects in the study sample had this quality of data. For this reason, project locations were simplified to single points which limited the accuracy of the result maps.

Project Documents

Project documents were collected through internet searches, and in some cases personal communication with project representatives. Information like project cost, general location, lead agency(s), project size, construction dates, and project descriptions were extracted from these documents. As Stanford et al. (2018) experienced, the availability of online EbA documentation was occasionally limited, therefore personal investigation was warranted in order to obtain documentation from project managers or representatives if needed. Similar to Stanford et al.'s study on stream restoration projects, this research focused only on publicly-funded EbA because of more reliable access to quality data. Privately-funded projects were also excluded from this study due to the potentially skewed findings they would produce.

Geospatial Data

Geospatial data was collected from project documents and online geodatabases, however data availability and data quality was inconsistent between projects. While some projects had polygon or line vector data representing exact project boundaries, other projects had only X-Y point coordinates representing general location. For this reason, project locations were simplified to point features. Using ArcGIS Pro software, centroid points were calculated for projects with polygon vector boundary data and used to represent project location. Similarly, for riverine/riparian projects with line vector data, midpoints were calculated and used to represent project location. This simplification of project locations to a single point impacts the results of this study since projects with greater areas or linear mileage could span across multiple census tracts.

Census Tract Data

Secondary census tract data was obtained using the CalEnviroscreen 4.0 open source geodatabase. Released in October 2021, CalEnviroscreen 4.0 is the most recent edition of the California Communities Environmental Health Screening Tool, a tool used by California policymakers to identify disproportionately vulnerable communities to environmental hazards (California Office of Environmental Health Hazard Assessment, 2023). CalEnviroscreen 4.0 sociodemographic and socioeconomic data at the census tract level was provided by the U.S. Census Bureau’s 2019 ACS population estimates. The source for asthma rates, and other public health data was the emergency department and patient discharge datasets from the Office of Statewide Health Planning and Development (California Office of Environmental Health Hazard Assessment, 2023).

Green Stormwater Infrastructure Data (San Mateo County Only)

A geodatabase for all provision C.3-regulated public GSI projects SMC was obtained through email communication with a representative the SMC wide Water Pollution Prevention Program (FlowsToBay). All GSI projects within this geodatabase were represented as single X-Y points.

Data Analysis

ArcGIS Pro, a GIS software produced by Environmental Systems Research Institute, was used to create maps that visualize EbA project locations and characteristics in relation to census tract population and environmental characteristics. Following map creation, broad descriptive analysis was performed to identify any trends in EbA project distribution. Due to the small sample size (n=40), further statistical and inferential analysis was not found to be appropriate for this study.

Results

EbA Project Descriptives

Project Costs

Table 1 shows descriptive statistics for EbA project costs within SCC, SMC, and the total of both counties. Overall, a total of 40 EbA projects were analyzed for this project, 12 (30%) of which were within SCC, and 28 (70%) of which were in SMC. Of the 40 total EbA projects analyzed in this study, nine (22.5%) are in the planning stage, 14 (35%) are under construction, and 17 (42.5%) have been completed. The average EbA project cost for both counties was $24,368,543, while the average EbA project cost for SCC was $67,433,888, and the average EbA project cost for SMC was $5,228,390 (see Table 1). This difference in average EbA project cost by county is due to the fact that SMC had 14 projects that cost $20,000 or less, while SCC had three projects that cost over $100,000,000. The total amount of money spent (or expected to be spent) on EbA projects in SCC and SMC is $809,206,649 and $141,166,520, respectively.

Table 1
EbA Project Costs for Santa Clara and San Mateo County

	SCC	SMC	Total
Minimum	$2,729,000	$3,000	$3,000
Maximum	$213,000,000	$90,000,000	$213,000,000
Mean	$67,433,887	$5,228,390	$24,368,543
Median	$52,965,775	$20,000	$1,392,903
Total amount spent on EbAs	$809,206,649	$141,166,520	$950,373,169

Table 2 presents the type of lead agencies implementing EbA projects within the study sample in SCC, SMC, and both counties collectively. EbA projects were classified into four lead agency types including public agencies, multi-agency collaborations, non-profits, and independent special districts (ISDs).

Table 2

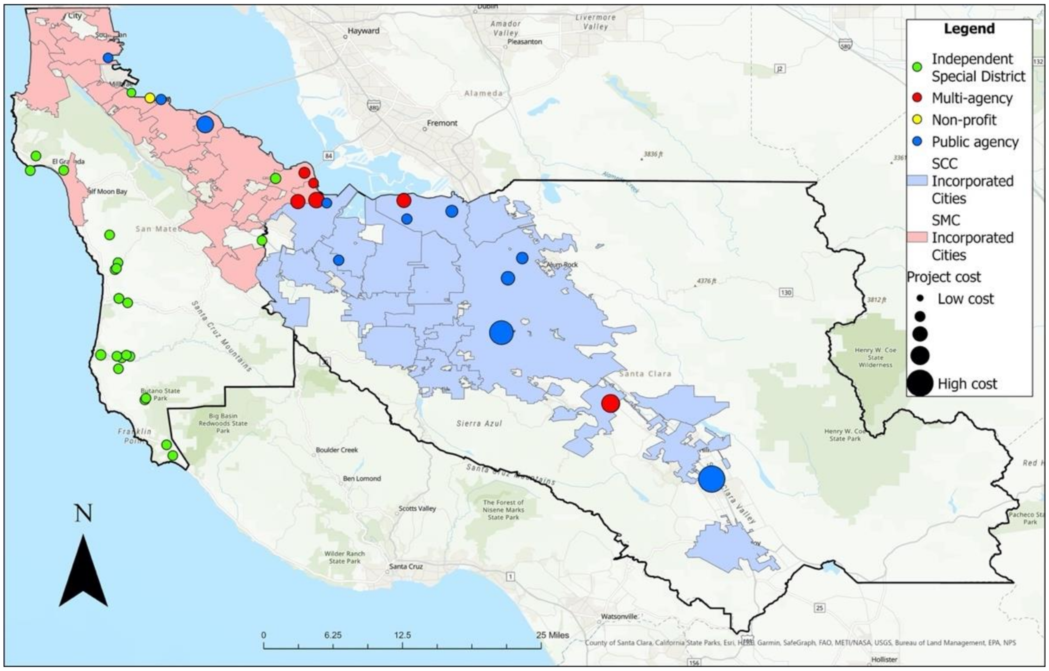
Projects Led by Different Lead Agency Types by County

Lead Agency Type	SCC	SMC	Total (Both Counties)
Public agency	8	3	11
Multi-agency	4	2	6
Independent special district	0	22	22
Non-profit	0	1	1

A public agency is defined as 'any city, county, district, other local authority or public body of or within [California]" (Cal. Gov. Code § 20056). Multi-agency collaborations are two or more lead agencies that work together to implement a project. A non-profit is "an entity designed to better its community by facilitating donations and grants into programs [and that] may receive funding from individuals, corporations, government entities, or other entities" (Kenton, 2023). Lastly, ISDs "obtain their authority directly from the community they serve through a governing body that serves independently from other government agencies [and] are governed by a constituent-elected board of directors" (California Special Districts Association, 2023). Included in the ISD category are Resource Conservation Districts (RCDs), volunteer based ISDs that work to conserve natural resources for soil and water conservation, habitat health, public education, and more recently, climate change resilience. RCDs were created to provide federal and California State funding to farmers and ranchers, in response to the Dust Bowl crisis in the 1930s and its devastating effects that wrecked cropland, soil composition, and other natural resources. Today, RCDs have shifted focus to ensuring agricultural system, human, and ecosystem health by adapting to climate change (California Association of RCDs, n.d.). The SMC RCD (n.d.) was established in 1939 and is the first RCD in California. SCC has two RCDs, the North Santa Clara RCD (formerly the Loma Prieta RCD), and the Guadalupe-Coyote RCD. While the SMC RCD is highly active in EbA implementation, no data was found for EbA projects implemented by the North Santa Clara and Guadalupe-Coyote RCDs.

Figure 5 shows EbA project lead agency types, costs, and incorporated city boundaries to visualize the relationship between agency types, project costs, and whether they take place in incorporated or unincorporated areas.

Figure 5
Lead Agency Types, Project Costs, and Incorporated Cities



Both SMC and SCC have a significant amount of incorporated and unincorporated communities. An unincorporated community is a community that “that is not officially considered to be a municipal area of its own accord” as opposed to incorporated communities which are “officially labeled and demarcated via a municipality” (Weinberger, 2023). While county governments are responsible for providing municipal services to unincorporated areas, these communities are often overlooked as incorporated areas tend to be prioritized

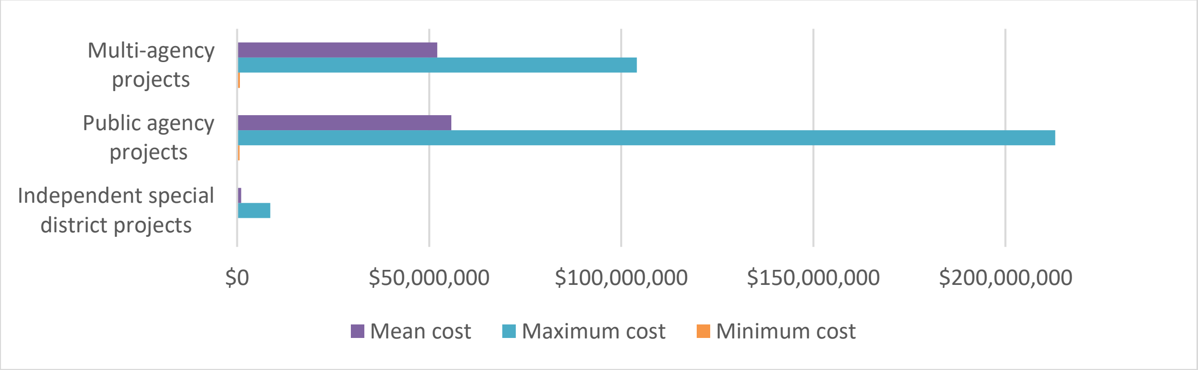
(California Unincorporated, 2023). In unincorporated communities, funding for initiatives, such as climate resilience and adaptation projects, mostly comes in the form of grants and community fundraising (California Strategic Growth Council, 2022), while incorporated communities obtain funding from taxes and government funds. Looking at Figure 5, we see that nearly all of SCC's EbA projects (11 of 12) are located within incorporated cities, while only 1/3 of SMC's EbA projects are located within incorporated cities. In this sample, the only public-agency led EbA project within an unincorporated area is the Upper Llagas Creek Flood Protection Project, the most expensive project in the sample ($213,000,000), which is upstream of nearly all of SCC's incorporated cities including the City of San José, the tenth most populous city in the United States. In SMC, 19 of 22 ISD-led projects are located in unincorporated areas, but none of the unincorporated projects are led by public agencies, multi-agencies, or non-profits, instead all 19 were implemented by SMC RCD. Of these 19 ISD-Led projects in unincorporated areas, 17 are agricultural EbAs, and two are riparian EbAs. It is apparent that public agencies and multi-agency collaborations prioritize the implementation of EbA in incorporated areas. ISDs, on the other hand, clearly implement most of their EbAs in unincorporated areas.

In SCC, the agency that implemented the most EbA projects was Santa Clara Valley Water, a public agency and California State Special District that provides safe, clean water; flood protection; and stewardship of streams for the 2 million residents in the County of Santa Clara (Valley Water, 2023). Valley Water was the lead agency for seven EbA projects, of which five were riparian, and two were coastal. In SMC, the most active agency in EbA implementation was the SMC RCD, who led 19 EbA projects, of which 17 were agricultural, and two were riparian.

In both counties, EbA projects implemented by public agencies are the most expensive, with an average cost of $55,798,909 per project (see Figure 6). The two costliest EbAs by public agencies are the Upper Llagas Creek Flood Protection Project (led by Valley Water) with a cost of $213,000,000, and the Upper Guadalupe River Flood Protection Project (led by Valley Water) with a cost of $180,700,000. On the other hand, ISD projects are the least expensive with a maximum project cost of $8,590,000 for the Bayfront Canal and Atherton Channel Flood Management and Restoration Project, and an average cost of $1,062,870.

Figure 6

EbA Project Costs by Lead Agency Types

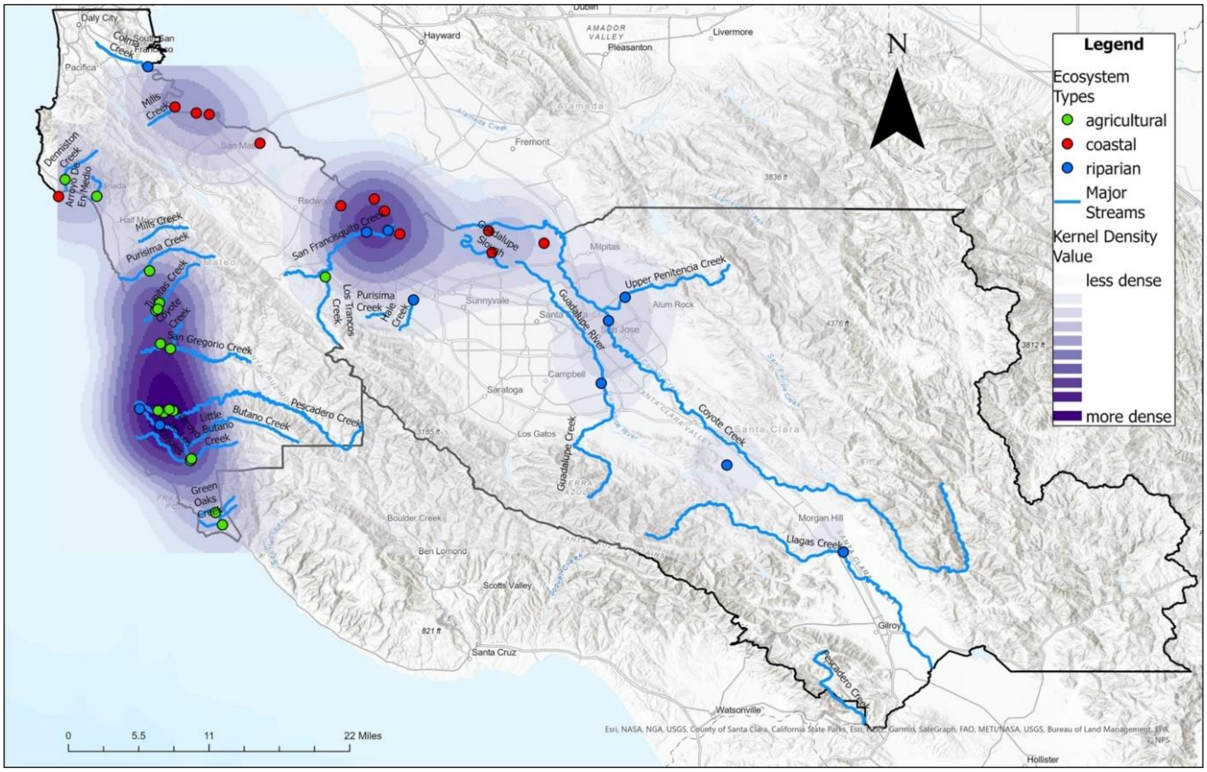


EbA Hotspots and Ecosystem Types

The ArcGIS Pro kernel density spatial analysis tool was used to identify ‘hot spots’ with high density of EbA (see Figure 7). Additionally, each project of the 40 EbA project sample, was categorized into three different ecosystem types to identify if there are any predominant ecosystems involved in these projects. One of the ecosystem categories is ‘coastal’, which means that the project is located where land meets either the SF Bay or the Pacific Ocean.

Figure 7

EbA Ecosystem Types, Project Density, and Major Streams



Coastal EbAs include living shorelines, vegetated levees, and tidal marsh restoration projects. Another of the ecosystem categories is ‘riparian’, which means that the project is located along a river, stream, or other flowing body of water. Riparian EbAs include stream restoration, stream bank vegetation planting, and stream-floodplain reconnection projects. The third ecosystem category is ‘agricultural’, meaning the project is located on farm land. Agricultural EbAs include agroecology and agroforestry projects. Figure 7 shows two hotspots with high EbA project density, one of which consists of mostly agricultural projects, while the other consists of coastal and riparian EbAs. Additionally, the study sample consists of 12 coastal EbA projects, 11 riparian EbA projects, and 17 agricultural EbA projects.

Figure 7 presents two clear EbA hotspots, one of which is located along the Pacific Ocean coast of SMC in Pescadero, a coastal, unincorporated, and rural area with a majority White population. This area is home to Butano State Park, Año Nuevo State Park, and a number of state beaches. Of the 15 projects found in this hotspot, 13 are agricultural EbAs, two are riparian EbAs, but none are coastal EbAs. The other hotspot is located at the junction of the two counties along the SF Bay coast, in East Palo Alto. The City of East Palo Alto has a majority Hispanic population, and the largest populations of Black residents within the study site and has one of the highest poverty rates of census tracks within the study site. Of the 6 EbA projects found in this hotspot, four projects are coastal and two are riparian EbAs.

Of the 12 total coastal EbAs included in the sample, 11 are along the San Francisco Bay, and one is sited along the Pacific Ocean Coast. Interestingly, all of the coastal EbA projects are located within different watersheds. All coastal EbAs aim to increase resilience against SLR, all but one aim to increase resilience against coastal flooding and storm surge, only two out of the 12 aim to address coastal erosion, while only one cites adaptive benefits to extreme heat.

All of the agricultural EbAs in the sample (17) are located within SMC (Figure 7). All of these projects are part of SMC RCD’s Conservation and Carbon Farm Planning Initiative, in which small local farms request the RCD’s assistance and funding to create a site plan for climate change adaptation and mitigation efforts. These projects include agroforestry practices such as hedgerows, vegetated windbreaks, riparian plantings, and crop covers to increase farm resilience to climate change impacts such as drought, flooding and extreme heat.

Lastly, there are 11 riparian EbAs in the study sample, eight within SCC and three within SMC. In SCC, six different watersheds have at least one riparian EbA within them, while one, the Coyote Creek Watershed, has three. In SMC, there only two watersheds have a riparian EbA within them, of which the Pescadero-Butano Creek Watershed has two. The SCC riparian EbAs are generally located more upstream as opposed to SMC's riparian EbAs which appear more downstream, closer to their estuaries. The goal for all 11 of the riparian EbAs is to increase resilience to flooding. Eight of the 11 total riparian EbAs are located in highly urbanized areas including the cities of South San Francisco, Palo Alto, East Palo Alto, Mountain View, San José, Campbell, and Morgan Hill.

EbA and Race

SCC and SMC have different racial makeups from one another, and from California as a whole (Table 3).

Table 3
Racial Makeup by County

	SCC	**SMC**	**California**
Percentage White	32.8%	42.2%	38.7%
Percentage Latino	25.4%	22.2%	38.1%
Percentage Black	2.3%	2.0%	5.6%
Percentage Native American	0.2%	0.2%	0.4%
Percentage Asian American	35.1%	27.6%	13.6%
Percentage Pacific Islander	0.3%	1.2%	0.3%
Percentage other race	3.9%	4.6%	3.3%

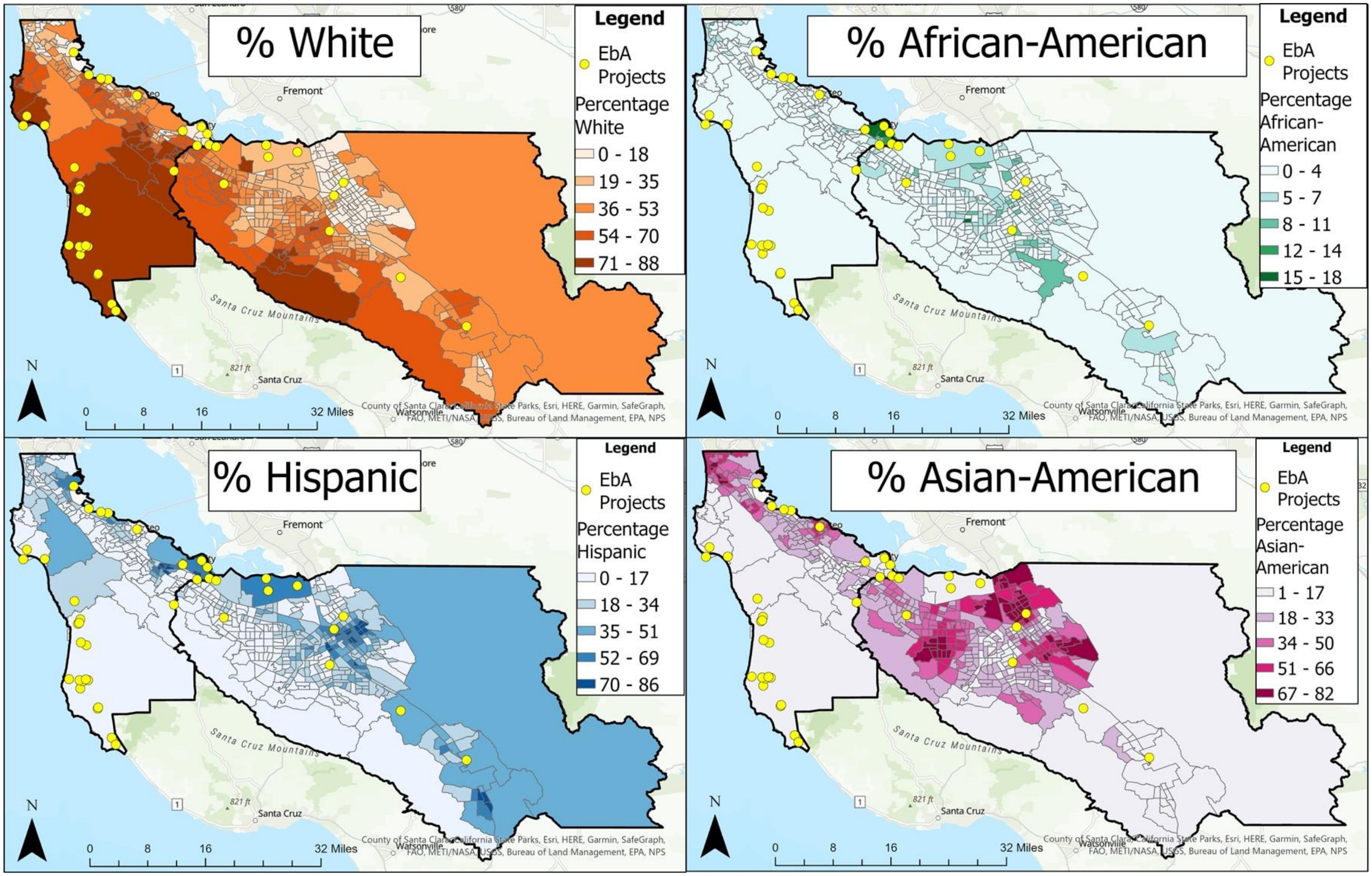
Asian-Americans are the majority population in SCC making up 35.1% of SCC residents, and 27.6% of SMC residents, which are both well above the state average of 13.6%. SCC's White population is about 6% less than the California average. SCC and SMC's Latino populations are much less than the California average and the percentage of Black population in both counties is less than half of the state average. This section will look at the relationship between these racial distributions and the distribution of EbA projects in both counties.

Figure 8 shows EbA project locations in relation to census tract population percentages for four different race/ethnicities including White, African-American, Hispanic, and Asian-American. At first glance, it appears as though EbA projects most often take place in areas with larger White and Hispanic populations, while there is a clear lack of EbA projects in areas with larger Asian populations. Now let’s look more closely at EbA locations in relation to each racial group. When we look at both SMC and SCC, we see one population cluster with a relatively high percentage of African-American residents (15-18%) just above the SMC-SCC border in East Palo Alto (see Figure 8). In this cluster, we see three EbA projects: the Baylands Habitat Restoration and Community Engagement Project (Baylands Habitat Project), the South Bay Salt Pond Restoration Ravenswood Project (SBSPR Ravenswood), and the Bayfront Canal & Atherton Channel Flood Management and Restoration Project (Bayfront Canal Project). The adaptive goals for all three of these projects include SLR resilience and flood mitigation.

The five areas with the highest percentages of Hispanic residents include South San Francisco, East Palo Alto/Redwood City, Alviso, San José, and Gilroy. Within these five areas, there are 11 EbA projects, four of which are riparian and seven of which are coastal. Ten of these EbAs were led either by public agencies alone or multi-agency collaborations with public agency partners, while one EbA was led by an ISD.

Figure 8

EbA Locations and Racial Distributions



While SCC has a majority Asian-American population (35.1%) and SMC also has a large Asian-American population (27.6%), the majority (32 of 40) of the EbA projects are located in census tracts with a very low percentage of Asian-American residents (1-17%). Only one project, the Upper Penitencia Creek Project which is a riparian flood mitigation project led by Valley Water, is located within a census tract with a high percentage of Asian residents (67-82%). It is in the planning stage and is set to begin construction in 2024 and be completed in 2028. This project is expected to cost $23,600,000 and will span 4.2 linear miles along the Penitencia Creek. This project will restore riparian habitat, create water recharge ponds, and creek-side parks to reduce the help local communities adapt to flood risk.

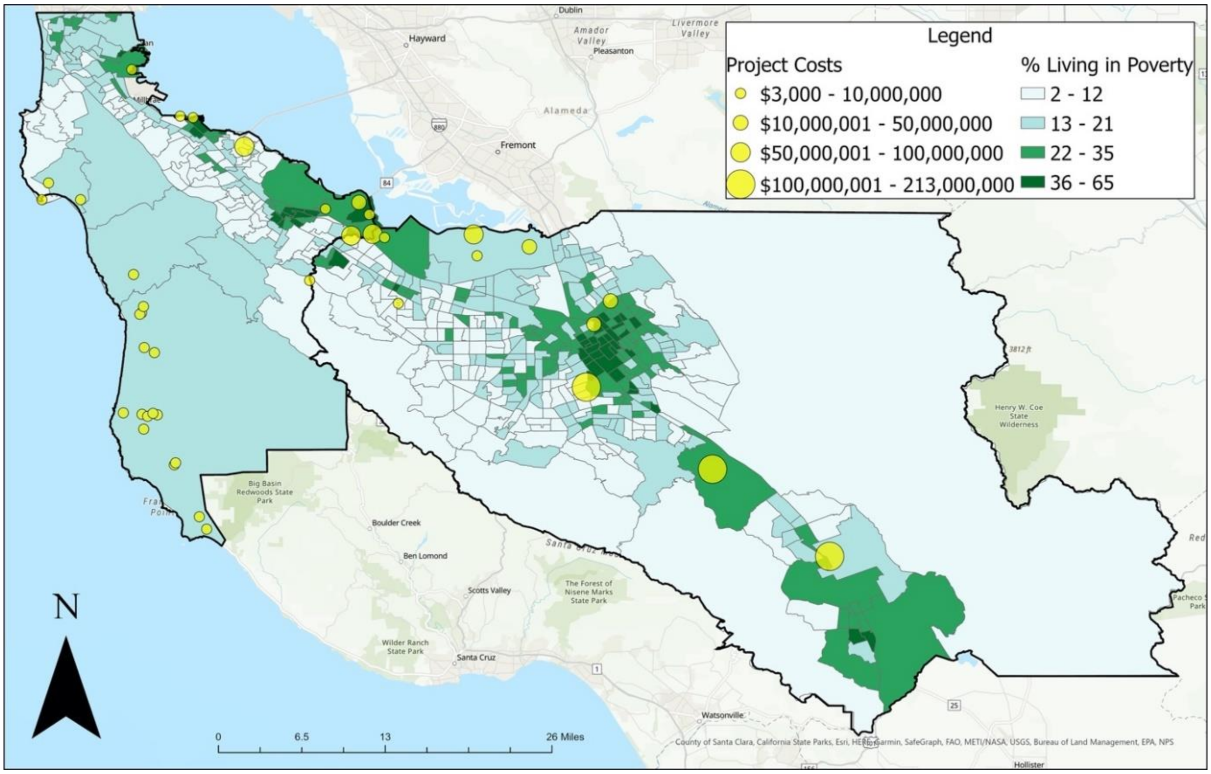
While there is a clear segmentation in racial distribution in both counties, it is evident that there is also uneven distribution of EbA projects. It is unclear whether the presence EbA projects in a neighborhood is always a positive thing, as they can provide both ecosystem services, in the form of adaptive benefits and recreational benefits, and disservices such as the introduction of allergens, lost sense of safety, and financial burdens.

EbA Vulnerability Indicators (CalEnviroscreen 4.0)

CalEnviroscreen 4.0 is a model that assesses the cumulative impacts of exposures, public health, environmental conditions, and socioeconomic & sociodemographic factors to produce a census tract score that represents a population’s vulnerability to environmental conditions (August et al., 2021). Released in 2021, CalEnviroscreen 4.0 is the fourth and most recent publication of the California Communities Environmental Health Screening Tool, developed by the Office of Environmental Health Hazard Assessment. This tool utilizes data at the census tract level regarding pollution burden indicators and population characteristic indicators to produce a CalEnviroscreen vulnerability score that identifies which communities are most vulnerable to environmental issues such as climate change impacts. Looking at different variables of this tool in relation to EbA distribution, trends are observed and discussed in this section.

Poverty rates, one of the population characteristic indicators utilized in CalEnviroscreen 4.0, is defined for California as the “percent of the population living below two times the federal poverty level,” because of California’s very high cost of living as compared to the rest of the country (August et al., 2021). In both SMC and SCC there are groupings of census tracts with high poverty rates (see Figure 9).

Figure 9
EbA Project Costs and Poverty



County of Santa Clara, California State Parks, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land Management, EPA, NPS

Interestingly, while five of the seven most expensive EbAs that cost over fifty million dollars, are located in areas that with moderately high poverty rates, none of them are located in areas with very high poverty rates. On the other hand, the least expensive EbAs, that cost under ten million dollars, are located in areas with relatively low poverty rates. The most expensive three projects, the Upper Guadalupe River Flood Protection Project, the Coyote Valley Conservation Area, and the Upper Llagas Creek Flood Protection Project are all adjacent to, overlapping with, or within census tracts with moderate-high (22-35%) poverty rates.

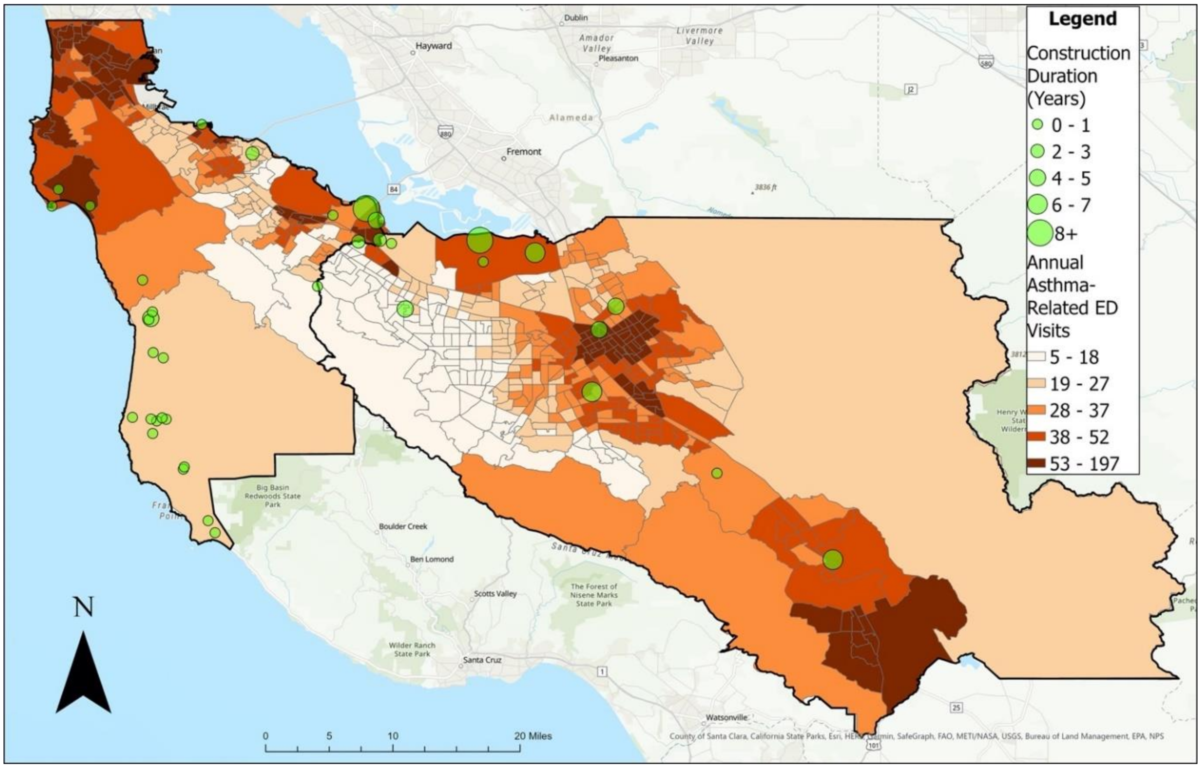
Only one-eighth of EbA projects were located within or directly adjacent to census tracts with very high poverty rates (36-65%), with an average project cost of $51,131,949. As compared to the average EbA cost of $24,368,543 for the entire study sample, it can be inferred that fewer, but more expensive EbAs are being implemented in areas with higher poverty rates.

Another CalEnviroscreen 4.0 population characteristic indicator of vulnerability is asthma rates. Asthma rate is defined by the Office of Environmental Health Hazard Assessment as “age-adjusted rate of [emergency department] visits for asthma per 10,000 [residents]” (August et al., 2021). It is well understood that the incidence of asthma is likely to be higher in areas with high car traffic and outdoor air pollutants, and disproportionately impacts low-income populations (August et al., 2021). While the finished EbAs can help remove aerosolized irritants and improve air quality, on top of providing climate change adaptive benefits, the construction of EbA projects can also have negative impacts on local populations including worsening air quality with fugitive dust and vehicle emissions, sound & light pollution, temporary aesthetic loss, and loss of access to the project site.

Figure 10 shows asthma rates by census tract and the duration of construction for each EbA project, which allows us to understand the potential relationship between construction and the burden of asthma that EbA construction could exacerbate. With the exception of the agricultural EbA projects on the western side of SMC, all other EbA projects appears to coincide with areas that have moderate to high asthma rates (see Figure 10).

Figure 10

EbA Project Construction Durations and Asthma Incidence



The two EbA projects with longest construction times are the SBSPRP Ravenswood Project and the SBSPRP Alviso Project, both of which are projected to take over eight years to complete. The construction of these two projects involves the use of heavy construction equipment and vehicles, in order to move mass amounts of soil, stone, and sediment. During any phase of construction, a number of dump trucks and bull dozers could be operational and emitting the aerosolized irritants known to harmful for the respiratory health of locals (AECOM, 2017). The concern with long construction times is that the projects may harm the very communities that they are intended to aid. Both the SBSPRP Ravenswood and Alviso Projects are of particular concern for asthma due to the fact that marsh restoration projects are known to harm air quality by releasing phosphorous and increasing localized GHG levels (Klimas et al., 2016; Pataki et al., 2011). Both projects are located in areas with high rates of asthma, and they are adjacent to two of the most historically underserved communities within the study site, East Palo Alto and Alviso.

The City of East Palo Alto has moderate to very high rates of asthma-related emergency department visits. On top of the SBSPRP Ravenswood Project, the construction of the five other EbA projects take place in direct proximity to East Palo Alto. The average construction duration of these projects is over two years and entail intensive heavy equipment to construct them. In fact, at any point between the years 2016 and 2027, there will be at least one EbA project under construction in this area, and four EbA projects will be under construction during the years 2024 and 2025. This could be problematic considering the compounding impacts of multiple EbA project constructions on air quality, potentially exacerbating asthma related emergency department visit rates in an already vulnerable community with low socioeconomic status and large minority populations.

Similarly, SCC's coastal city of Alviso that has high rates of asthma, has three large scale EbA projects in direct proximity. One of these projects, the SBSPRP Alviso project, began construction in 2006 and is still under construction in 2023. Another of these projects, the San Francisco Bay Shoreline Protection Project, began construction in 2022 with an expected six year construction time. These projects, similar to those in East Palo Alto require heavy equipment that disrupt air quality, coastal accessibility, among other quality of life conditions.

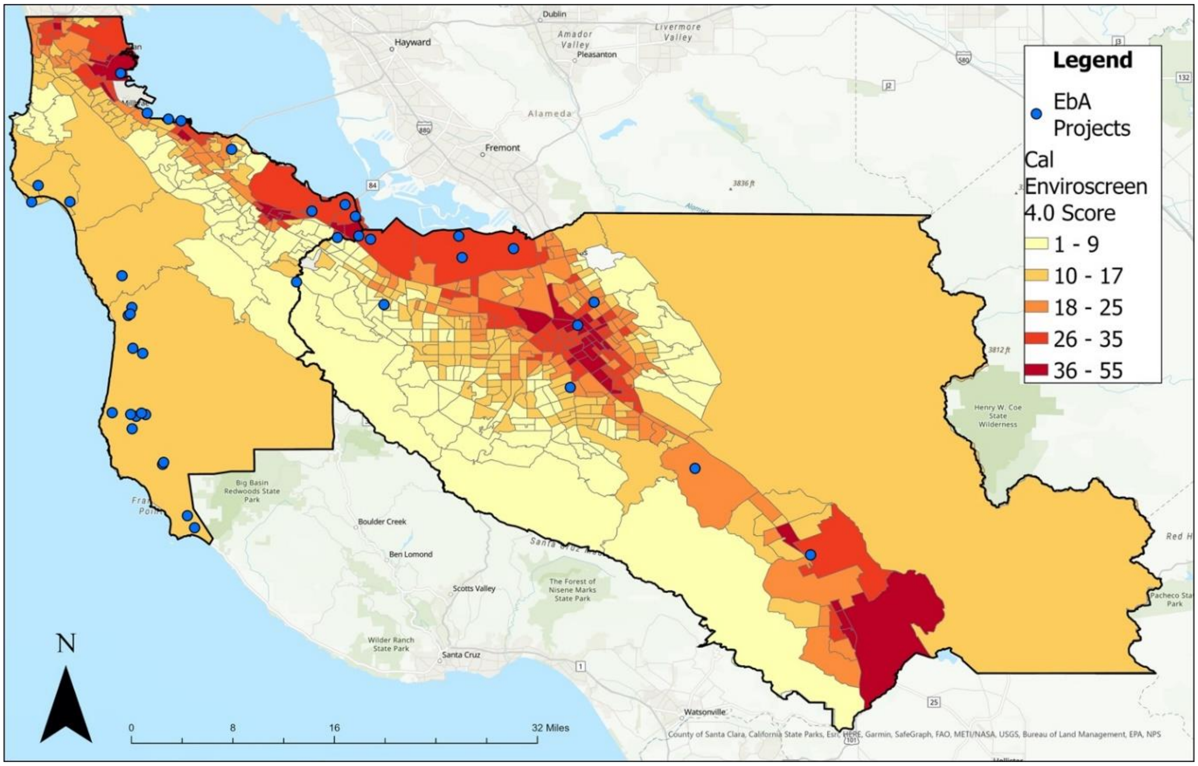
Finally, Figure 11 shows EbA project locations in relation to CalEnviroscreen 4.0 overall scores, in which the higher the score the greater the population vulnerability, in order to understand whether EbA projects benefit the most climate-vulnerable communities. Looking at counties together, there is no apparent relationship between EbA locations and areas identified as most vulnerable by CalEnviroscreen 4.0. However, eleven of the twelve EbA project in SCC are located in areas with moderate to high vulnerability scores (18+). On the contrary, in SMC, only one-fourth of EbA projects are located in areas with moderate to high vulnerability scores (18+), which can be explained by the large number of agricultural EbAs in the western side of SMC, a low vulnerability area. The lower vulnerability scores of this area can possibly be attributed to smaller population numbers in which the sociodemographic population indicators hold less weight as opposed to more urban, highly populated areas.

EbA and Gentrification

Gentrification is the displacement and replacement of low-income urban communities, with wealthier populations, businesses, and developments. To understand the relationship between EbA projects and gentrification, EbA locations were overlayed with gentrification status and risk by census tract, as provided by the California Estimated Displacement Risk Model developed by the Urban Displacement Project (2022). For the purpose of this study,

Figure 11

EbA Projects and CalEnviroscreen 4.0 Score

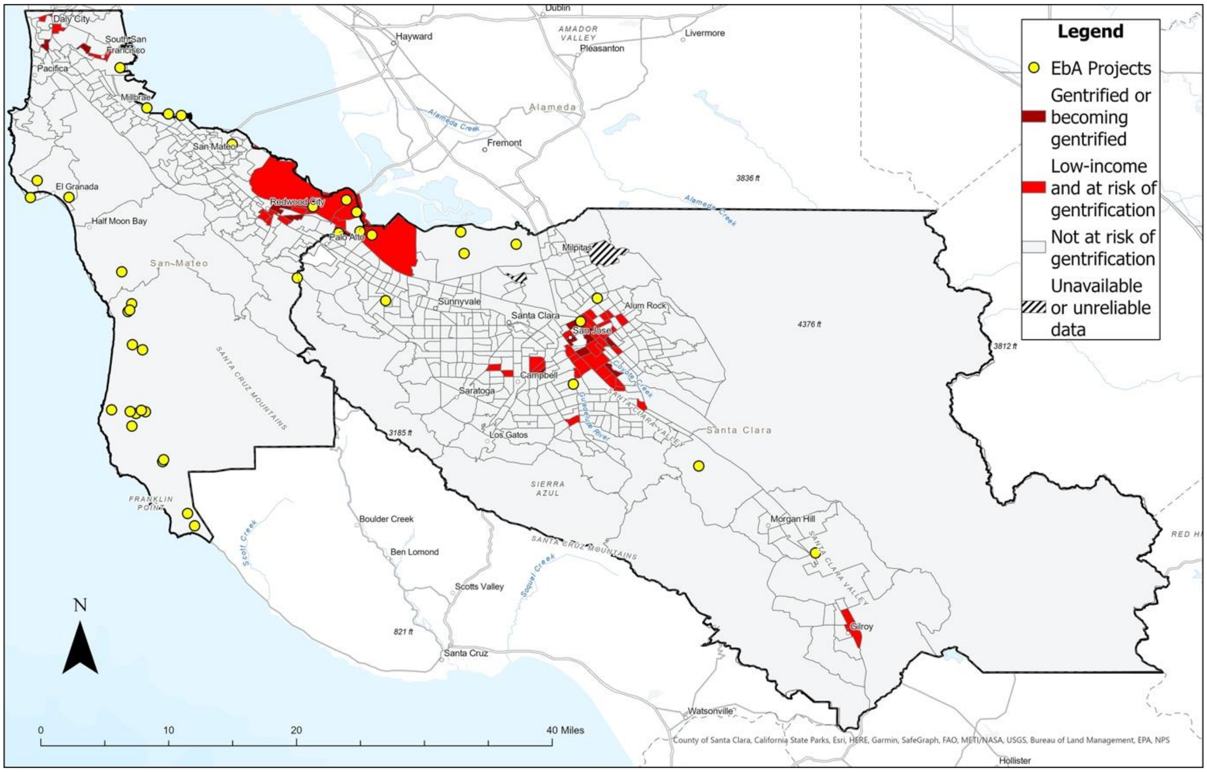


census tract gentrification status was simplified into three categories, "gentrified or becoming gentrified", "low-income and at risk of gentrification", and "not at risk of gentrification" based on household socioeconomic status, housing affordability, and the extent of changes in rent cost over time.

Looking at Figure 12, we see two clusters of census tracts that are either gentrified, becoming gentrified, or are low-income and at risk of gentrification. The first cluster is located in Downtown San José, and there is only one EbA project within it, the Coyote Creek Flood Protection Project. The second cluster, encompassing Redwood City, East Palo Alto, and Palo Alto, has six EbA projects within it. Collectively, seven of the sample's 40 EbA

Figure 12

EbA Projects and Gentrification Status



projects (17.5%) are located within these census tract clusters, which make up only 8.3% of study site's total census tracts.

Green Storm Infrastructure in San Mateo County

GSI is defined as "soil-water-plant systems that intercept stormwater, infiltrate a portion of it into the ground, evaporate a portion of it into the air, and in some cases release a portion of it slowly back into the sewer system" (PennFuture, 2023). Provision C.3 of the California Municipal Regional Stormwater Permit (2015) requires stormwater management solutions for new development and redevelopment projects, of which GSI is a popular option. Examples of GSI that fall within the scope of this study because they provide increase adaptive capacity against climatic changes include bioretention systems, green roofs, constructed wetlands, and land conservation (EPA, 2023d; Vijayaraghavan et al., 2021). A geodatabase of SMC's public and private C.3-regulated GSI projects was provided by the SMC wide Water Pollution Prevention Program (FlowsToBay). Only public GSI projects were used in this study because the scope of this research is interested in publicly accessible EbAs. A sufficient geodatabase for SCC's C.3-regulated GSI projects was unavailable, therefore only SMC GSIs were examined for this part of the analysis, separately from other 40 EbA projects.

Figure 13 illustrates the distribution of public GSI projects in SMC in relation to the concentration of different races by census tract. It is clear that there are very few GSI projects in areas with high percentages of White, Black, and Asian-American residents. On the other hand, there appears to be a more GSIs in areas with large Hispanic populations. Particularly we see a cluster census tracts inland of Redwood City with a high concentration of GSI projects and high percentages of Hispanic residents. The high concentration of C.3-regulated GSI in inland Redwood City can be explained by a great amount of development, including construction of office buildings, hotels, retail buildings, and multi-story residential apartment buildings. Such widespread development is a precursor to gentrification, and GSI EbAs may exacerbate it since the introduction of new green spaces are known to push out low-income and vulnerable populations (Anguelovski et al., 2019).

Taking a closer look at inland Redwood City, it is notable that this is also an area of the greatest poverty rates in SMC, made up of seven census tracts with poverty rates between 35 and 47% and is home to 11 Provision C.3-regulated public GSI projects (Figure 14). Another

Figure 13

Public Green Stormwater Infrastructure and Race

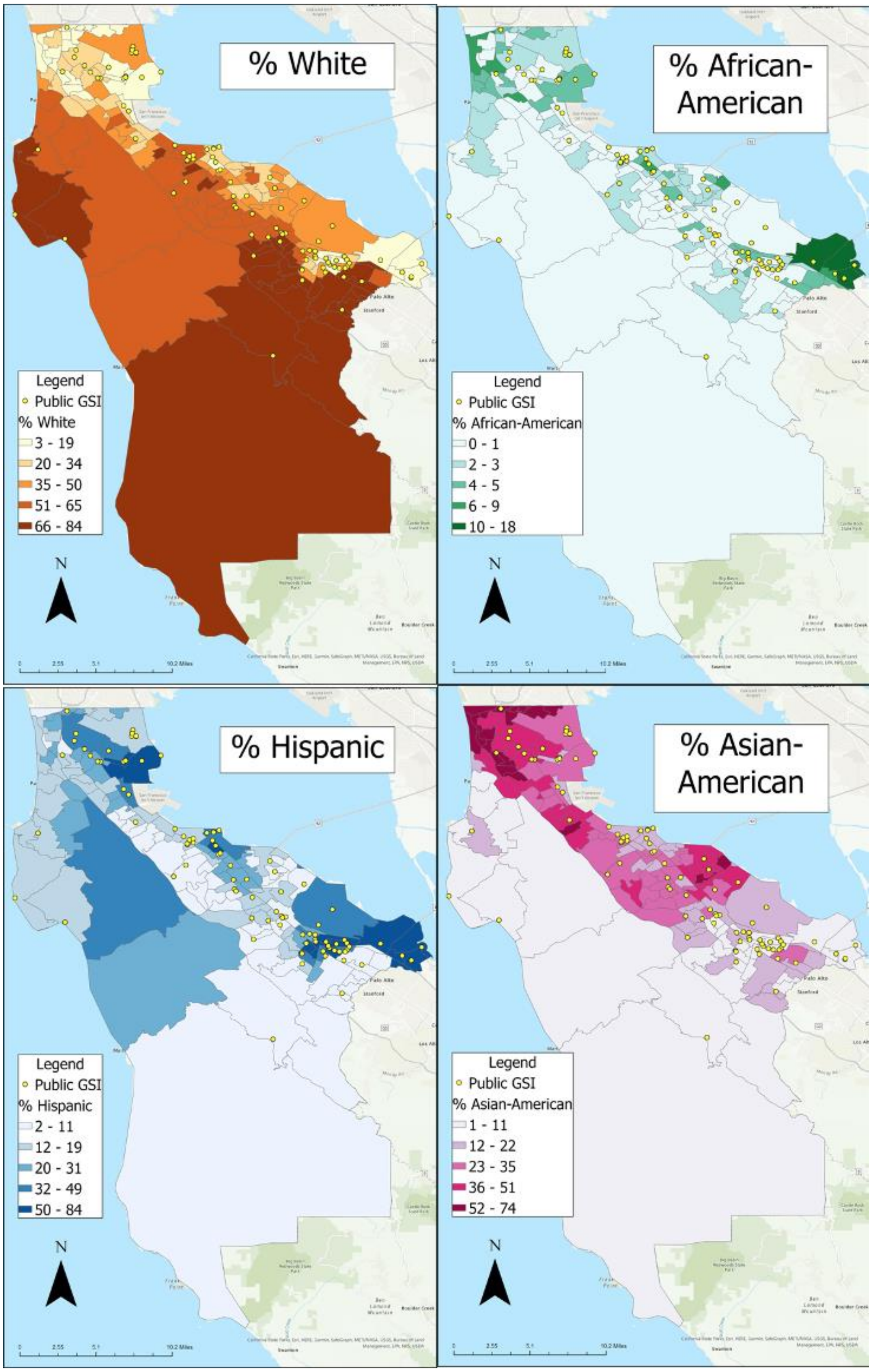
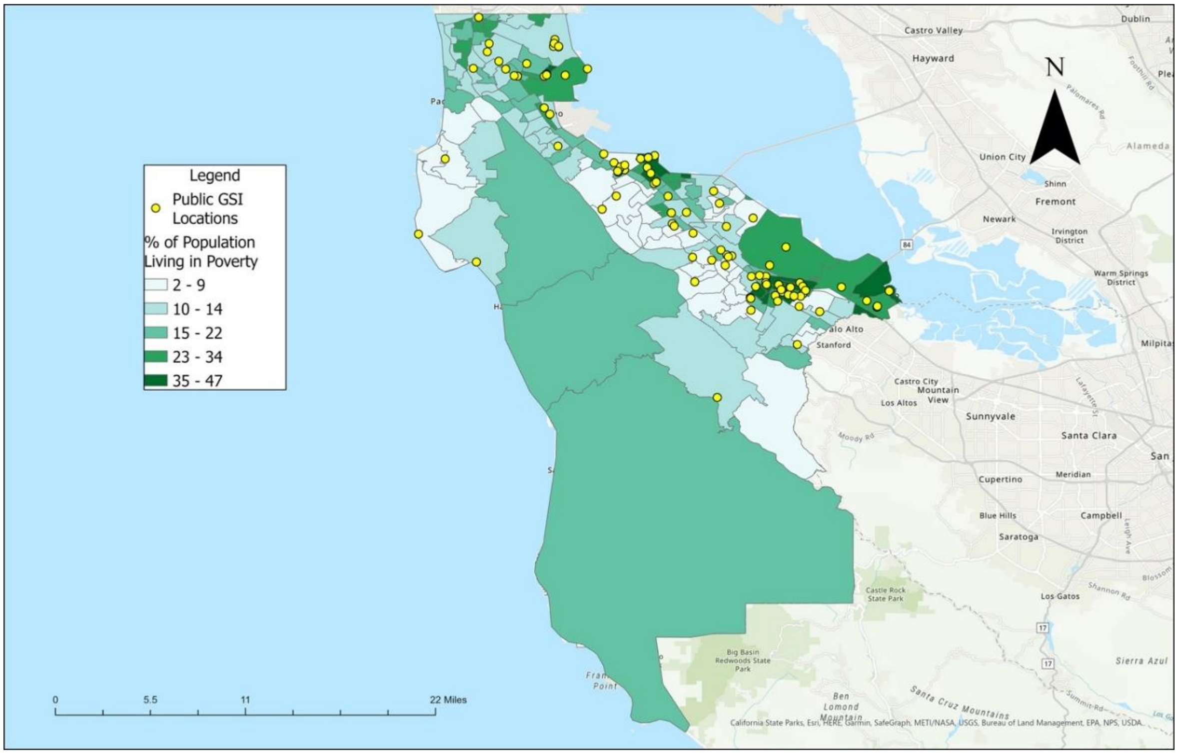


Figure 14
Public GSI and Poverty Rates

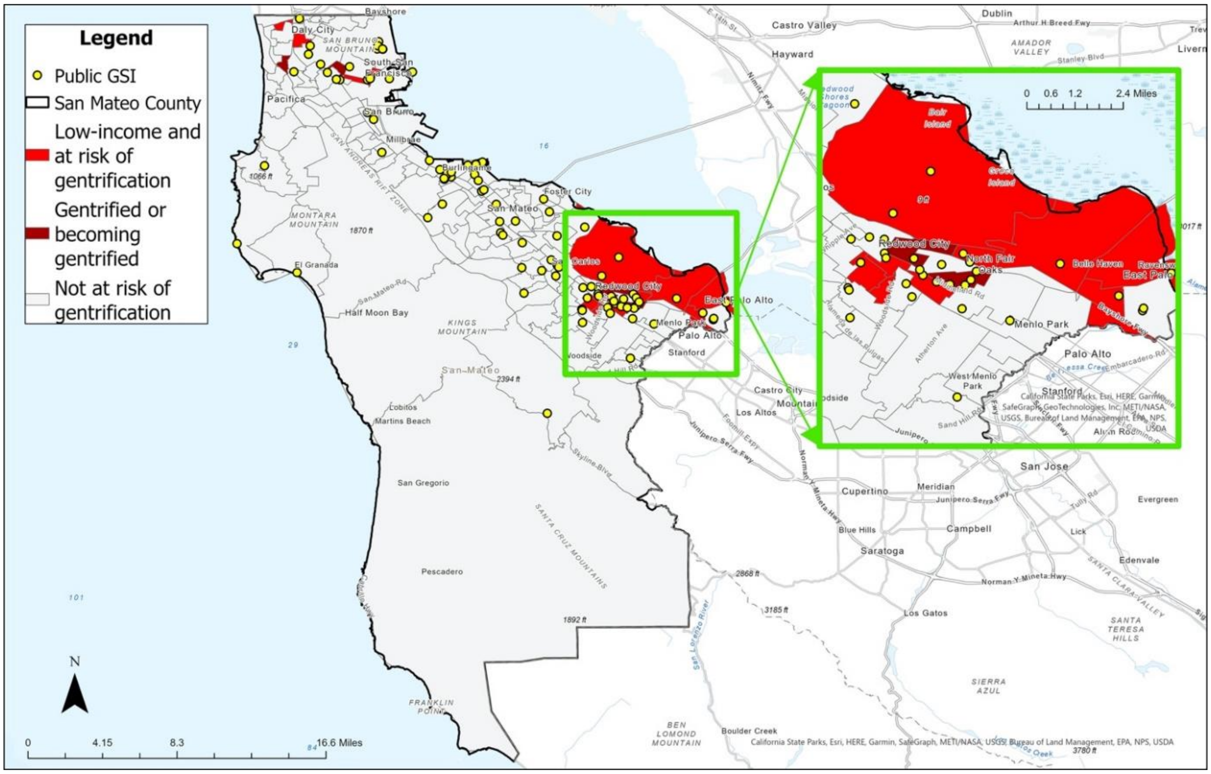


area in which high poverty rates (35-47%) and large Hispanic populations overlap is two adjacent census tracts, visible along the Bay Coast in the City of Burlingame. These two census tracts collectively have 8 Provision C.3-regulated public GSI projects.

Both of these locations with high poverty rates, large Hispanic populations, and numerous GSI projects present a potentially ripe situation for green gentrification as development and the introduction of new green spaces and GSI EbA could drive costs of living up, forcing these lower-income Hispanic residents to eventually relocate. Using data from the California Estimated Displacement Risk Model developed by the Urban Displacement Project (2022), public GSI projects were visualized in relation to gentrification status by census tract. One particular area of interest, highlighted by the magnified section of

Figure 15, are the census tracts in inland Redwood City which have one of the highest concentrations of GSI projects in the entire county. This area has high poverty rates, large Hispanic populations, and is experiencing advanced gentrification. This gentrification is a result of the City's prioritization of market-rate housing, tech companies, commercial businesses, without any protections for low-income working class families (Chapple, 2015). As Provision C.3 requires stormwater management measures for new development and redevelopment projects, it makes sense that there are a great number of GSIs in this highly gentrified area. It is out of the scope of this study to determine the causal impact of GSI on gentrification, however in this case, there appears to be a relationship between GSI projects and gentrification.

Figure 15
Public GSI and Gentrification Status



Discussion

The San Francisco Bay Area is already experiencing the devastating impacts of climate change including sea level rise, floods, and prolonged droughts. EbA, or the use of nature and ecosystem services to increase humans' adaptive capacity has become a popular solution to help communities adapt to climate change's various impacts. National, state, and city level climate change adaptation plans are increasingly prioritizing EbAs as adaptive solutions because of their multiple social, economic, public health, and mitigation side benefits (State of California, 2022; United Nations Environment Programme, 2023). Although EbAs are known to increase adaptive capacity and reduce risk and exposure levels of communities to climate change, the equitability of these practices is poorly understood (Jones et al., 2012). To date, very little research has looked at the distribution of EbAs in relation to people's socio-economic status and differential vulnerability to climatic impacts (Brink et al., 2016). This research aims to contribute to the growing body of EbA literature, by considering the climate justice implications of these increasingly popular adaptation strategies.

In this study of Santa Clara and San Mateo Counties, we found that EbA project locations, costs, and adaptation goals are not equitably distributed across geographic, racial, economic, and vulnerability spectrums. For example, despite the fact that Asian residents make up the majority of SCC and nearly 30% of SMC, only two EbAs were located in census tracts with predominantly Asian populations. We also found that census tracts with very high percentages of White residents had nearly half of the total sample of EbA projects (19 out of 40). It is important to note, that of the 19 EbAs in predominantly White census tracts, 16 of them were agricultural. On the other hand, areas with moderate to high percentages of

Hispanic residents also had a great number of EbAs, but these are mostly coastal and riparian projects, and are primarily concerned with flooding and sea level rise impacts. In the one small cluster of census tracts with relatively large percentages of African-American residents, we found six EbAs within or directly adjacent to them, all of which aim to address either coastal or riparian flooding. These findings are contrary to the findings of Stanford et al. (2018), who found that stream restoration projects along California's central coast were primarily concentrated in areas with predominantly White populations. There are clear differences between where different racial groups reside and the adaptation goals of EbA projects in those areas. For example, it appears that EbAs in areas with predominantly White populations aim to address drought and agricultural-related climate change impacts, while EbAs in areas with greater Hispanic and African-American populations aim to address inundation from sea level rise and flooding damages.

Since the relatively low cost of EbA strategies is argued to make these projects more accessible to lower socioeconomic populations (Brink et al., 2016; Richerzhagen et al., 2019), this study examined the relationship between EbA project costs and the socioeconomic status of census tracts to see if this stands true. We found that areas with moderate to high poverty rates had the most expensive EbAs, possibly indicating either a greater need, or prioritization of EbA funding for lower income populations. However, it is notable that very few EbAs were present in areas with the lowest or the greatest poverty rates indicating the need for agencies to ensure the poorest communities also benefit from these projects.

At first glance, it is promising that EbAs are being implemented in lower-income neighborhoods with minority populations, echoing the findings of other research that green space initiatives were used as remediations for previous racist and redlining environmental policies (Burghardt et al., 2022). Although EbA solutions are often believed to be “no regret” and “win-win” silver bullets (T. W. Haase et al., 2017; Mees & Driessen, 2011), this may not be the case. While EbAs are known to increase adaptive capacity and provide a number of environmental, public health, and social benefits (de Vries et al., 2013; Seeland et al., 2008; Shepley et al., 2019), they can also be sources of significant disservices and burdens (Lyytimäki & Sipilä, 2009). For example, the construction of EbA projects often includes heavy equipment that result in noise pollution, degradation of air and water quality, and increased traffic to name a few (EDAW et al., 2007; Santa Clara Valley Water District, 2019). In this sample, the author found that EbA construction durations are longest in areas with high or very high asthma rates. These areas of high asthma rates also happen to be the same areas with the largest Hispanic and Black populations. Construction times for EbA projects within this study sample range from less than 1 year to over 10 years. This raises concerns about the negative public health impacts of EbA construction on underserved populations, especially those with higher asthma rates.

The City of East Palo Alto is a good case study to examine the relationship between EbA construction and asthma rates. This study found that East Palo Alto is home to the EbA projects with the longest construction times. This area also has the largest Black population, one of the largest Hispanic populations, the greatest poverty rates within the study site, and also has moderate to very high incidence of asthma. At any point in time from 2016 to 2027, there will be at least one EbA project under construction in this area, resulting in over a decade of potentially harmful construction impacts for these already marginalized, underserved, and vulnerable communities. This span of time with impaired air quality, can potentially exacerbate the already high rates of asthma in this community.

Another potential side effect of EbA projects for marginalized and lower socioeconomic populations is green gentrification. Green gentrification is the "implementation of an environmental planning agenda related to public green spaces that leads to the displacement or exclusion of the most economically vulnerable human population" (Dooling, 2009, p. 621). EbA's impact on green gentrification should be discussed as this topic presents an important consideration for urban planners, policymakers, and future EbA researchers. Research has shown that more green space, trees, and nature are correlated with White and wealthy populations (Stanford et al., 2018; Wolch et al., 2014). This issue of inequitable access to nature and green spaces is likely one of the reasons that many EbAs in this study are located in areas of low-income and minority populations, as municipalities try to address this inequity of access to green spaces. However, these projects may actually drive out the very populations that they were intended to benefit, by attracting wealthier and whiter residents, new commercial businesses, and raising the cost of living (Anguelovski et al., 2022; Dooling, 2009; Shokry et al., 2020). This study begins to shed light on the relationship between green spaces, EbAs, and green gentrification. To illustrate this, East Palo Alto and Redwood City, one of the two hotspots with the greatest concentration of EbA projects are at high risk for gentrification and in fact, are already experiencing it.

EbA projects in historically underserved communities may increase local adaptive capacity, beautify the space, and increase property value. At the same time, they also may force the relocation of the people who had to withstand the projects' negative construction impacts, and preclude them from experiencing the long-term adaptive benefits of these projects. It is essential that the distribution of both short-term and long-term impacts, benefits, and burdens are thoroughly considered prior to future EbA project implementation to ensure equitable outcomes.

This study looked at GSI projects separately from the other EbA projects, and found that they were mostly concentrated in areas with the greatest Hispanic populations. The implementation of GSI projects is often indicative of new development and redevelopment projects, because of Provision C.3 of the California Municipal Regional Stormwater Permit, which requires stormwater management solutions for new and redevelopment. New development and redevelopment are known drivers of gentrification, especially in the San Francisco Bay Area, where tech businesses and expensive new housing projects displace lower-income populations, and people of color (National Low Income Housing Coalition, 2019). The addition of GSI into these development projects threatens additional green gentrification. The idea of 'just green enough' arose from the concern that the introduction of too much greenery, whether green spaces, trees, or GSI, can drive gentrification, as seen in Boston, Philadelphia, among other locations (Anguelovski et al., 2019; Rigolon & Németh, 2020; Shokry et al., 2020). This study found the greatest concentration of GSI projects in inland Redwood City, which is undergoing extensive gentrification by new and redevelopment (Urban Displacement Project, 2022; Worthington, 2021). This area of high

GSI concentration and gentrification has high poverty rates, and a majority Hispanic population, making this not only a socio-economic issue, but a racial issue as well. It is important that cities such as Redwood City implement gentrification protections for low-income and Hispanic families to allow for green spaces and EbAs without displacing these populations so they can receive the benefits of these solutions as well.

This study has shown that EbAs including GSIs are not equitably located in relation to socio-economic and racial variables. Although there appears to be a focus of implementing EbAs in areas of low-income and minority populations, the mere presence of EbA is not necessarily a positive thing for these populations. Harmful construction impacts and green gentrification are of particular concern for EbAs, since these impacts may actually harm and displace these underserved and vulnerable communities.

Conclusion

This thesis adds to a growing body of research on EbAs, climate justice, and sustainable urban planning by examining the location and characteristics of Santa Clara and San Mateo Counties' EbA projects in relation to population sociodemographic, economic, and vulnerability characteristics. The results of this study can help inform urban planners and policymakers in their efforts to equitably implement EbA projects to benefit the most vulnerable communities, while minimizing negative side effects of EbAs. This study has unearthed some important research gaps that future EbA and climate justice researchers can pursue including the impact of EbA projects on green gentrification, community perceptions of EbA burdens and benefits, and the decision process of how lead agencies decide where to implement EbAs. It is recommended that more research is conducted on the short-term impacts of EbA construction on local communities, and on the long-term impacts of EbAs on gentrification and displacement of low income folks and people of color. Future studies should also combine secondary data with on-the-ground primary data collected through interviews of local community members and EbA lead agencies. This information can provide some answers on whether EbAs are welcomed by underserved communities or not, and on the decision making process of lead agencies on where to implement EbAs.

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Appendix A: List of Projects and Project Attributes

Project number	Project Name	County	Project Cost (or expected cost)	Ecosystem type	Climate change impact addressed	EbA components	Status/Phase	Time of construction (years)	Lead agency(s)
1	Foster City Levee Improvements Project	San Mateo	$90,000,000	coastal	sea level rise, flooding	earthen levee	under construction	3	City of Foster City
2	Colma Creek Restoration and Adaptation Project	San Mateo	$595,000	riparian	sea level rise, flooding	shoreline restoration, tidal marsh expansion	planning	TBD	San Francisco Bay Restoration Authority
3	Bayfront Canal & Atherton Channel Flood Management and Restoration Project	San Mateo	$8,590,000	coastal	sea level rise, flooding	stormwater redirection to tidal marsh	completed	1	OneShoreline
4	Pillar Point Harbor West Trail Living Shoreline Project	San Mateo	$3,000,000	coastal	sea level rise, coastal erosion	living shoreline, creation of beach and dune habitat	completed	1	San Mateo County Harbor District
5	Baylands Habitat Restoration and Community Engagement Project	San Mateo	$688,016	coastal	sea level rise, flooding	restore marsh-upland transition zone habitat	under construction	4	San Francisco Bay Restoration Authority
6	Coyote Point Recreation Area Eastern Promenade Rejuvenation Project	San Mateo	$7,600,000	coastal	sea level rise, flooding, coastal erosion	beach habitat restoration	completed	1	County of San Mateo
7	Shoreline Park - Burlingame	San Mateo	$1,491,499	coastal	sea level rise, flooding	public park, tidal marsh restoration, transition zone habitat restoration	planning	TBD	The SPHERE Institute
8	South Bay Salt Pond Restoration Project - Ravenswood	San Mateo	$18,471,730	coastal	sea level rise, flooding	tidal marsh restoration	under construction	10	Valley Water, US Army Corps of Engineers, CA State Coastal Conservancy, US Fish and Wildlife Service, CA Department of Fish and Wildlife
9	Butano Creek Floodplain Restoration Project	San Mateo	$937,926	riparian	flooding	floodplain restoration	completed	1	San Mateo RCD
10	Butano Creek Channel Reconnection & Resiliency Project	San Mateo	$7,000,000	riparian	flooding	creek restoration, marsh restoration	completed	1	San Mateo RCD
11	Conservation and Carbon Farm Plan for Butano Farms	San Mateo	$10,000	agricultural	heat, drought, flooding	agroforestry, cover crops	completed	0-1	San Mateo RCD
12	Conservation and Carbon Farm Plan for Cascade Ranch	San Mateo	$10,000	agricultural	heat, drought, flooding	agroforestry, cover crops	planning	0-1	San Mateo RCD

13	Conservation and Carbon Farm Plan for Cloverdale Ranch	San Mateo	$10,000	agricultural	heat, drought, flooding	agroforestry, cover crops	completed	0-1	San Mateo RCD
14	Conservation and Carbon Farm Plan for Miramar Farms	San Mateo	$8,000	agricultural	heat, drought, flooding	agroforestry, cover crops	under construction	0-1	San Mateo RCD
15	Conservation and Carbon Farm Plan for Potrero Nuevo Farm	San Mateo	$10,000	agricultural	heat, drought, flooding	agroforestry, cover crops	under construction	0-1	San Mateo RCD
16	Conservation and Carbon Farm Plan for the HEAL Project	San Mateo	$3,000	agricultural	heat, drought, flooding	agroforestry, cover crops	under construction	0-1	San Mateo RCD
17	Conservation and Carbon Farm Plan for TomKat Ranch	San Mateo	$20,000	agricultural	heat, drought, flooding	agroforestry, cover crops	completed	0-1	San Mateo RCD
18	Conservation and Carbon Farm Plan for Tunitas Creek Family Farm	San Mateo	$10,000	agricultural	heat, drought, flooding	agroforestry, cover crops	completed	0-1	San Mateo RCD
19	Conservation and Carbon Farm Plan #4	San Mateo	$12,000	agricultural	heat, drought, flooding	agroforestry, cover crops	completed	0-1	San Mateo RCD
20	Conservation and Carbon Plan for UC Elkus Ranch	San Mateo	$8,000	agricultural	heat, drought, flooding	agroforestry, cover crops	completed	0-1	San Mateo RCD
21	Conservation and Carbon Plan Webb Ranch	San Mateo	$10,000	agricultural	heat, drought, flooding	agroforestry, cover crops	under construction	0-1	San Mateo RCD
22	Conservation Carbon Plan for Fogline Farm	San Mateo	$8,000	agricultural	heat, drought, flooding	agroforestry, cover crops	under construction	0-1	San Mateo RCD
23	Conservation Carbon Plan for Harley Farms	San Mateo	$8,000	agricultural	heat, drought, flooding	agroforestry, cover crops	completed	0-1	San Mateo RCD
24	Conservation-Carbon Farm Plan for Root Down Farm	San Mateo	$8,000	agricultural	heat, drought, flooding	agroforestry, cover crops	completed	0-1	San Mateo RCD
25	Potrero Nuevo Farm Restoration Project	San Mateo	$100,000	agricultural	heat, drought	riparian plantings, invasives removal, pond restoration	under construction	5	San Mateo RCD
26	San Gregorio Creek Streamflow Enhancement Project, Klingman-Moty Farm	San Mateo	$1,164,446	agricultural	drought, flooding	creek restoration	completed	0-1	San Mateo RCD
27	San Gregorio Creek Streamflow Enhancement Project, Blue House Farm	San Mateo	$1,392,903	agricultural	drought, flooding	creek restoration	completed	0-1	San Mateo RCD
28	Millbrae and Burlingame Shoreline Project	San Mateo	TBD	coastal	sea level rise, flooding, heat	living shoreline, waterfront park, green space	planning	TBD	OneShoreline
29	Calabazas/San Tomas Aquino Creek-Marsh Connection Project	Santa Clara	$8,000,000	coastal	sea level rise, flooding	restoration of natural connections between watershed and SF	planning	1	Valley Water

30	Hale Creek Enhancement Pilot Project	Santa Clara	$8,964,000	riparian	flooding	vegetated soft bottom channel, stream restoration	under construction	4	Valley Water
31	Coyote Creek Flood Protection Project	Santa Clara	$48,200,000	riparian	flooding	vegetated berms, riparian plantings	planning	4	Valley Water
32	Upper Penitencia Creek Flood Protection Project	Santa Clara	$23,600,000	riparian	flooding	stream restoration	planning	4	Valley Water
33	San Francisquito Creek Flood Protection Downstream Project	Santa Clara	$74,000,000	riparian	flooding	tidal marsh restoration, floodplain expansion, high tide refugia habitat enhancement, creek connectivity	completed	3	San Francisquito Creek Joint Powers Authority
34	San Francisquito Creek Flood Protection Upstream Project	Santa Clara	$57,860,000	riparian	flooding	removal of concrete floodwall and replace with natural vegetated creek bank	planning	2	San Francisquito Creek Joint Powers Authority
35	Upper Llagas Creek Flood Protection Project	Santa Clara	$213,000,000	riparian	flooding	creek restoration, riparian plantings	under construction	6	Valley Water
36	South San Francisco Bay Shoreline Project	Santa Clara	$30,400,000	coastal	sea level rise, flooding	tidal marsh restoration, vegetated levee	under construction	6	Valley Water
37	Upper Guadalupe River Flood Protection Project	Santa Clara	$180,700,000	riparian	flooding	restoration, riparian plantings, tree plantings	under construction	7	Valley Water
38	Palo Alto Horizontal Levee	Santa Clara	$2,729,000	coastal	sea level rise, flooding	horizontal vegetated levee	planning	1	City of Palo Alto
39	Coyote Valley Conservation Areas Master Plan	Santa Clara	$104,022,100	riparian	flooding, drought	land conservation	completed	0-1	Peninsula Open Space Trust, City of San José, Open Space Authority
40	South Bay Salt Pond Restoration Project - Alviso	Santa Clara	$57,731,549	coastal	sea level rise, flooding	tidal marsh restoration	under construction	10	Valley Water, US Army Corps of Engineers, CA State Coastal Conservancy, US Fish and Wildlife Service, CA Department of Fish and Wildlife

Appendix B: Map of Labeled Projects