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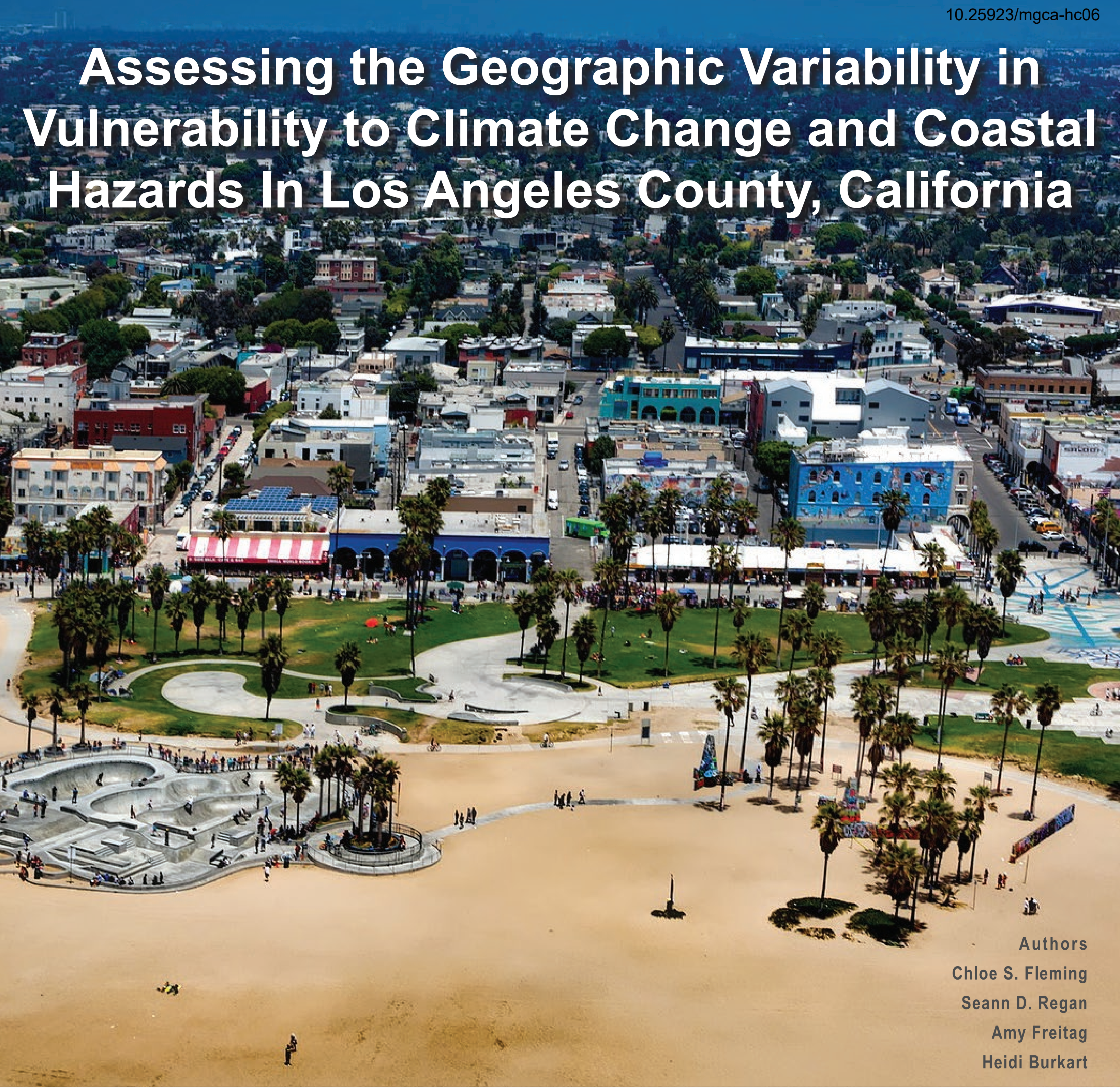
Assessing the Geographic Variability in Vulnerability to Climate Change and Coastal Hazards In Los Angeles County, California



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Assessing the Geographic Variability in Vulnerability to Climate Change and Coastal Hazards in Los Angeles County, California

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Beach. Credit: Theresa Goedeke, NOAA

LIST OF ACRONYMS

ACS	American Community Survey
BMPs	Best management practices
BSh	Hot semi-arid climate
BSk	Cold semi-arid climate
CanESM2	Canadian Earth System Model (version 2)
CoSMoS	Coastal Storm Modelling System
Csa	Hot-summer Mediterranean climate
Csc	Cool-summer Mediterranean climate
DEM	Digital Elevation Model
ENSO	El Niño-Southern Oscillation
FEMA	Federal Emergency Management Agency
Framework	Integrated Vulnerability Assessment Framework
GHG	Greenhouse gas
IDW	Inverse distance weighted
IPCC	Intergovernmental Panel on Climate Change
L.A.	Los Angeles
LARC	Los Angeles Regional Collaborative
LARIAC4	Los Angeles Region Imagery Acquisition Consortium (version 4)
LOCA	Localized Constructed Analog
NAD	North American Datum
NCCOS	National Centers for Coastal Ocean Science
NDVI	Normalized Difference Vegetation Index
NFIP	National Flood Insurance Program
NOAA	National Oceanic and Atmospheric Administration
OCM	Office for Coastal Management
PAD-US	Protected Areas Database of the United States
PCA	Principle Components Analysis
PDO	Pacific Decadal Oscillation
PCH	Pacific Coast Highway
pLAn	L.A. Sustainable City Plan
RCP	Representative Concentration Pathway
SEA	Significant Ecological Area
SFHA	Special Flood Hazard Area
SoVI	Social Vulnerability Index
SPA	Service Planning Area
USC Sea Grant	University of Southern California Sea Grant
USDA	United States Department of Agriculture
USDM	United States Drought Monitor
USGS	United States Geological Survey
UTM	Universal Transverse Mercator

King Tide at Long Beach Peninsula. Credit: California King Tides Project

Executive Summary

This report presents background, methodology, and findings from the third application of the National Centers for Coastal Ocean Science's (NCCOS) Integrated Vulnerability Assessment Framework. Building upon previous work done in the Chesapeake Bay, the Framework was applied in Los Angeles (L.A.) County, California. The overarching goals of the project were to: 1) provide partners with the ability to more easily understand the complexities of overall vulnerability and risk within their region, thereby leading to informed management action; and 2) expand upon previous iterations of the Framework in a new geography with variability in demographics, ecology, and climate concerns.

To meet these goals, the project team advanced and implemented the NCCOS Framework (first operationalized by Messick and Dillard (2016) and Fleming et al. (2017)) for Census block groups in three L.A. geographies through the following steps:

1. Engage local partners and stakeholders to identify aspects of vulnerability and climate-driven risk within the study area
2. Develop indicators and indices for each vulnerability and risk
3. Assess social vulnerability, structural vulnerability, and natural resource vulnerability within the study area
4. Assess risks within the study area
5. Intersect vulnerability and risk profiles
6. Engage local partners and stakeholders for prioritization of adaptation areas and next steps to mitigate climate-driven impacts[1]

Social vulnerability components included seven factors derived from demographic variables, and developed through principal components analysis. Structural vulnerability components included parcel age, critical infrastructure, disaster routes, historic places, and improvement value. Natural resource vulnerability components included habitat fragmentation, wetland cover, significant ecological areas, greenness, canopy cover, and modelled species richness.

Identified climate and coastal risks included coastal flooding, stormwater flooding, combined flooding, erosion, drought, heat, and wildfire. Coastal flooding risk was determined through three coastal flooding risk scenarios that incorporated storm surge, currents, wave-driven run up, sea level rise projections, and coastal erosion patterns. Stormwater flooding components included flow accumulation, drainage density, elevation, land cover, rainfall intensity, slope, and hydrologic soil groups. Combined flooding risk combined the first two flooding profiles. Erosion risk combined both wind and water erosion likelihoods. Drought risk used drought severity and coverage information. Heat risk used temperature normals that assessed number of days over 90 degrees Fahrenheit. Lastly, wildfire risk incorporated fire frequency and potential fire behavior.

This application of the Framework was first applied to L.A. County, with secondary applications for an urban boundary and a 10-mile coastal geography. The three vulnerability assessments from this effort can best be used as determined by different management needs, where each assessment provides vulnerability and risk analyses in comparison to other Census geographies within the assessment.

In addition to implementing the Framework, the project team synthesized information gaps identified through a regional gap analysis, feedback from local partners and stakeholders, and expert knowledge to conduct additional coastal analyses. These included exploration of National Flood Insurance Program (NFIP) claims, access to green space, access to cultural/historic space, impacts of erosion and flooding on critical infrastructure, and the relationship between erosion and blufftop development.

[1]While step six is initiated by the research team, it is often implemented by local partners and managers

This report examines each of the above themes in detail, and each set of findings can be prioritized by various partner and stakeholder group needs. The bullets below state key findings from each results section of this report; key findings are briefly summarized in Chapter 6.

- Drought risk may impact both rural and urban areas.
- Heat risk occurs further inland.
- Wildfire threatens rural and newly suburban areas.
- Erosion risk is tightly interwoven with flooding impacts.
- There are many areas of high social vulnerability and high combined flooding risk.
- Areas of high flood risk have fewer flood insurance claims.
- At-risk populations and areas lack green space.
- Cultural and historical resources are at risk of flooding.
- Many disaster routes are at risk of flooding and erosion (e.g., the Pacific Coastal Highway).
- There are overlapping areas of new development and high erosion risk.
- Risks are likely to compound.
- Overlapping vulnerability and risk presents opportunity.

This application of the Framework was marked by both advancements and challenges, including implementation in a highly urbanized environment, development of an urban nature index, expansion beyond flood risk to drought, heat, and erosion, assessment at multiple geographies within the study area, inclusion of additional coastal analyses, and continued refinement of indicators. The vulnerability assessments completed for three different geographies within L.A. County are relevant for differing management needs. Areas of high risk and high vulnerability change as the number and location of total block groups change with each assessment, and as a result, each assessment provides a unique opportunity for planners to make educated trade-offs when prioritizing resources for adaptation and mitigation action.

The NCCOS Framework provides a large scale integration of a combination of various vulnerabilities and risks within each assessment geography. The research is intended as a holistic first step to identify priority geographies or intersections that warrant future investments of attention and adaptation funds. The final bivariate maps included in each assessment serve as visual tools to expose areas where high vulnerability corresponds to high risk. These maps and greater assessments can be used by local partners and stakeholders to establish adaptation priority areas for the coastal and climate-driven risks explored in this research. California Senate Bill 379 (later codified) requires all cities and counties to start incorporating climate adaptation and resiliency strategies into their general plans or hazard mitigation plans (California SB 379). While many local communities in L.A. County already have sustainability or climate action plans in place (e.g., Cities of L.A., Long Beach, Hawthorne, Santa Monica), these assessments may provide information for determining the locations for planned adaptation activities and goals. For communities that are in the process of developing these plans, these assessments and the underlying data may aid these efforts. The project team is already assisting the Cities of Malibu and West Hollywood with data needs. As other communities are identified, USC Sea Grant colleagues will be able to share the data and findings from these assessments.

Despite the emphasis on the bivariate map combinations, the individual variables or components of these assessments may also be independently useful for other management and planning purposes. Further, while this research limited bivariate map combinations to a single risk intersected with a single vulnerability, users may find it informative to overlay two risks or two vulnerabilities. Areas that share multiple aspects of vulnerability and/or risk create the need for adaptation action in the face of a changing climate, but they also present an opportunity to develop and implement innovative strategies that mitigate various concerns across multiple sectors at once. The flexibility allows for management action based on various time horizons, management needs, levels of political and public support, and availability of funding.

In addition to the Framework's high-level integration and overview, the additional coastal analyses can be used to strengthen L.A.'s coastal zone. Data may support implementation of educational outreach efforts, inform and aid in the creation of emergency preparedness plans, or support further development of coastal management plans in and across local and regional jurisdictions. These additional analyses also highlight how assessment profiles can be used as foundational pieces to supplement new and ongoing research in the County.

Ultimately, the design of the Framework continues to provide a level of flexibility that can be applied to multiple geographies and contexts. This work is reliant upon the iterative involvement of local partners and stakeholders to provide meaningful information to better protect, advance, and manage climate change impacts within local communities in various coastal geographies.

Cliffside ocean view. Credit: Theresa Goedeke, NOAA

Oceanfront home. Credit: Theresa Goedeke, NOAA

Chapter 1: Introduction

Coastal communities are increasingly vulnerable to climate-driven effects, such as sea level rise and coastal erosion. To address these and other coastal risks in Los Angeles (L.A.) County, researchers at the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Coastal Ocean Science (NCCOS) partnered with University of Southern California Sea Grant (USC Sea Grant) and NOAA's Office for Coastal Management (OCM) - West Coast Region to extend their Integrated Vulnerability Assessment Framework to this densely populated and highly urbanized region.

1.1 STUDY AREA

L.A. County is one of the nation's largest and most populated counties, with over 4,000 square miles and over 10 million residents (USCB 2018a; USCB 2010). The County's geography, ecology, and communities are highly variable, as are its climate impacts and risks. The region is influenced by a variety of threats, such as bluff erosion, sea level rise, wildfire, saltwater intrusion, water availability, and water quality. Similarly, L.A. County also faces extreme variation in social and economic factors, including disparities in income, education, and employment opportunities.

L.A. County is located in Southern California, bordering the Pacific Ocean, with an area of 4,084 square miles (Figure 1.1). It is home to 88 incorporated cities, ranging from Vernon (population of 96 people in 2010) to the City of Los Angeles (home to 4 million people) (County of Los Angeles, 2018). In 2010, 89.5% of the County's population lived within incorporated cities; the remainder lived in rural, unincorporated areas (County of Los Angeles 2018). The County is largely a desert-like flood basin surrounded by the San Gabriel Mountain Range and divided by the Santa Monica Mountains. The area is primarily composed of mountains

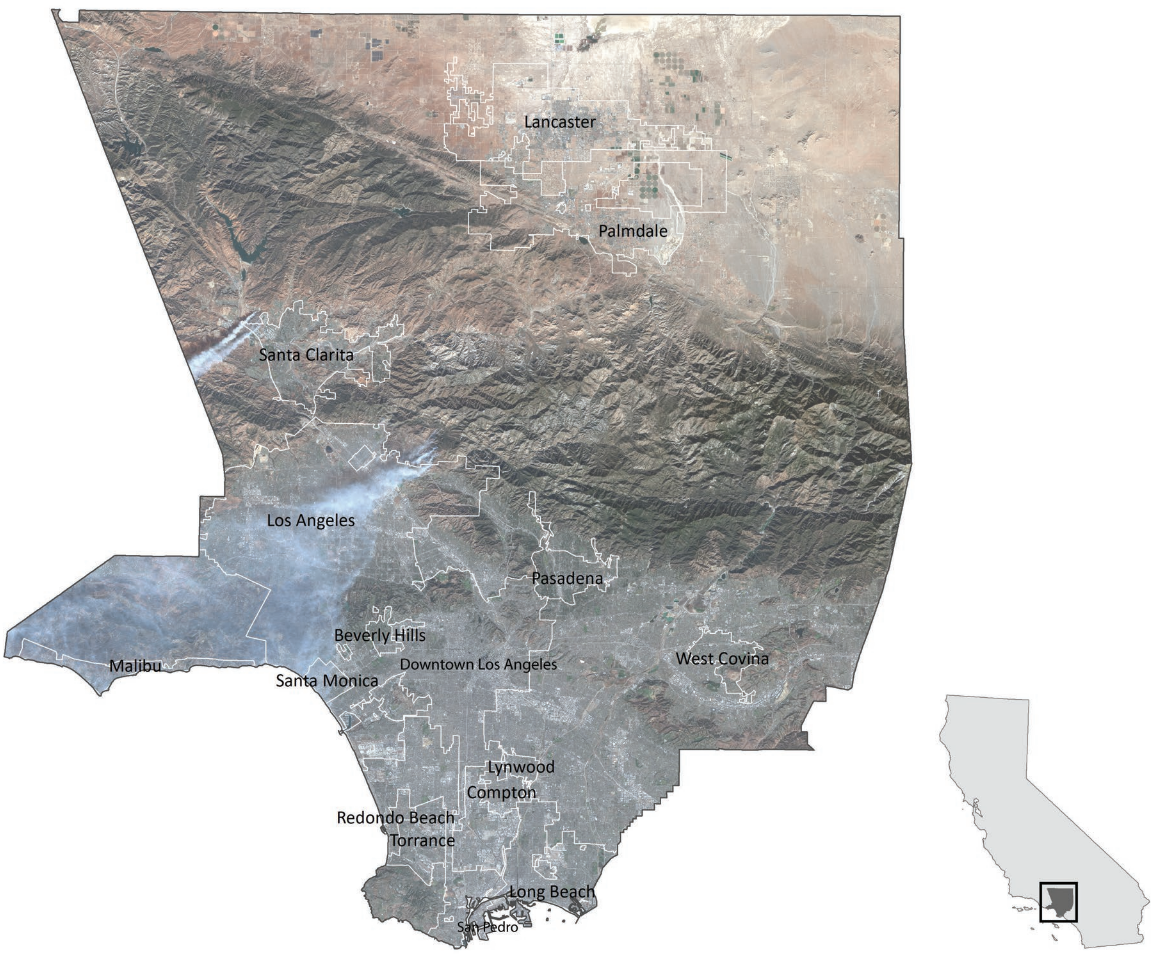

Figure 1.1. Geographic reference for L.A. County, excluding Santa Catalina and San Clemente Islands.

and flat land (1,875 and 1,741 square miles, respectively), but also contains 246 square miles of hilly land and 59 square miles of mountain valleys (County of Los Angeles 2018). Given its geography, elevations range from 9 feet below sea level at Wilmington to 10,080 feet above sea level atop Mount San Antonio (County of Los Angeles 2018). L.A. County has 75 miles of Pacific coastline, known for Southern California's famous beaches, and 129 square miles of island area, namely Santa Catalina and San Clemente Islands (County of Los Angeles 2018).[2] The County's water resources also include 28 square miles of marshland (County of Los Angeles 2018) and eight major watersheds (LACPW 2019).

1.1.1 Climate Profile

L.A. County is nested within Coastal Southern California, which extends from Santa Barbara south to the Mexican border. The County is comprised of three climate zones as defined by the Köppen-Geiger climate classification system. Updated in 2017, higher resolution climate zone mapping reflects the more recent 25-year period from 1986-2010.[3] Climate zones are determined through the combination of each location's main climate, its precipitation levels, and its temperature. The three climate zones found in L.A. include cold semi-arid (or steppe) climate (BSk), hot-summer Mediterranean climate (Csa), and warm-summer Mediterranean climate (Csb) (Rubel and Kottek, 2010; Kottek et al., 2006). Much of central L.A. falls into the BSk categorization, the northern and western portions of the County are considered Csb, and only a few pockets between the two primary zones are considered Csa.[4]

US climate normals data are collected and calculated for 30-year periods from temperature and precipitation stations throughout the United States. In L.A. County, there are 44 precipitation gauges and 26 temperature gauges used to calculate monthly climate normals from 1981-2010 (NOAA NCEI 2018b). These gauges collect an average annual precipitation throughout the County of 17.14 inches. The maximum annual rainfall is 35.98 inches at Mount Wilson station, and the minimum annual rainfall is 6.73 inches at Pearblossom station. Using the temperature stations, L.A. County has an average annual temperature of 63.4°F, with a maximum annual average at Montebello (67.4°F) and a minimum annual average at Sandberg (56.4°F). The average temperature across the County in August is 75.3°F, ranging from 81.4°F in Palmdale to 66.9°F at the Santa Monica Pier, and the average temperature within the County in January is 53.6°F, ranging from 59.1°F in Montebello to 43.0°F in Sandberg (NOAA NCEI 2018b).

1.1.1.1 Climate-Driven Risks and Impacts from Climate Change

The risk portfolio of L.A. County is more diverse than in many other geographies, given its exposure to the ocean, mountains, desert conditions, and the bowl-shaped air system over the City. Many of these risks are adversely influenced by a changing climate, and are considered climate-driven. They include extreme heat, wildfire, drought, deteriorating air and water quality, erosion, stormwater flooding and mudslides, earthquakes and tsunamis, and coastal flooding from storms, sea level rise, and El Niño events, among others (Spanger-Siegfried et al. 2017; Adelaine 2016; Grifman, Newton Mann, and Sadrpour 2016; Schubel et al. 2015; Finzi Hart et al. 2012; Noriega and Ludwig 2012; Pacific Institute 2012; Wisner 2009).

With climate and land use changes, it is anticipated that many of these risks will intensify in frequency, strength, and/or duration (Spanger-Siegfried et al. 2017; Moser, Ekstrom, and Franco 2012). Average temperatures across the State of California increased by 1.7°F from 1895 to 2011, and climate models suggest that California will warm by 2.7°F above year 2000 averages by year 2050. Models indicate a range of an additional 4.1-8.6°F by year 2100 (Moser, Ekstrom, and Franco 2012).

Increased temperatures and humidity are expected to result in an increased annual number of extreme heat days and danger days.[5] In L.A., the average number of annual danger days is projected to increase from 16 in 2000 to 21 by 2030, and to 29 by 2050 (Climate Central 2016). An increased number of annual extreme

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[2]Santa Catalina and San Clemente Islands were excluded from analyses in this report due to insufficient secondary data.
[3]Downscaling algorithms explained in Rubel et al., 2017.
[4]To view maps for the United States alone, visit http://koeppen-geiger.vu-wien.ac.at/usa.htm.(last accessed December 2019)
[5] Extreme heat days can refer to days over 90°F, 95°F, or 100°F, and danger days are defined by the National Weather Service as any day where the heat index (combination of heat and humidity) exceeds 104°F (Climate Central 2016)

heat days will likely result in an increased ratio of emergency room visits due to heat illnesses (English et al. 2013). Temperature also impacts air quality by creating ground-level ozone. This can increase incidents of lung inflammation, asthma attacks, and other respiratory problems (Climate Central 2014). Increased temperatures are also impacting snowfall rates and the ability to retain the supply of fresh water across the State of California, thereby increasing drought and decreasing the availability of fresh water for consumption, groundwater recharge, and agriculture. Salt water intrusion from rising sea levels poses a risk to coastal water supplies as well (Spanger-Siegfried et al. 2017). Increased heat and decreased water supply will likely result in increased wildfire risk (Moser, Ekstrom, and Franco 2012). In addition to the threat of fire itself, wildfires adversely influence air quality through the large quantities of smoke and particulate matter they produce (Pacific Institute 2012; Lipsett et al. 2008). Wildfires that result in the destruction of vegetation and complex root systems can lead to higher risk of erosion, mudslides, and landslides (Zachos 2018).

While wildfire can ultimately lead to the risk of erosion, other risks, including coastal flooding, precipitation, and wind, can also increase erosion potential. Climatic changes in sea level, wave strength and height, rainfall frequency and intensity, soil conditions, and wind strength and direction will have direct and indirect impacts on erosion rates in L.A. County (Grifman, Newton Mann, and Sadrpour 2016; Noble Consultants 2016; USDA 2013; Finzi Hart et al. 2012; Breshears et al. 2003). While normal precipitation patterns impact current erosion rates, intense rainfall over a short period of time can result in severe mudslides and stormwater flooding, which exacerbates erosion (Tchekmedyian, Mejia, and Livingston 2018).

Coastal flooding and sea level are expected to continue increasing globally, and will likely place people, ecosystems, and property at greater risk (Fleming et al. 2018; Arkema et al. 2013; IPCC 2014a; IPCC 2014b). In L.A., sea level rise is projected to range between 13.5 and 17.8 cm by year 2030, and range between 93 and 288 cm by year 2100 (CA NRA and CA OPC 2018; Grifman, Newton Mann, and Sadrpour 2016; Kopp et al. 2014). Rising sea level brings with it increased flooding and erosion risk from tides, wave-driven run-up, and storm surge (IPCC 2014a; IPCC 2014b; Grifman et al. 2013). In L.A. County, sea level rise and coastal flooding threaten public beaches (Noble Consultants 2016), socially vulnerable populations (Ekstrom and Moser 2013; Pacific Institute 2012), and critical infrastructure, including hospitals (Adelaine 2016), energy compounds and transmission lines (Moser and Finzi Hart 2018; Sathaye et al. 2012), and the transportation sector (de Ruig et al. 2019; Grifman, Newton Mann, and Sadrpour 2016).

King Tide at Broad Beach-Point Dume Marine Protected Area in Malibu, California. Credit: LA Waterkeeper

Coastal flooding and erosion are further influenced by King Tides, Spring Tides, El Niño, and the Pacific Decadal Oscillation (PDO). A King Tide is a non-scientific term given to exceptionally high tides that are seasonally driven by a new or full moon (NOAA NOS 2015). The historical, common term for gravitational lunar and solar-influenced King Tides is Spring Tide (NOAA NOS 2019), and their occurrences increase the tidal range, as well as the potential for coastal flooding and erosion (NOAA NOS 2015). A cyclical climate pattern called the El Niño-Southern Oscillation (ENSO) has direct and indirect impacts on many of the climate risks mentioned above, in addition to coastal flooding and erosion. This atmospheric and oceanic phenomenon shifts between El Niño, La Niña, and neutral phases every 2-7 years, and affects conditions across the Pacific. Changes in barometric pressure, sea surface temperature, oceanic thermocline, and trade winds influence global and local atmospheric and oceanic conditions (NOAA NCEI 2018a; L'Heureux 2014). Southern California is most impacted by ENSO in its strong El Niño years, which result in increased sea surface temperature and sea level. When compounded with King Tides or coastal storms, ENSO further increases the risk of coastal flooding and erosion (NOAA NOS 2015). ENSO also influences local weather patterns through increased winds and rainfall (USGS 2015). Sometimes described as a long-lived version of ENSO patterns (Zhang, Wallace, and Battisti 1997), the PDO also impacts Pacific climate variability. Extreme phases of the PDO influence sea surface temperature and sea surface pressure anomalies (NOAA NCEI 2019b; Mantua 1999), which further influence climate in Southern California.

California and L.A. are also infamously known for their risk of earthquakes and tsunamis (Cal OES 2018a; Cal OES 2018b). The active San Andreas Fault system makes a large left bend near Los Angeles, and the region's tectonic movement is responsible for the creation of the San Gabriel and San Bernardino Mountains (Dolan et al. 1995; Wallace 1990). Seaward of the San Andreas Fault are a series of quaternary active faults that traverse L.A. County, including the Santa Monica Fault, Newport-Inglewood Fault, Sierra Madre Fault, Palos Verdes Fault, Hollywood Fault, and Raymond Fault. These and other active fault lines run beneath urban areas within L.A. City and County (Toké et al. 2014). In 2008 the Working Group on California Earthquake Probabilities reported that the probability of an earthquake of magnitude 6.7 or higher has a greater than 99% chance of occurring in California within the next 30 years (Noriega and Ludwig 2012). In addition to the destruction caused by local earthquakes, oceanic earthquakes across the Pacific present the threat of tsunami to coastal L.A. County (Cal OES 2018b). Recent research also indicates that there may be connections between the occurrence of tropical cyclones and earthquakes (Liu, Linde, and Sacks 2009), which suggests that a changing climate may also affect occurrence or magnitude of earthquakes and tsunamis.

1.1.1.2 Climate Projection Models

Due to the many anticipated impacts of climate change on L.A. County in future years, the County's climate-driven risks are expected to shift with time. To better understand how these risks will change in response to a changing climate, a series of modeled, downscaled climate projections are available from a wide variety of research organizations. The chosen models from Scripps Institute of Oceanography, shown in Figure 1.2 and Figure 1.3, align with two commonly used scenarios from the Intergovernmental Panel on Climate Change (IPCC) assessment (IPCC 2014a; IPCC 2014b). Modeled climate projections based on the Representative Concentration Pathways (RCP) of 4.5 and 8.5 were considered, as these two scenarios align with California's Fourth Climate Change Assessment (CalEPA 2015), and are commonly used in scenario planning in the region. The RCP 4.5 and RCP 8.5 scenarios include a wide range of possible changes in future anthropogenic-driven greenhouse gas (GHG) emissions, and subsequent atmospheric concentrations of GHGs. Figure 2 and Figure 3 show modeled climate change scenarios under RCP 8.5 conditions[6] using a technique called Localized Constructed Analogs (LOCAs). LOCAs are a statistical process in which past history is used to add improved fine-scale detail to global climate models that typically have a global resolution and are less useful at local or regional scales (Pierce, Cayan, and Thrasher 2014). These LOCAs all have a spatial resolution of ~1/16º or approximately 6 km at the equator. Each of the climate projections outlined here use the second generation Canadian Earth System Model (CanESM2), as this model is widely

[6] RCP 8.5 conditions, and not RCP 4.5, are shown to better align with scientific and partner-driven coastal flooding projections described in section 2.2.4 of this report.

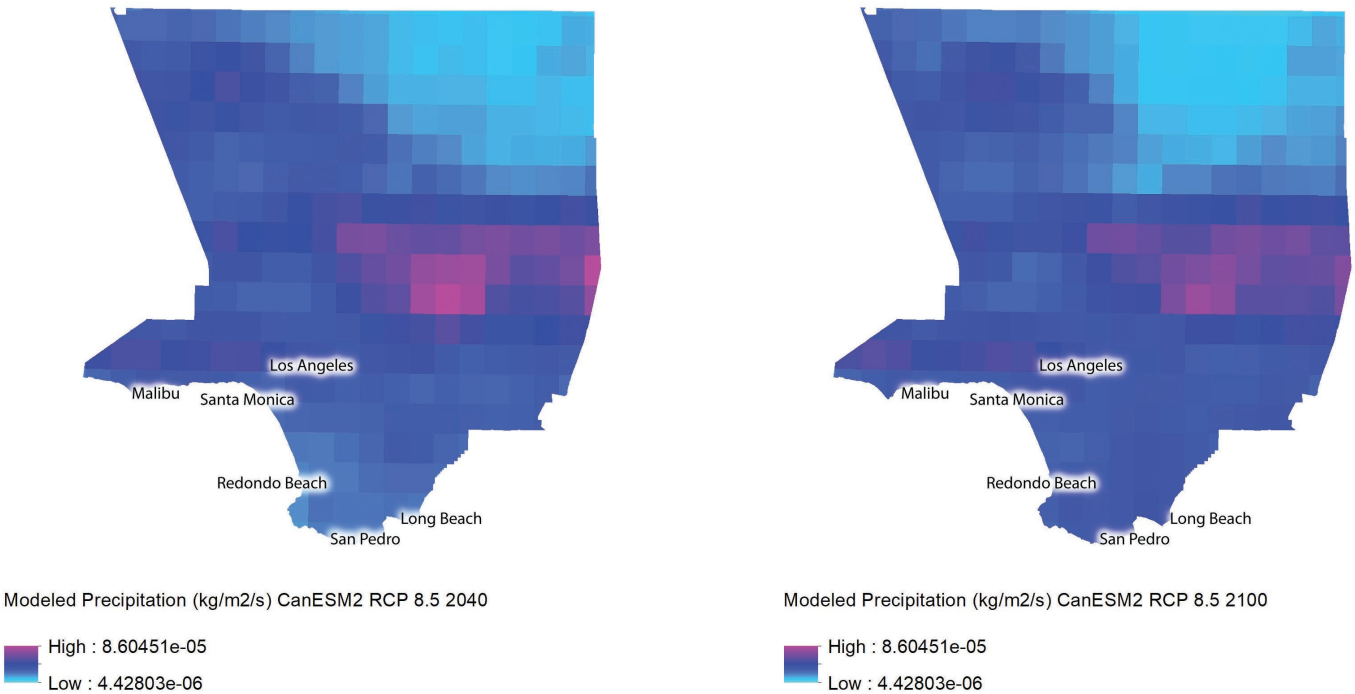

Figure 1.2. Modeled precipitation (kg/m^2/s) increase in 2040 and 2100 with a RCP 8.5 scenario.

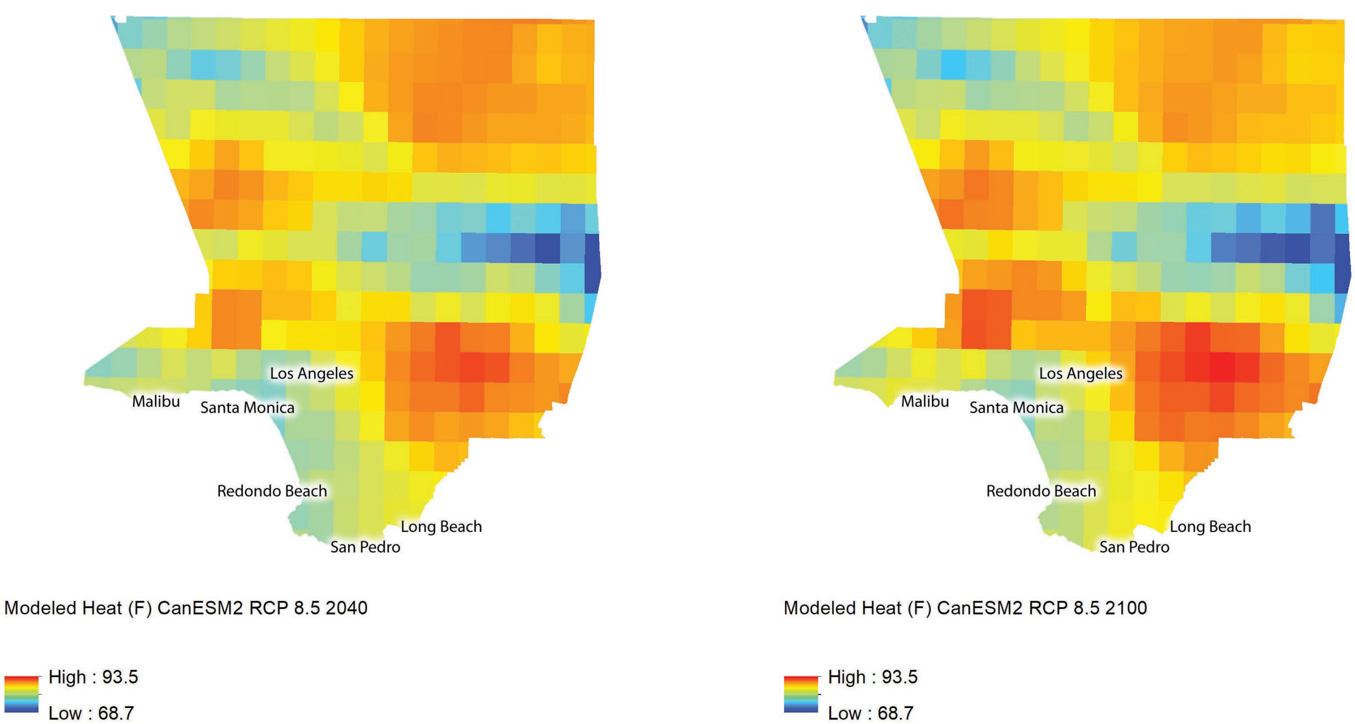

Figure 1.3. Modeled maximum temperature increase in degrees Fahrenheit in 2040 and 2100 with RCP 8.5 scenario.

used in climate change planning in California (CalEPA 2015). Further details can be found at the Canadian Center for Climate Modeling[7].

Figure 1.2 and Figure 1.3 show CanESM2 models of precipitation and heat for RCP 8.5 in years 2040 and 2100. In each of these figures, the differences between years 2040 and 2100 are subtle, yet show overall decreases in precipitation and increases in temperature, respectively. Importantly, slight changes to climate can have cascading effects on ecosystems, and these impacted areas vary spatially across the County. Some of the areas projected to experience increased heat and decreased precipitation currently experience drought and wildfires on a regular basis. These changes are likely to exacerbate conditions. Some areas highlighted as likely to experience heavy precipitation are located in regions of the County already experiencing issues with water driven erosion and mudslides, such as the Angeles National Forest and hilly areas inland of the Malibu coastline (dark blue, pink and purple areas; Figure 1.2). Other areas are in locations already experiencing issues with stormwater and coastal flooding, and these impacts will continue to be felt in 2100 (areas turning a darker shade of blue; Figure 1.2). Figure 1.3 shows that while modeled temperature is expected to make the northern, already-arid regions hotter and areas of the inland empire warmer (increases in orange and red areas), mountainous and coastal areas will experience less warming (subtle increases in yellow areas along the coast and fairly consistent coloring in the mountains).

1.1.2 Ecological Profile

L.A. County is a fundamentally urban landscape, with famously channelized rivers and a large and growing human population. Yet, it also hosts significant green space outside the City of L.A., including Angeles National Forest (McPherson et al. 2011). The variety of landscapes, from mountains to desert to coastal wetlands, create a variety of habitat types to host many species both inside and outside developed areas (Elmqvist et al. 2015). L.A. County therefore pushes scientific understanding of nature, natural resources, and ecology in an urban context (Clarke et al. 2013).

The research coalition Sustainable L.A. (University of California Los Angeles) assigned a grade of C- to L.A. County's ecosystem health in 2015. They cited 886,443 acres of protected lands and 41,807 acres of protected ocean as positives, and low greenness (indicating extreme drought), poor stream function, wetland loss, and fire potential as negatives in their assessment (Gold et al. 2015). The stretches of protected lands and waters are especially important considering many point to habitat fragmentation caused by development as the largest pressure on ecosystem health in the County (Gold et al. 2015). In 2010, the County was 25.61% developed with 12.33% impervious surface, 7.49% forest, and 0.48% wetland, with the rest a mix of grassland, shrub/scrub, and agriculture (CCAP 2010).

In addition to habitat concerns, biodiversity is considered one of the most useful metrics of ecosystem health in an urban context (Kinzig et al. 2005). A biodiversity plan was recently developed as part of the Sustainable City pLAn program. The plan cites over 1,200 species in L.A. City, with almost double that expected with better documentation, and still more when counting species that live in the County outside the City boundaries. This includes over 150 endangered species, and the total makes the region considered a global biodiversity hotspot. Their calculation of the Singapore Index (a global measure of biodiversity in cities) yielded L.A. 48 out of a possible 72 points, scoring notably well in native bird species and protected sensitive species, but showing need for improvement in urban tree canopy and citizen education (City of Los Angeles 2019). The City also plans to develop an amended Singapore Index to better account for the data gaps, unequal distribution of natural areas, and large spatial footprint of L.A. (City of Los Angeles 2019). Recent research combining remotely sensed data with citizen science records classified nine types of urban habitats within the urbanized area of L.A. County, some of which contained higher biodiversity than previously expected based on high impervious surface cover (Li et al. 2019).

[7] http://climate-modelling.canada.ca/data/cgcm4/CanESM2/index.shtml (last accessed November 2019)

1.1.3 Socioeconomic Profile

Figure 1.4 depicts the study area of L.A. County and its 6,394 Census-defined block groups by population density.[8] The 2012-2016 American Community Survey (ACS) 5-Year Estimates projected a total population of 10,057,155 for the County, ranging from 5 persons in one block group to 10,384 persons in another (USCB 2016). This estimate was an increase from the 2010 Decennial Census total population figure of 9,818,605 (USCB 2010). Although there is sizeable demographic diversity among block groups in L.A. County, the aggregated demographics below provide averages across the County in 2016.

The average of all block groups' median household income in L.A. County was $66,594 with a standard deviation (SD) of 34,607, and the average median per capita income was $31,325 (SD of 22,237). On average, 16.4% of the population lived in poverty, whereas 7.5% of households earned over $200,000 annually (SDs of 13.0 and 10.9, respectively). The average of all block groups' median rent was $1,420 per month (SD of 491.2), and the average of all block groups' median housing value was $508,046 (SD of 276,390). Of all housing units, 49.0% were rented (SD of 28.3), and only 5.6% of housing units were vacant (SD of 6.2). Approximately 1.4% of the population lived in mobile homes (SD of 6.3), and 9.0% had no access to a vehicle (SD of 10.2) (USCB 2016).

Average household size across block groups was 3.2 persons (SD of 0.9). Inhabitants had an average median age of 37.5 years (SD of 7.8), with 6.0% of the population under the age of five and 13.0% over the age of sixty-five (SDs of 3.7 and 7.5, respectively). On average, 70.2% of the population lived in family

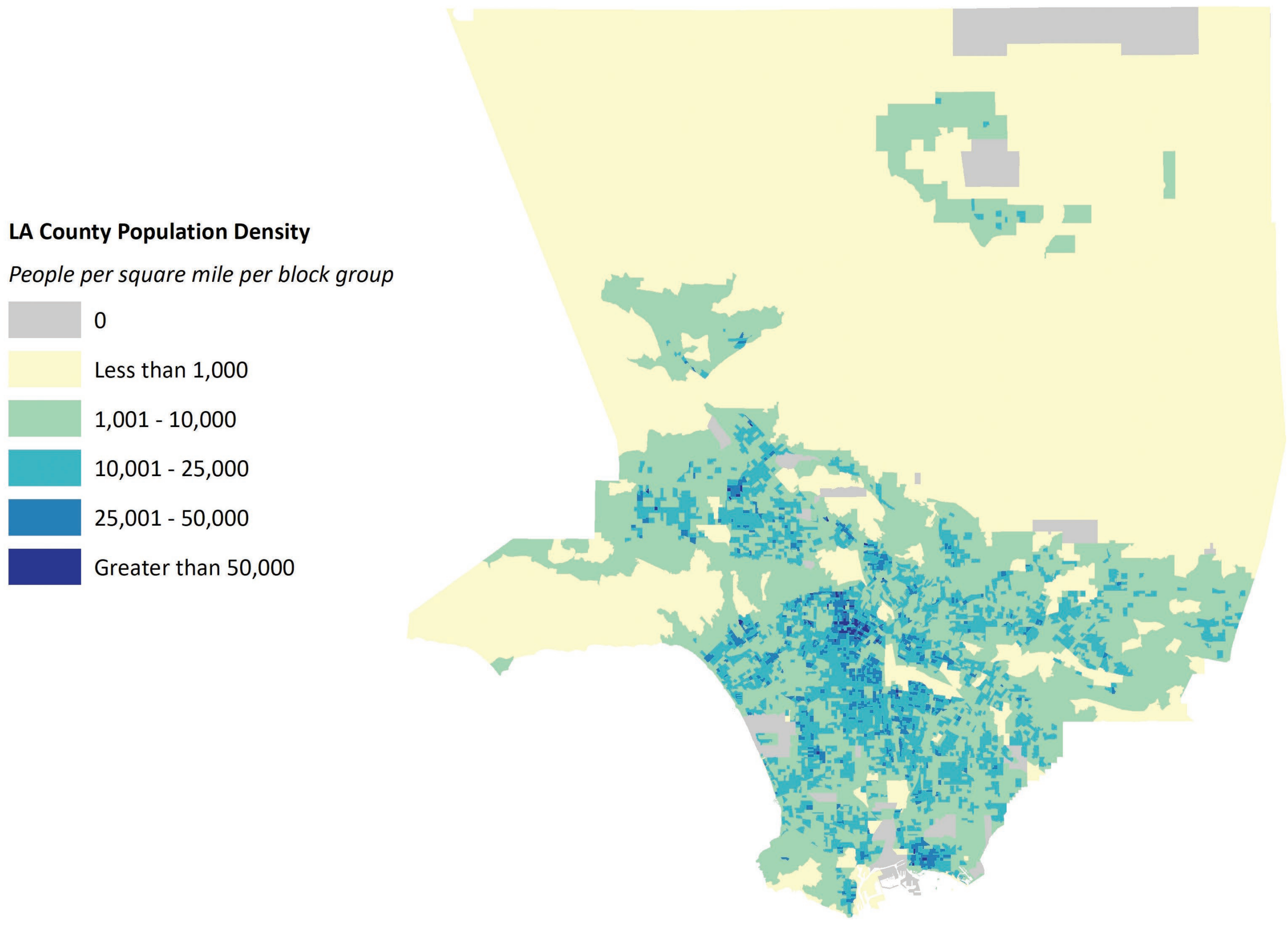

Figure 1.4. Study area - L.A. County population density by Census Block Group.

[8]Block groups depicted in grey lack Census population data, and include industrial complexes, airports, and ports.

households (SD of 18.1), and 16.2% of the population lived in female headed households (without a spouse; SD of 10.4). Just over half of the population was female (50.8% with a SD of 5.8) (USCB 2016).

On average, 25.3% of households collected social security income (SD of 11.7), and 9.6% collected food stamps or supplement nutrition assistance program (SNAP) benefits in the 12 months prior to Census data collection (SD of 10.2). Across the County, an average of 22.7% of the population aged 25 or older did not hold a high school diploma (SD of 18.3), 13.3% spoke English as a second language and had limited English proficiency (SD of 12.2), and 13.9% did not have health insurance (SD of 9.1) (USCB 2016).

On average, 8.9% of the population was unemployed (SD of 5.7). Over half of the population (53.1%) was employed in service industries, which include retail trade, administrative and support services, arts, entertainment and recreation, and accommodation and food services (SD of 11.1). Only 0.5% of the County population was employed in extractive industries, including agriculture, forestry, fishing, hunting, mining, quarrying, and oil and gas extraction (SD of 1.5) (USCB 2016).

1.1.3.1 Racial and Ethnic Profiles

Figure 1.5 and Figure 1.6 display the distribution of the ethnically and racially diverse L.A. County population based on data from the 2012-2016 ACS 5-Year Estimates. The U.S. Census Bureau defines race and ethnicity separately. Ethnicity describes a person's Hispanic origins, while race refers to "a person's self-identification with one or more social groups" (USCB 2018b). Nearly half of the population (48.3%) identified as Hispanic or Latino, and were distributed throughout various regions of the County, as shown in Figure 1.5. Across the County,

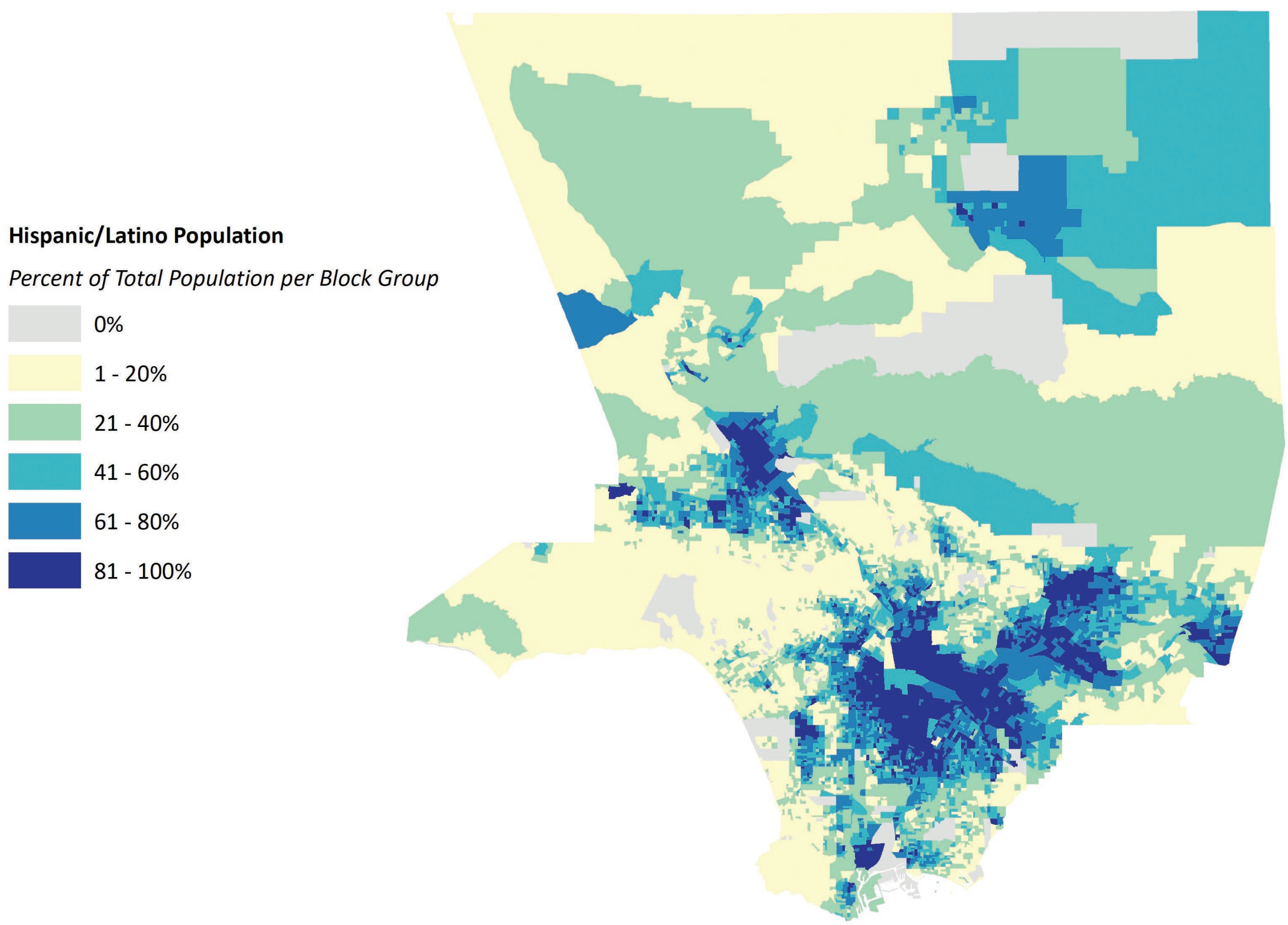

Figure 1.5. Percent of the total population per block group identifying as Hispanic or Latino.

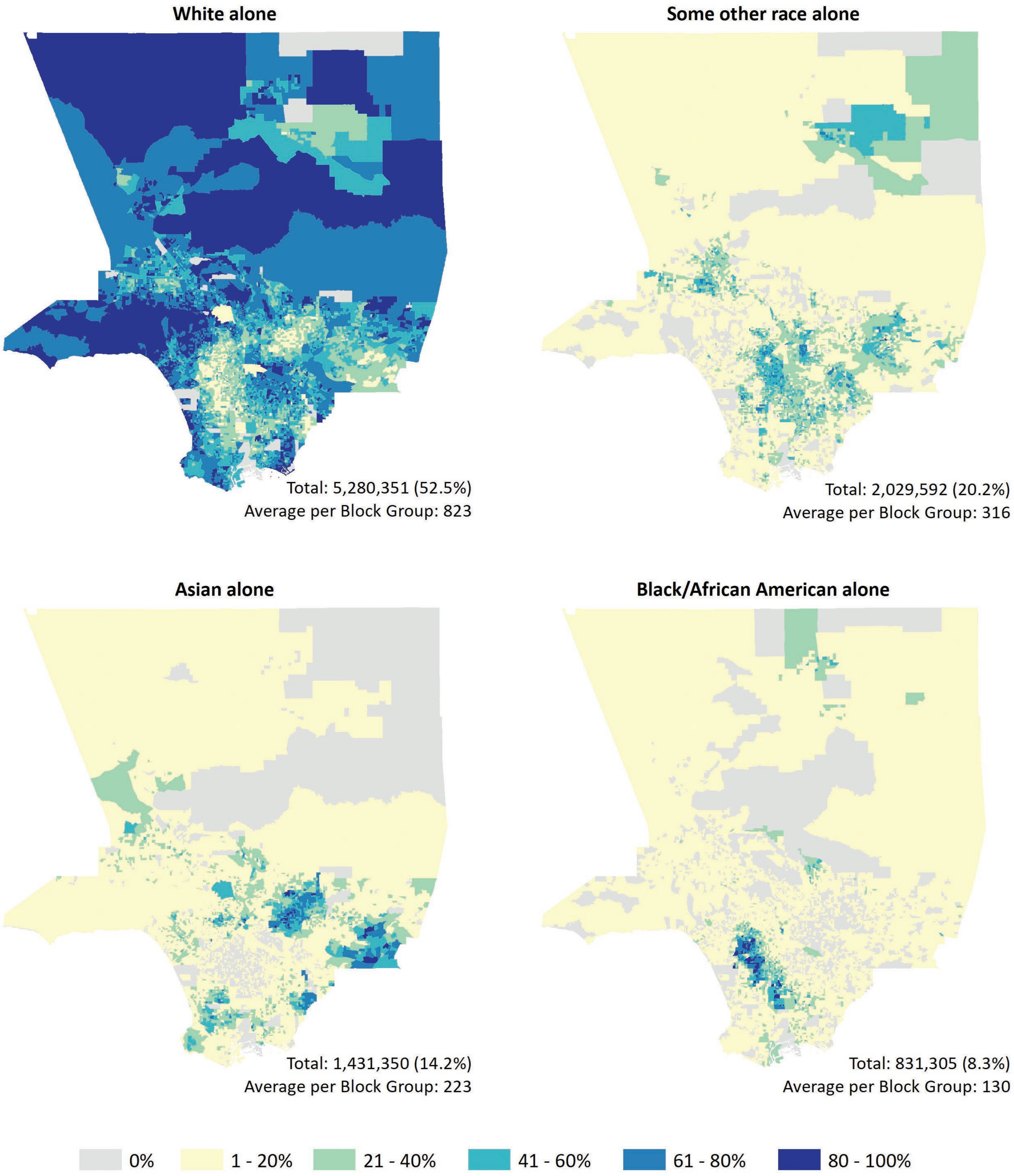

Figure 1.6. Percent of total population by race per block group.

an average of 33.3% of each block group's population was foreign born (USCB 2016). Slightly over half of the population (52.5%) identified as white alone, with an average of 823 white alone persons per block group (SD of 546.0). An average of 14.2% identified as Asian alone, 8.3% identified as Black or African American alone, and less than 1.0% identified as American Indian/Alaskan Native alone or native Hawaiian/other Pacific Islander alone (0.6% and 0.3%, respectively). Roughly one fifth of the population (20.2%), however, identified as some other race alone, and as seen in Figure 1.6, this percent is primarily distributed throughout the southern region of L.A. County. For those claiming multiple racial identities, 3.9% of the population identified as two or more races, with white and Asian as the most common combination (1.0%). A very small subset of the population identified as three or four races (0.3% and 0.03%, respectively) (USCB 2016).

1.1.3.2 Homelessness Profile

Since 2010 there has been an overall trend of increasing incidence of individuals and families who are homeless in L.A. County. According to the 2019 Greater Los Angeles Homeless Count, 58,936 persons in the County experienced homelessness on any given night (Figure 1.7). This represents a 12% increase from the 2018 count and a 34% increase since 2010.

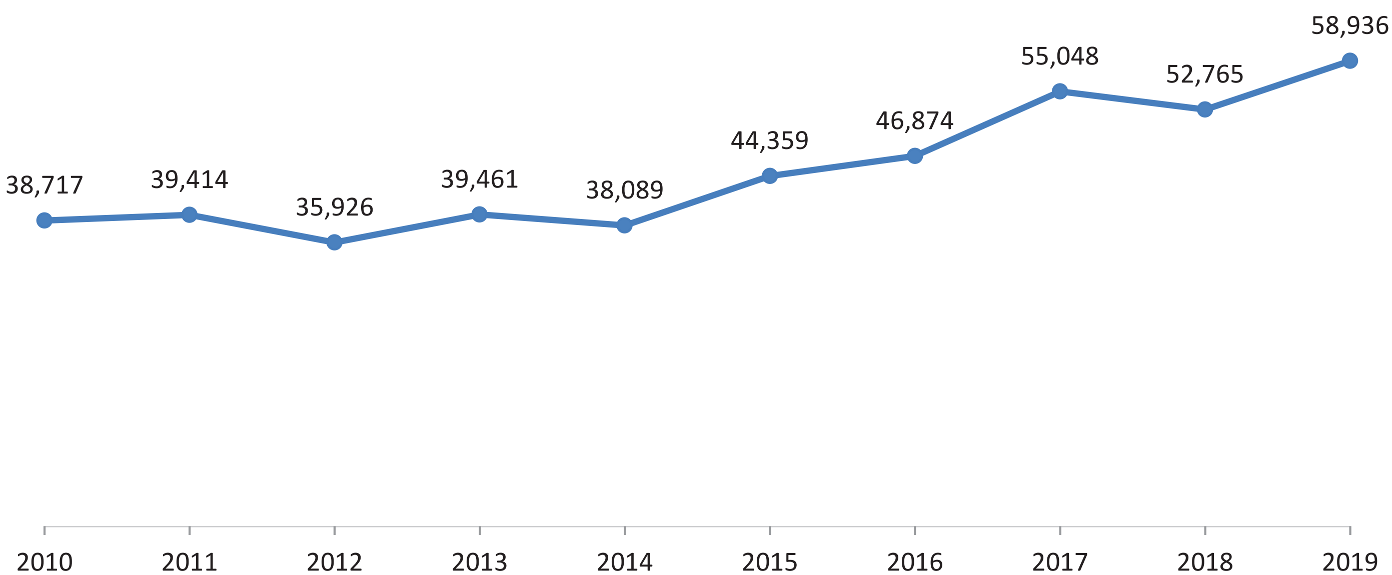

Figure 1.7. L.A. County total homeless population (2010-2019).

The majority of individuals experiencing homelessness were identified as male (67%) and Hispanic/Latino (48%). Veterans represented 7% of individuals experiencing homelessness in L.A. County in 2019, which is a slight decrease from previous years; this could be attributed to programs specifically targeted to assist veterans in need. Many individuals experiencing homelessness also experienced one or more of the following: lifetime experience with domestic/intimate partner violence (5%), chronic homelessness (27%), mental illness (23%), and substance use disorder (13%) (LAHSA 2019).

Of those individuals who experienced homelessness in 2019, it is estimated that only 25% (14,722) of that population was sheltered (75% unsheltered) through the use of cars, vans, recreational vehicles, campers, tents, and makeshift shelters. Figure 1.8 shows the total sheltered and unsheltered individuals experiencing homelessness per Service Planning Area (SPA) across the County. Nearly 15% (8,799) of the population experiencing homelessness lived within family units, and the majority of those individuals were sheltered (7,111); family units included 5,214 children whom were either sheltered (4,322) or unsheltered (892) (LAHSA 2019). The majority of individuals experiencing homelessness in 2019 were located in the Metro, South L.A., and San Fernando SPAs.

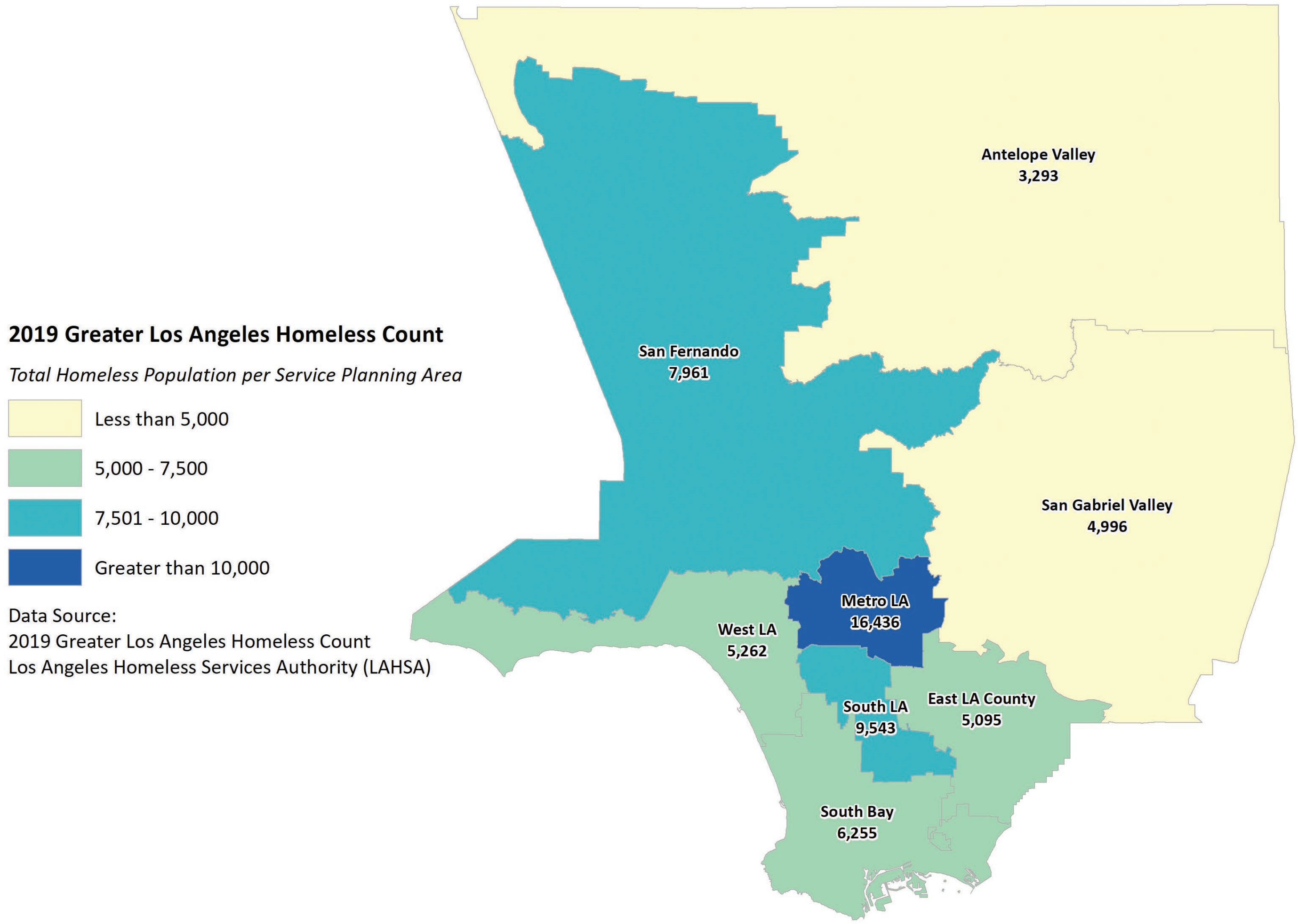

Figure 1.8. L.A. County total sheltered and unsheltered homeless population per Service Planning Area.

1.1.4 Structural Profile

L.A. County is well-known for its sprawling suburbs and requisite wide highways to get people from place to place. Yet, the County as a whole has a wide diversity of built infrastructure, from a dense urban core to open fields of almond groves and forested land. The City of L.A. partners with the Department of Homeland Security to run a program called Operation Archangel to identify the critical infrastructure and key resources in the City and make suggestions for ways to make those assets more resilient (LAPD 2018). The State of California also maintains designated disaster routes in case emergency personnel or equipment must be brought into an area of the City. These routes receive priority maintenance and repair. The L.A. County Department of Public Works notes that these are not the same as evacuation routes, but may be secondarily used during instances of tsunami, earthquake, or wildfire (LACPW 2018).

Two of the biggest vulnerabilities in the infrastructure of the County are water supply and power. The fight over water rights has a long history dating back to the City's founding, referred to as the California Water Wars. The solution to bringing water to the County's desert ecosystem involves a massive system of channelized rivers and aqueducts delivering water from other watersheds, including the Colorado River, and tapping fossil groundwater (LACWD 2018). Recent megadrought across California has strained the water transfer arrangements that support the County's water supply as water-donating regions have requested to keep their water in a time of greater need (Sahagun 2017). A recent study by the University of California, Los Angeles assessed the feasibility of the City (and portions of the County) becoming water independent. This study found that, with conservation measures and water recycling efforts, independence is possible, but would be difficult and potentially expensive (Mika et al. 2018). Similarly, decades of hot and dry weather have strained the County's power system to the point that on high-heat (and therefore high air conditioning) days, brownouts and outages are becoming more common (Fischbach 2018). Both the power and water system need updating for increased capacity and maintenance to ensure consistent delivery.

1.2 PROJECT BACKGROUND

The primary goal of the present study was to examine complexities across L.A. County to indicate areas of overlapping vulnerability and risk to inform decision making within the region. In this research, vulnerability is defined as the susceptibility of resources, infrastructure, and populations to be adversely impacted by environmental hazards or variables. Risk is defined as a coastal or climate-driven hazard that has the potential to cause damage to, or result in the loss of, coastal resources, built environments, and coastal populations. Additional coastal analyses provide deeper understanding beyond the initial intersections of vulnerability and risk.

A secondary goal of this project was to continue NCCOS's vulnerability assessment portfolio through expansion of the Integrated Vulnerability Assessment Framework (Framework). The Framework was developed for the Town of Oxford and Talbot County, Maryland (Messick and Dillard 2016), and was then extended to the Choptank Habitat Focus Area in Maryland and Delaware (Fleming et al. 2017). In all applications, the Framework incorporates partner and stakeholder engagement to identify risks and vulnerabilities of most concern.

To meet the project goals, the research team implemented the NCCOS Framework at multiple geographies within L.A. County beginning with a county-wide assessment. The Framework is summarized below:

1. Engage local partners and stakeholders to identify aspects of vulnerability and climate-driven risk within the study area
2. Develop indicators and indices for each vulnerability and risk
3. Assess social vulnerability, structural vulnerability, and natural resource vulnerability within the study area
4. Assess risks within the study area
5. Intersect vulnerability and risk profiles
6. Engage local partners and stakeholders for prioritization of adaptation areas and next steps to mitigate climate-driven impacts[9]

In addition to implementing the Framework, the project team synthesized information gaps identified through a regional gap analysis (see section 1.2.2), feedback from local partners and stakeholders (see section 1.2.3), and expert knowledge to conduct additional coastal analyses. Coastal analyses included exploration of National Flood Insurance Program (NFIP) claims, access to green space, access to cultural/historic space, impacts of erosion and flooding on critical infrastructure, and the relationship between erosion and blufftop development.

1.2.1 Vulnerability Assessments

Integrated vulnerability assessments at the community or regional level can be implemented in order to understand and more easily compare populations, economies, and the built and natural environment alongside climate-driven risks. A variety of ecological, social, economic, and structural indicators are critical to understanding the potential impacts of climate and coastal risks on coastal communities. Vulnerability assessments may use existing indicators of vulnerability, such as the Social Vulnerability Index (SoVI), an index that uses factor analysis to organize and reduce explanatory variables that are known to contribute to social vulnerability in regard to environmental hazards (Cutter, Boruff, and Shirley 2003), in addition to new approaches to indicator development as applied to coastal communities (Fleming et al. 2017; Messick and Dillard 2016; Dillard et al. 2013; Jepson and Colburn 2013).

This project built upon a range of NOAA methods and products (e.g., OCM's Digital Coast, National Marine Fisheries Service's Social Indicators, NCCOS's Community Well-being Indicators, NCCOS's Biogeographic Assessment Framework, and previous iterations of NCCOS's Integrated Vulnerability Assessment Framework), in concert with regional data and literature, expert opinion, and partner and stakeholder engagement.

[9] While step six is initiated by the research team, it is often implemented by local partners and managers.

1.2.2 Partner and Stakeholder Engagement

In October 2017, the research team initiated step 1 of the Framework (Engage local partners to identify aspects of vulnerability and risk) by holding a prioritization ranking exercise with project partners (colleagues from USC Sea Grant and NOAA's OCM) and local stakeholders (USC Sea Grant's regional partners). This interactive exercise encouraged partners and stakeholders to prioritize vulnerabilities and risks of most concern within L.A. County, and compare variations of these rankings. This exercise also asked partners and stakeholders to prioritize economic themes or analyses of interest, as well as a geographic mapping component, in which participants identified particular geographies of interest or concern. Please see Appendix A for a detailed description of the exercise. Findings from the exercise were used to inform decisions throughout the course of the project, including vulnerability and risk selections, assessment geographies, bivariate combinations, and thematic areas of interest for additional coastal analyses. The team regularly engaged with partners throughout the Framework steps and made project modifications where appropriate.

In June 2019, the research team presented preliminary assessment findings and coastal analysis results to partners and local stakeholders as a series of maps. To accompany the review of preliminary findings, the team led a second geographic mapping exercise to reassess partner and stakeholder geographies of interest. These areas supplemented the geographies identified in 2017, and informed final products. Recognizing the large number of possible vulnerability and risk combinations on which to focus, the team also led a SNAP exercise[10] in order to help partners and stakeholders identify combinations of risks and vulnerabilities of most interest. These results helped inform the information presented in Chapter 4. The SNAP exercise also asked partners and stakeholders to consider the drivers of their prioritized vulnerability and risk combinations, and these findings led to additional thematic areas and analysis. Please see Appendix B for a detailed description of the 2019 exercise.

1.2.3 Regional Gap Analysis

In concert with partner and stakeholder engagement, researchers conducted a regional gap analysis to enhance understanding of existing vulnerability research within the L.A. region. This information also helped inform additional geographies that could benefit from implementation of the Framework as well as gaps in existing coastal research (see section 2.4 and Chapter 3). The project team collected literature from local partners and used a keyword search on "Los Angeles" and "vulnerability" through Google Scholar and university library databases. Studies that directly addressed or overlapped L.A. County at some scale were included as long as they explicitly addressed L.A. (County or City). In all, the team reviewed 27 studies, and identified existing research gaps.

1.2.3.1 Gaps Identified

One of the motivating factors for this study was an interest in exploring vulnerability to climate-driven risks at a finer spatial scale, such as for a community or neighborhood. The literature review confirmed that only two studies parsed vulnerabilities to acute hazards specifically at the community scale below the Census Tract level. The first study investigated the relationship between vegetation, elevation, and socioeconomic status at the City block scale in order to make predictions about climate preparedness (Tayyebi and Jenerette 2016). The second tested the hypothesis that building regulations structured the social vulnerability of the City, but found that distance to amenities such as parks was more strongly correlated with the spatial distribution of social vulnerabilities (Toké et al. 2014). Other studies occurred at the Census Tract level, which in some instances could be considered the community level due to population density, but in other instances may combine multiple self-identified communities into a single unit. Due to data limitations and privacy concerns, the community scale of work is difficult when considering complex, interacting risks, and these studies form a foundation for the intersection of vulnerabilities across multiple types of risk.

Existing studies also showed a temporal scale gap. One study (Cutter and Finch 2008) identified the gap, and investigated social vulnerability over time by comparing SoVI values calculated via the 1960-2010

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[10]This technique was introduced to the project team by University of Maryland Center for Environmental Science (UMCES) colleagues at a 2019 status report development workshop. More information on SNAP can be found on their blog post: http://ian.umces.edu/blog/2017/12/04/sharing-tools-for-stakeholder-engagement-and-collaboration-at-the-chesapeake-watershed-forum/

Los Angeles urban sprawl. Credit: Chloe Fleming, NOAA-CSS

decennial Censuses; however, more could be done in this area. In addition, no other studies looked at natural or structural vulnerability over time to see how the changes in social vulnerability might correlate with other types of vulnerability. The common approach of taking a snapshot of vulnerabilities at a given time also fails to capture how quickly vulnerabilities might be changing, which might miss some rapidly growing vulnerabilities when prioritizing greatest need.

Overall, most of the literature described independent case studies highlighting a single risk (i.e., coastal flooding or earthquakes) and how that risk impacted the vulnerability of segments of the Los Angeles or California population. A couple of studies sought to prioritize these types of risk through qualitative methods (Schubel et al. 2015; Pacific Institute 2012; Union of Concerned Scientists 2012). None of the studies looked at the interactions among risks (e.g., considering fire risk and flood risk simultaneously). Media reports suggest that heavy rains followed by drought leave abundant fuel for wildfire, for example, and that risks are linked in time and space (e.g., Serna 2015).

Finally, only the studies concerned with extreme acute risks (earthquakes and tsunamis) validated their models of vulnerability after an actual event, largely by measuring economic impact in the direct aftermath of the event (Noriega and Ludwig 2012; Rose and Lim 2002). While these studies are helpful, they do not represent the majority of risks that are slow-moving, such as rising seas and changing precipitation. These slow-moving risks do not have a distinct 'before' and 'after' that can be tested in the form of a natural experiment, but when these risks are coupled with an extreme acute event (e.g., a winter storm coupled with high tides and run-up), it may be possible to partially quantify their potential impact. Additionally, long-term trend studies could help address these concerns (following the discussion of the temporal analysis gap above), as could validation studies after impactful acute events occur.

1.2.3.2 Prioritization of Risks

A few studies ranked the risks of greatest concern to Los Angeles in the coming decades. The Pacific Institute (2012) named extreme heat, wildfire, coastal flooding from sea level rise, and air quality as the top four climate-related risks for the L.A. region. Similarly, Schubel et al. (2015) named drought, extreme heat, sea level rise and coastal flooding, deteriorating air quality, and public health/social vulnerability as the top five climate-related risks for the City of Long Beach. Finally, the Spanger-Siegfried et al. (2017) listed extreme heat, air pollution, water shortages, electricity disruptions, and sea level rise as the L.A. region's biggest risks.

These high-priority risks match closely with what local partners and stakeholders identified in early NCCOS scoping work specific to this project (see section 1.2.2). Partners drafted a conceptual diagram of how the diverse risks are connected, while stressing that risks should not be considered holistically in order to understand the intersections and dynamics amongst combined or jointly occurring risks. Understanding impacts of multiple stressors is made challenging by the fact that there is a different set of expertise associated with each type of risk. For example, NOAA's expertise and jurisdiction corresponds with oceans and weather, but has no grounding in earthquakes. This makes a comprehensive risk profile almost impossible – but, there is room for integration and a higher-level view than what exists in the scientific literature already.

1.2.3.3 Commonly Suggested Metrics

The project team also compared common vulnerability themes within the literature to results from the project's initial partner and stakeholder engagement exercises (see section 1.2.2), which identified vulnerability themes and coastal hazards or risks of highest interest to local partners. The majority of the literature included social vulnerability assessments with common themes of well-being (economics, health, access to services, etc.), displacement, exposure to coastal hazards, social/environmental justice, and human health impacts. These themes align with the top ranked prioritizations identified by local partners and stakeholders (see section 1.2.2). Although ranked lower by partners, fewer studies focused on social cohesion, and no studies were found that assessed coastal public access or gentrification within a social vulnerability context.

Structural vulnerability was also a common element found within the literature. City or County infrastructure, residential properties or structures, and commercial properties or structures were common variables in assessing structural vulnerability to hazards and risks. These align with local partners' top ranked prioritizations. Very few studies considered variables of culturally significant places or insurance coverage, yet some authors noted the need to consider insurance coverage as an indicator of vulnerability from an economic and well-being perspective (Noriega and Ludwig 2012; Rodrigue 1993). A significant gap in the literature and of relevance to the L.A. region is the vulnerability of port services or delivery of goods.

Compared to social and structural vulnerability, natural resource vulnerability was a less common element assessed within this collection of literature. The studies that did incorporate a natural resource component were primarily focused on climate change and sea level rise (Grifman et al. 2016; Noble Consultants 2016; Schubel et al. 2015; Arkema et al. 2013; English et al. 2013; Grifman et al. 2013; Pacific Institute 2012). Green space preservation, shoreline vulnerability, wetlands, and the reduction of flood risk were common themes. The L.A. River and other named water bodies were not specifically mentioned.

The most common hazards or risks found in the literature included sea level rise, coastal flooding, wildfire, heat, earthquakes, and air quality. These aligned closely with local partner and stakeholder concerns, although partners were quick to emphasize the interconnectedness of these risks while the literature addressed them one at a time.

1.2.3.4 Identified Next Steps

Most (17) of the vulnerability studies identified through this review identified next steps for research needs. Almost all of the studies had research suggestions particular to their risk of interest and case study population that followed directly from their research results. Those that were more general support our assessment of the gaps in the literature. The most common calls for further research were to investigate at smaller scales (i.e., local or community levels) (5), to include multiple types of vulnerabilities in the analysis (5), and to incorporate social factors into the vulnerability framework (3). Other suggestions that only appeared once included validation of predictions made through vulnerability analysis, incorporation of institutional challenges and limits in responding to vulnerabilities, and the addition of risk assessments or adaptation plans following assessment.

Pedestrian walkway along Los Angeles River. Credit: Chloe Fleming, NOAA-CSS

Chapter 2: Assessment Methods – Implementation of the Framework

As described in Chapter 1, this project utilized an integrated approach to assess vulnerability via the NCCOS Framework. The methodology involved capturing and defining the region's climate and coastal risks of most relevance, followed by data collection and analysis. All data used in this assessment were secondary data. Analyses included indicator development and examination of vulnerability and risk for Census block groups within L.A. County (Figure 2.1). Due to the scale of the study area, block groups rather than blocks were used. The L.A. port complex and block groups with null Census data were removed, for a total of 6,416 remaining block groups. The research team assessed vulnerabilities individually, assessed risks individually, combined select risks, and finally, intersected and assessed integrated vulnerabilities with risks in order to prioritize areas of interest.

2.1 IDENTIFYING RISKS OF MOST CONCERN

In this research, risk is defined as a coastal or climate-driven hazard that has the potential to cause damage to, or result in the loss of, coastal resources, built environments, and coastal populations. In previous iterations of the Framework, researchers and stakeholders placed a strong emphasis on flood risks (Fleming et al. 2017; Messick and Dillard 2016); however, due to the climatic variability of L.A., partners identified a wider range of potential risks to consider. Drawing upon feedback derived from the prioritization ranking exercise, findings from the team's gap analysis, and expert opinion, the project team focused on the following suite of climate-driven risks: coastal flooding, stormwater flooding, erosion, drought, heat, and wildfire.

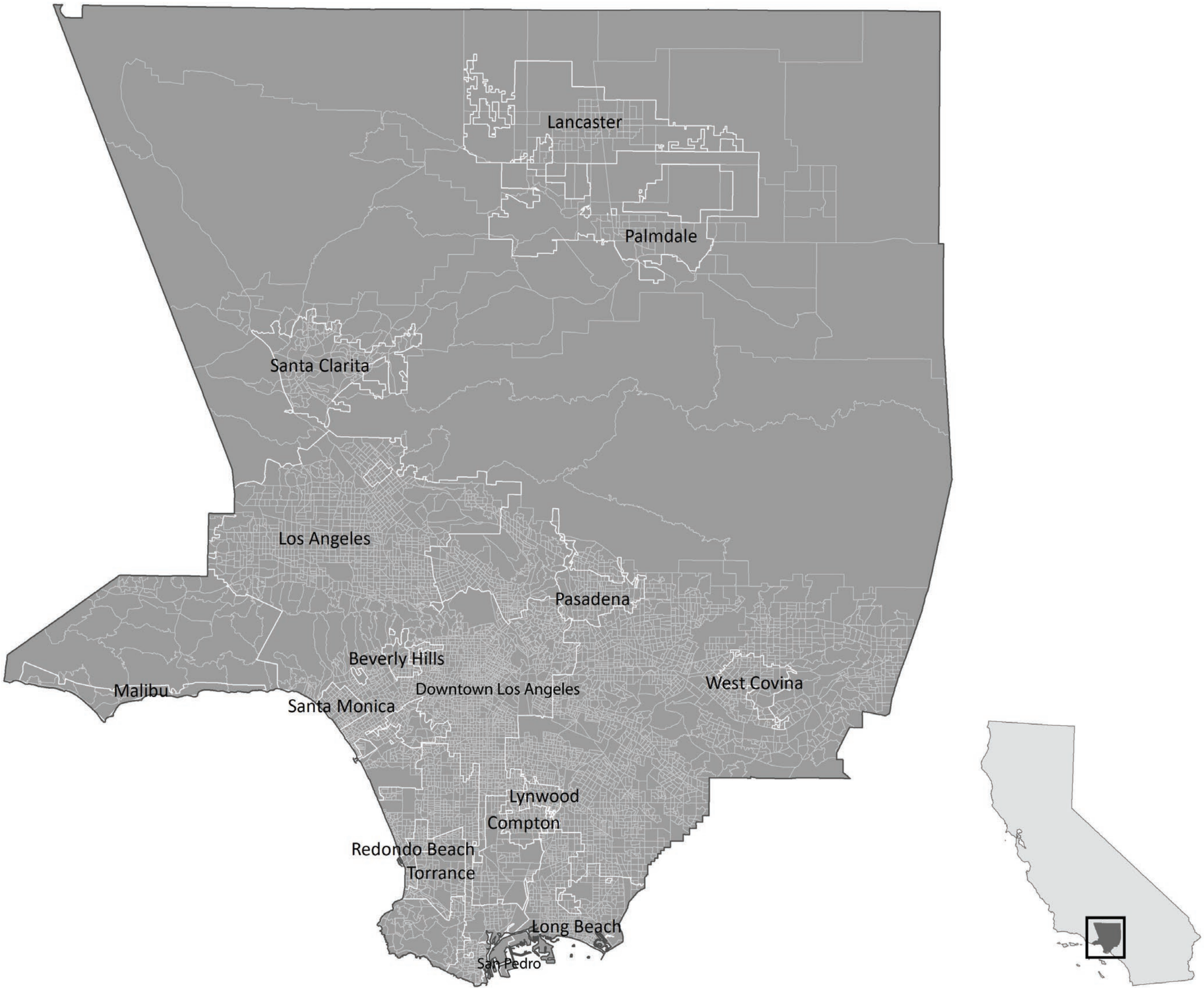

Figure 2.1. L.A. County assessment geography.

2.2 INDICATOR SELECTION AND DEVELOPMENT

This study utilized a "vulnerability of places" framework (e.g., Cutter et al. 2009; Cutter 2008) to examine social, structural, and environmental vulnerability to climate variability and impacts. Implementing step two of the Framework (Develop indicators and indices for each vulnerability and risk), each vulnerability and risk profile was created through the use of indicators or components. As described in Chapter 1, this research defines vulnerability as the susceptibility of resources, infrastructure, and populations to be adversely impacted by environmental hazards or variables. Similar to the method used by Wu et al. (2002), indices of social vulnerability, structural vulnerability, and natural resource vulnerability were employed alongside indices of risk.

Each vulnerability and risk index used current secondary data. Tabular and spatial data were collected from a range of sources, and then cleaned and processed by the research team. All spatial data were projected to NAD 1983 UTM Zone 11N and clipped to the L.A. County boundary (excluding Santa Catalina and San Clemente Islands). As a result, vulnerability and risk profiles do not include marine resources or interests. Each section below briefly discusses data usage, but please see Appendix C for detailed tables on all assessment variable data sources.

Each vulnerability and risk profile was then measured relative to other block groups within the study area. After indicator and index development, the team initiated steps three and four of the Framework (Assess social, structural, and natural resource vulnerability; Assess risk).

2.2.1 Social Vulnerability

To assess social vulnerability in the event of a climate-driven risk, this assessment utilized a modified SoVI methodology (Cutter, Boruff, and Shirley 2003). This approach includes a principal components analysis (PCA) on a suite of secondary data that the academic literature suggests contribute to vulnerability in the event of an environmental hazard.[11] SoVI is generally calculated at the county scale and includes 29 variables in the latest iteration, SoVI 2010-14. The data sources for SoVI 2010-14 are the 2010 U.S. Decennial Census and the 2010-2014 ACS 5-Year Estimates (HVRI 2016). In this analysis, the variables were modified due to the change of scale from county to Census block group, and all data were derived from the 2012-2016 ACS 5-Year Estimates (USCB 2016). PCA was used to determine the factors and variables to include in the final index, and each variable was standardized using z-scores before running the PCA. The PCA analysis used a Varimax rotation with 25 iterations and a required factor loading of at least 0.50. Cross-loading variables were removed, with the exception of inverse cross-loadings.[12] The Kaiser-Meyer-Olkin Measure of Sampling Adequacy was .902, and the Bartlett's Test of Sphericity was significant ($p \leq 0.001$), indicating that the data were suitable for factor analysis and there was sufficient sampling adequacy. Number of factors was determined using a combination of the Kaiser Criterion and Cattell's Scree Plot (Costello and Osborne 2005; Fabrigar et al. 1999).

The final social vulnerability index was comprised of 26 variables and resulted in seven factors, labeled Factors 1 through 7.[13] These factors collectively explained 68.16% of the variance in the total variability among data for the blocks groups within L.A. County. Table 2.1 shows the variables and factors that explained the majority of variance in the data (Suhr 2006; Tabachnick and Fidell 2001). For example, Factor 1 explained more variance than the other factors alone, but together these seven components provided a better measurement of social vulnerability for L.A. County.[14]

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[11]PCA is a variable reduction technique that is frequently used in indicator and index development. It is designed to reduce the number of variables to the smallest number of key components that explain the most variance in the data (Thompson 2008).

[12]These decisions were informed by existing literature (Cutter et al. 2003; Costello and Osborne 2005; Cutter and Emrich 2017) and team expertise.

[13]Cutter and Emrich (2017) recommend naming the factors, and while this practice was applied in previous iterations of the NCCOS Framework (Fleming et al. 2017; Messick and Dillard 2016), partners in the L.A. application cautioned against naming to avoid oversimplification and misunderstanding by local stakeholders and decision makers.

[14]Some variables contribute to multiple factors, but inversely. For example, median income loads positively on Factor 1, but negatively on Factor 3.

The resulting factors are shown spatially in Figure 2.2. The factors were adjusted for directionality and placed in an equal-weighted additive model to achieve a single social vulnerability index score.[15] The social vulnerability index score for each Census block group is presented as a relative score using min-max normalization,[16] such that block groups closer to 'high' (value of 1) are more socially vulnerable compared to other block groups within the study area.

2.2.2 Structural Vulnerability

Five components, determined through stakeholder engagement and suggestions from the literature in the gap analysis, contributed to the structural vulnerability index. These components included 1) parcel age, 2) disaster routes, 3) improvement value, 4) critical infrastructure, and 5) historic places.

Parcel age was depicted at the block group level, and was incorporated into the overall index as the percentage of parcels in the block group with an effective build date before 1978. Building codes in California were substantially re-written in 1978 primarily to update earthquake standards, so this date serves as a significant cutoff for vulnerability. Effective build dates were derived from county-wide parcel data from the L.A. County Geoportal (County of Los Angeles 2016).

Disaster routes included freeway, highway, or arterial routes pre-identified by the L.A. County Department of Public Works for use in emergencies. The component factor was created by calculating the mileage of disaster routes in a block group normalized to the land area of the block group. Data were derived from the County's Disaster Route layer (LACDPW 2015).

Table 2.1. PCA findings for L.A. County.

Factor Name	Cardinality*	% Variance Explained	Variables	Loading
Factor 1	+	29.76	% population in poverty	0.796
			% households without a vehicle	0.700
			% households receiving SNAP benefits	0.661
			% rented housing units	0.561
			% population unemployed	0.550
			Median rent	-0.544
			Median income	-0.579
Factor 2	+	10.65	% rented housing units	-0.507
			% households with occu-pants over age 60	0.884
			% households receiving social security	0.878
			% population over age 65	0.798
			% population in labor force	-0.696
			Median age	0.636
Factor 3	-	8.56	Median housing value	0.820
			% households with income over $200,000	0.804
			Per capita income	0.762
			Median income	0.614
Factor 4		6.30	Average household size	0.878
			% family households	0.858
			% population without high school diploma	0.503
			% population under age 5	0.502
Factor 5		5.11	% foreign born	0.867
			% population with limited English proficiency	0.818
			% population without health insurance	0.514
Factor 6		4.37	% female	0.871
			% females in labor force	0.847
Factor 7		3.39	% population in extractive employment sector	0.721
			% mobile homes	0.628

*Positive = the factor contributes to vulnerability; Negative = the factor contributes to vulnerability inversely.

[15]The authors explored implementing a variance-explained weighted additive index, but literature suggests equal weighting as the acceptable practice (Cutter and Emrich 2017).

[16]Min-max normalization scaling is when the normalized value of xi for variable X in the i-th row is calculated as: Normalized (xi) = xi – Xmin / (Xmax – Xmin), where Xmin = the minimum value for variable X, and Xmax = the maximum value for variable X (Salzman 2003).

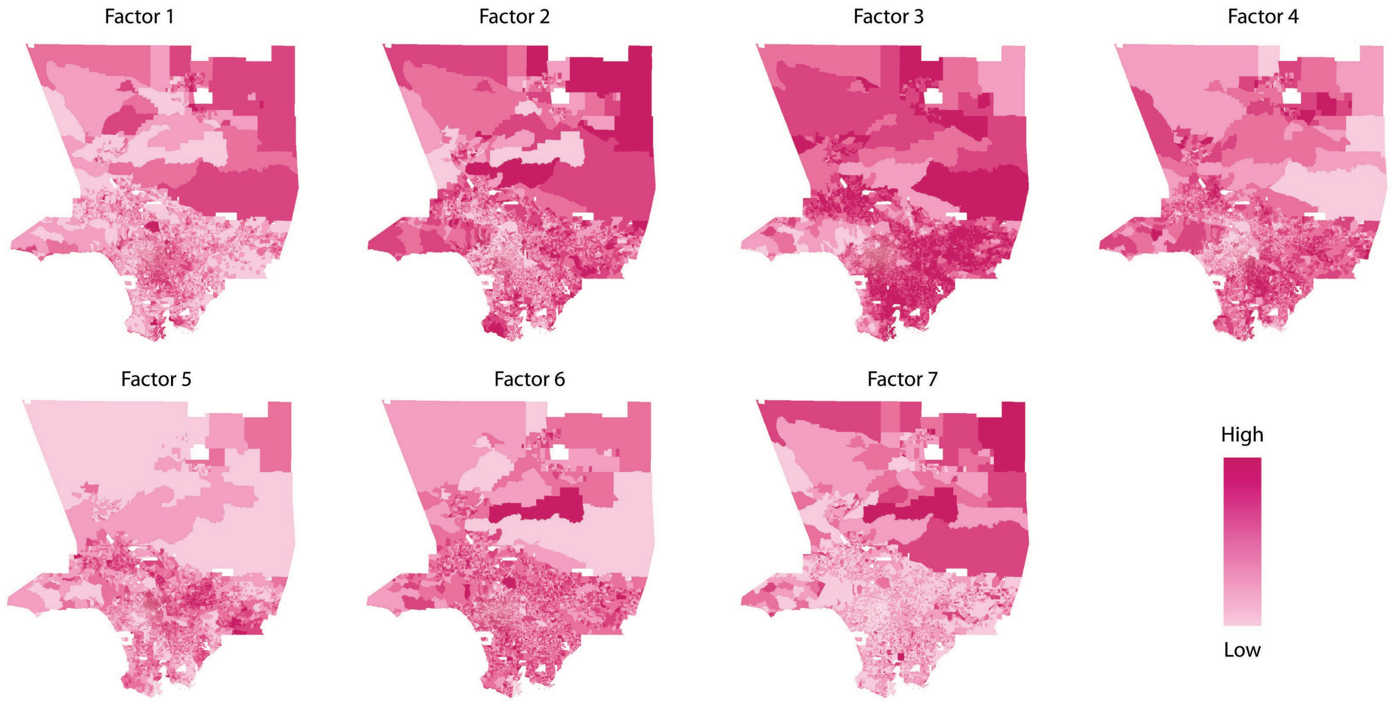

Figure 2.2. Components contributing to social vulnerability.

Improvement value represents the value of the built structures on a piece of land. It was calculated as a component by determining the sum of the improvement values for each building in each block group, and normalized as a percentage of the maximum block group value. Improvement values per building were provided by L.A. Region Imagery Acquisition Consortium (version 4) data (LARIAC 2014).

The critical infrastructure component was a location count per block group of facilities considered critical to the functioning of a city according to the Department of Homeland Security: power plants, wastewater treatment facilities, dams and reservoirs, police and fire stations, emergency services, educational facilities, and hospitals. The data were a subset of the County's Points of Interest layer (Grenninger 2017).

The historic places component was a location count per block group of places registered with the National Register of Historic Places (as of 2017) (NPS 2017). Historic districts represented by a polygon in the Register's geospatial database were counted at the centroid of the polygon. The Register is a national dataset that does not incorporate all locally-acknowledged places of historical significance, as evidenced by the larger but unfinished-at-the-time-of-analysis database collected by the Los Angeles Conservancy (2019), making it a conservative estimate of historic resources in the County.

The five structural components are shown in Figure 2.3. They were combined in an additive index, where each variable was equally weighted and normalized to a coordinated scale of 0-1. The final score was normalized to fit a 'low to high' (0-1) range, with block groups closer to 'high' (value of 1) being more structurally vulnerable.

2.2.3 Natural Resource Vulnerability

The natural resource vulnerability analysis used a modified landscape ecology approach that incorporated lessons from urban ecology. Urban ecology focuses attention on ecosystem services in order to highlight the most important parts of complex ecosystem dynamics in a severely anthropogenically altered landscape. Conversely, while an increasing number of urban ecology scholars are turning to the Singapore Index on Cities' Biodiversity (Singapore National Parks 2015) as a metric of natural resources in a city, the Singapore Index has extremely high data demands not feasible for L.A., especially given its desert context. In addition, the species focus of the Singapore Index did not adequately highlight stakeholders' concerns about habitat, so the research team modified the concepts from the Singapore Index into one relevant to L.A. scientific status and stakeholder needs. Habitat concerns are also articulated well in a vulnerability study of coastal

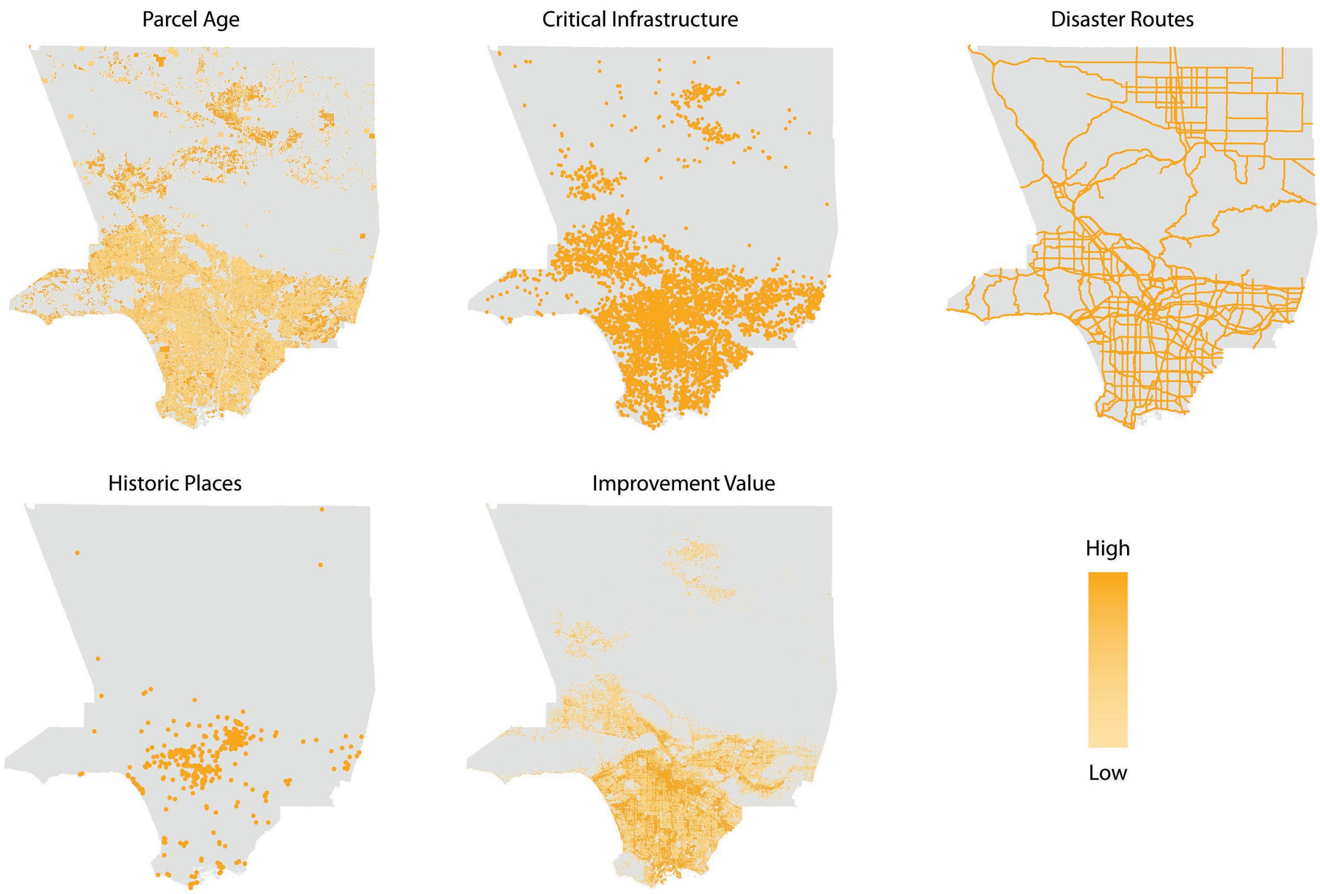

Figure 2.3. Components contributing to structural vulnerability.

habitats, which stressed the importance of both upper beach and estuarine habitat present in L.A. County as refuges of rare habitat along the West Coast (Heady et al. 2018).

The six components that contributed to the final natural resource vulnerability index were: 1) greenness, 2) tree canopy cover, 3) habitat fragmentation, 4) wetland cover, 5) predicted species richness, and 6) significant ecological areas. These components are present throughout the entirety of the study area.[17]

Greenness was derived from the Normalized Difference Vegetation Index (NDVI), calculated by the U.S. Geological Survey (USGS) and found on ESRI Online (USGS 2018a). NDVI represents the absorption of the wavelengths of light that activate chlorophyll, so it is a measure of photosynthetic activity in the landscape that incorporates all flora that photosynthesize (including lawns, gardens, and other urban greenery). Greenness was calculated for each block group by determining the percentage of pixels in each block group with an NDVI value greater than 0.2, representing areas of non-desert vegetative growth.

Tree canopy was part of the National Land Cover Database that uses a Random Forest regression algorithm to estimate the percent of each pixel covered with tree canopy. This layer was created by the United States Forest Service, and the analytical version was used (Coulston et al. 2011).

Habitat fragmentation represents the aggregation level of land cover types that can serve as habitats for mobile species in the region. These land cover types were reclassified from the National Land Cover Database into three broad categories: forest, shrub/scrub, and wetlands. Habitat fragmentation has two critical components – abundance and aggregation – and among the many metrics available to quantify habitat fragmentation, abundance must not be double counted (Jin et al. 2019). Since the natural resource vulnerability index already included a component that is essentially abundance (greenness), the habitat fragmentation component used a metric that is free from autocorrelation with abundance: the clumpiness index (Wang et al. 2014). Clumpiness was calculated for each block group using FRAGSTATS version 4 (McGarigal et al. 2012).

[17]Small scale, coastline-dependent features, such as beaches, had minor influence on analyses.

Wetland cover was incorporated as the percent areal cover of each block group designated as wetland in the National Wetlands Inventory (USFWS 2017). This included all types of wetlands, including riverine freshwater systems.

Predicted species richness is a common measure of biodiversity, which was a value expressed by local stakeholders, and is a simple count of the number of species in a given area (notably, this does not incorporate abundance at all). Species richness was modeled using MaxEnt software[18] that uses biodiversity observations recorded in the Global Biodiversity Information Facility (GBIF) and environmental layers from the Coastal Change Analysis Program, as well as digital elevation model and slope data (GBIF 2017). The environmental layers included were each significant according to a jackknife test; precipitation was not consistently significant and soil type was correlated with land cover, so these were omitted. One quarter (25%) of observations were withheld for testing the model. Nine-hundred and eighty total species had enough observations to be modeled (>5 observations in different locations), and this number was used as the total species count in normalizing the data. Total predicted species richness was calculated by adding the raster results from each species model together. The resulting summary raster was a prediction of the number of species found in each pixel (30m resolution), but because MaxEnt is probabilistic, was not a prediction of exactly which species would be found. In addition, all species included in the GBIF dataset were included, regardless of their status as native, non-native, or invasive, because non-native and invasive species still serve ecological functions in the County. It is difficult to define non-native species as records of introductions extend to the founding of L.A. (if not earlier), and non-native and invasive species contribute to the emergent properties of biodiversity.

Significant ecological areas (SEAs) are areas designated by the L.A. County Department of Regional Planning, and were used as the final natural resource vulnerability index component (LACDRP 2015). They are defined as areas "with irreplaceable biological resources," and the program is designed "to conserve genetic and physical diversity within L.A. County by designating biological resource areas that are capable of sustaining themselves into the future" (LACDRP 2019).

The six natural resource vulnerability components are shown in Figure 2.4. They were combined in an additive index, where each variable was equally weighted. The final score was normalized to fit a 'low to high' (0-1) range, with block groups closer to 'high' (value of 1) being more vulnerable (i.e., having more natural resources present should a risk impact the area).

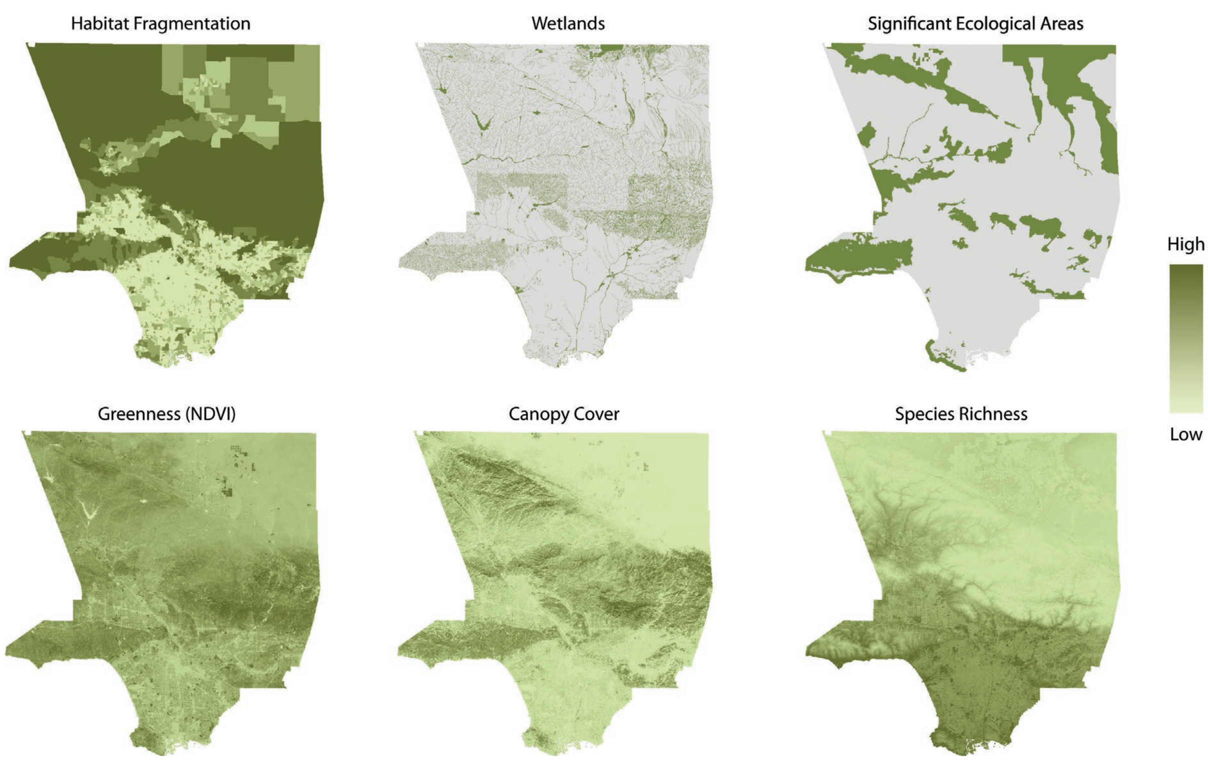

Figure 2.4. Components contributing to natural resource vulnerability.

[18]http://biodiversityinformatics.amnh.org/open_source/maxent/

2.2.4 Coastal Flooding Risk

Three coastal flooding risk scenarios were used to develop three separate coastal flooding risk profiles for L.A. County: near term-low risk, medium term-medium risk, and long term-high risk (Table 2.2). First, time horizons, or terms, were selected for each profile. In consultation with project partners and expert opinion, near term references the year 2040, medium term references the year 2070, and long term references the year 2100 (IPCC 2014b). Second, probabilistic projections for sea level rise height that are based on research by Kopp et al. (2014) and collated in the State of California's 2018 Sea Level Rise Guidance document (CA NRA and CA OPC 2018) were used to determine projected sea level rise estimates for each of the three scenarios. The probabilistic projections incorporate monitoring data from tide gauges along California's coast, including two gauges (Santa Monica and L.A.) within L.A. County. Scenarios were further developed through the consideration of projected emissions levels and risk aversion (also highlighted in the State's 2018 Sea Level Rise Guidance document (CA NRA and CA OPC 2018)). For each chosen scenario, high emissions estimates were used. High emissions refers to the plausible RCP 8.5 scenario, which combines assumptions of high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, and ultimately results in high energy demand and global greenhouse gas emissions in the absence of global climate change policies (Riahi et al. 2011; Kopp et al. 2014). Risk aversion probabilities correspond to each of the chosen coastal flooding profiles. The near term-low risk profile utilized the Low Risk Aversion measure, which is the upper bound of the projected sea level rise likely range (a 66% probability that sea level rise is between x and y cm by year z). The medium term-medium risk profile used the Medium Risk Aversion measure, or the 1-in-20 chance projection (a 5% probability that sea level rise meets or exceeds x cm by year z). Lastly, the long term-high risk profile utilized the High Risk Aversion measure, or the 1-in-200 chance projection (a 0.5% probability that sea level rise meets or exceeds x cm by year z; CA NRA and CA OPC 2018). To finalize sea level rise heights for each profile, projections from Santa Monica and L.A. were compared and best matched to height options for Coastal Storm Modeling System (CoSMoS) models. For these specifics, please refer to Table 2.2.

Table 2.2. Coastal flooding risk scenarios.

Set Risk Scenarios	Term	Risk Aversion	Sea Level Rise Projection (ft)			Storm Event
			Santa Monica	Los Angeles	CoSMoS Option	
Near Term-Low Risk	2040	Low - 67% probability	0.8	0.7	0.8	Annual Storm
Medium Term-Medium Risk	2070	Medium - 5% probability	2.3	2.2	2.5	20 yr Storm
Long Term-High Risk	2100	High - 0.5% probability	6.8	6.7	6.6	100 yr Storm

Once terms and sea level rise projections were selected, storm scenario frequencies were chosen from those offered within the CoSMoS (Barnard et al. 2017). Near term-low risk was paired with an annual storm event, medium term-medium risk was paired with a 20 year storm event, and long term-high risk was paired with a 100 year storm event.[19] After selecting model parameters, the appropriate CoSMoS datasets were used for analysis (see Exhibit 1).

Exhibit 1: Brief explanation of CoSMoS modelling

The CoSMoS makes predictions of storm-induced coastal flooding and erosion for current and future sea level rise scenarios, and is comprised of three tiers. Tier I uses 1) a Delft3D hydrodynamics FLOW grid for computation of tides, water level variations, flows, and currents, and 2) a SWAN grid for computation of wave generation and propagation across the continental shelf. Tier II provides a higher resolution near shore and in bays, harbors, and estuaries through the use of additional FLOW and SWAN modelling. Tier III utilizes XBeach modelling to simulate wave propagation, two-way wave-current interaction, water-level variations, and wave run-up. This final tier accounts for infragravity waves (from which the U.S. west coast is particularly susceptible) that can extend the inland reach of wave run-up when compared to short-wave incident waves (Barnard et al. 2017).

[19]Storm event frequencies are estimates of how long it will be between storms of a certain magnitude. For example, a 20 year storm event is likely to occur once every 20 year period, or alternately, there is a 5% chance that a storm of that magnitude will occur in any given year (OCOF 2018).

Before modelling storm-induced coastal flooding, metrics or scenarios of interest were chosen. Scenarios were identified, and multiple storm events for each scenario (1 year, 20 year, and 100 year storms) at various levels of sea level rise were identified and computed to better account for regional and directional flooding events. Final outputs included projected flood-hazard depth and duration for each storm and sea level rise indicated, whereby data corresponded to "areas vulnerable to coastal flooding due to storm surge, sea level anomalies, tide elevation, and wave run-up" during each simulation (Barnard et al. 2017).

For each scenario, percent inundation per block group was determined, and is depicted in Figure 2.5.The long term-high risk scenario score was normalized to fit a 'low to high' (0-1) range, with block groups closer to 'high' (value of 1) being more at-risk relative to other block groups along the coastline of the study area. This is the only risk profile that is not compared to all block groups in the County. For this reason, the final coastal flooding risk score is later combined with the final stormwater flooding risk score (see section 2.2.5.1).

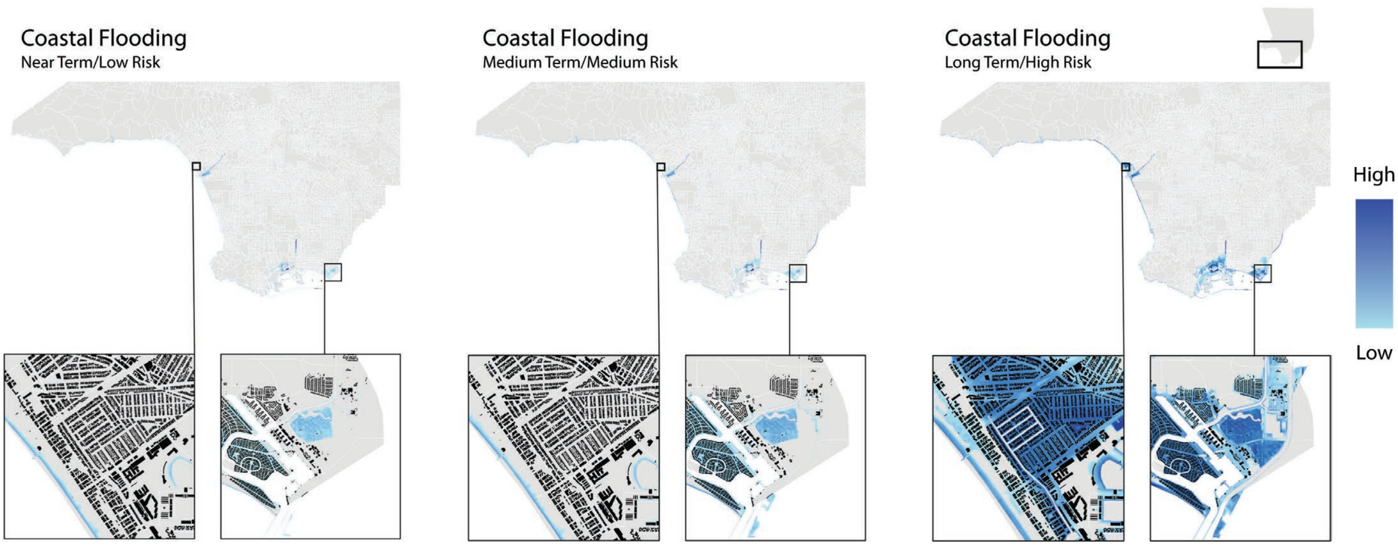

Figure 2.5. Coastal flooding scenarios that contribute to coastal flooding risk.

2.2.5 Stormwater Flooding Risk

To identify areas at risk of stormwater flooding within the County, an index was developed primarily based on the "FIGUSED" methodology used by Kazakis et al. (2015) in the development of the Flood Hazard Index (FHI) for the Rhodope-Evros region in Greece. The "FIGUSED" methodology incorporates seven parameters commonly used to identify areas of high flood risk potential. These parameters include: 1) flow accumulation – "F", 2) rainfall intensity - "I", 3) geology (hydrologic soil groups) - "G", 4) land use – "U", 5) slope - "S", 6) elevation - "E", and 7) distance from the drainage network - "D".

Flow accumulation is a quantitative measure used to delineate a drainage area (Jenson and Domingue 1988). Each grid cell of a digital elevation model (DEM) is assigned a value based on the number of cells identified as flowing into that particular cell. A flow accumulation raster was created for L.A. County by first filling sinks, or imperfections in the data, and then calculating the flow direction of a 10x10 meter resolution USGS DEM in ArcGIS 10.5 (USGS 2016). The resulting flow accumulation raster was then normalized on a scale of 0 to 1, with higher values indicating a drainage area with high flow accumulation or higher risk of flooding.

Rainfall intensity is a measure of the amount of rain which has fallen within a given amount of time, and at peak values can be indicative of a high runoff rate (Conkle et al. 2006). An L.A. County Department of Public Works rainfall intensity dataset representing a 50 year frequency rainfall for 24 hour duration was selected as an input for this parameter (LACDPW 2006). The data was normalized on a scale of 0 to 1 with values of 1 indicating areas more prone to high levels of rainfall intensity and higher risk of flooding.

The geology of a region can also play a major role in assessing flood risk. Hydrologic soil groups defined by the U.S. Department of Agriculture (USDA) are categorizations of soils according to their permeability and runoff potential (USDA NRCS 2018). There are four major hydrologic soil groups (Group A, Group B, Group C, and Group D) and three dual hydrologic groups (A/D, B/D, and C/D). Groups C and D represent soils, such as clays, that have a lower permeability and thus higher runoff potential than that of Groups A and B. Dual groupings are determined based on the presence and depth of the water table, and primarily represent wet soils that may potentially fall within Group D contingent on precipitation conditions. Additionally, some areas are void of a hydrologic soil group assignment. Under further investigation and comparison with land cover data, it was determined that areas void of hydrologic soil group assignments align closely with developed land where the ground is highly impermeable. Using USDA data, areas within the County with the presence of soil hydrologic groups A and B were classified to a value of 0, while areas with groups C, D, A/D, B/D, C/D, and void of data were assigned a value of 1, indicating a higher likelihood of flooding (Table 2.3).

Table 2.3. Hydrologic soil group and reclassified value.

Hydrologic Soil Group	Reclassified Value
No Group	1
Group A	0
Group B	0
Group C	1
Group D	1
Group B/D	1
Group C/D	1

As with geology, land cover type is an important component linked to the infiltration of water and flooding potential. Land cover data developed by the Coastal Change Analysis Program (C-CAP 2010) were reclassified to reflect this variation in land cover types. CCAP data are originally classified into 21 classes ranging from a variety of land use and cover types such as developed, agricultural, vegetated, and bare land or water. CCAP data were reclassified on a scale of 0 to 1 with more flood prone or commonly wet land cover types assigned values closer to 1 and other cover types assigned lower values according to land use type and vegetative cover (Table 2.4).

Table 2.4. Land cover and reclassified value.

Land Cover Type	Reclassified Value
High Intensity Developed	1
Medium Intensity Developed	1
Low Intensity Developed	1
Palustrine Emergent Wetland	1
Palustrine Forested Wetland	1
Palustrine Scrub/Shrub Wetland	1
Estuarine Emergent Wetland	1
Estuarine Forested Wetland	1
Estuarine Scrub/Shrub Wetland	1
Estuarine Aquatic Bed	1
Water	1
Developed Open Space	0.8
Bare Land	0.8
Unconsolidated Shore	0.8
Pasture/Hay	0.6
Cultivated	0.6
Grassland	0.4
Scrub/Shrub	0.2
Deciduous Forest	0.2
Evergreen Forest	0.2
Mixed Forest	0.2

Areas with flatter slopes and low elevations are more likely to experience flooding due to slower drainage from flat land and higher water tables (Fleming et al. 2017). Elevation data were normalized on an inverse scale of 0 to 1, with lower elevations assigned higher values closer to 1, indicating a higher risk of flooding. A slope grid was created from the same USGS DEM data used to derive the elevation and flow accumulation index parameters (USGS 2016). The slope grid was reclassified on an inverse scale of 0 to 1 following the classes defined by Kazakis et al. (2015). Steep slopes, defined as greater than a 35% slope, were reclassified to a value of 0.2, while flatter, more flood prone slopes were reclassified to higher values ranging up to 1 (Table 2.5).

Table 2.5. Degree of slope and reclassified value.

Slope (Degrees)	Slope (Percent)	Reclassified Value
0 - 1.15	0-2	1
1.15 - 2.86	2-5	0.8
2.86 - 8.53	5-15	0.6
8.53 - 19.29	15-35	0.4
19.29 - 81.979	>35	0.2

Kazakis et al. (2015) included distance from a drainage network as an input parameter within their flood index, and noted that the closer to a drainage source the more likely an area will flood. Using National Hydrology Dataset flowline data, a drainage network density grid was created to identify areas with a high prevalence of rivers, streams, and drainage sources (USGS 2018b). The final output was normalized on a scale of 0 to 1, with higher values indicating areas with a higher density of drainage networks and thus risk of flooding.

The seven stormwater flooding risk components are shown in Figure 2.6. These parameters were combined in an additive index, where each variable was equally weighted. The final index values range from 'low to high' (0-7), with higher values indicating areas with a higher risk of flooding.

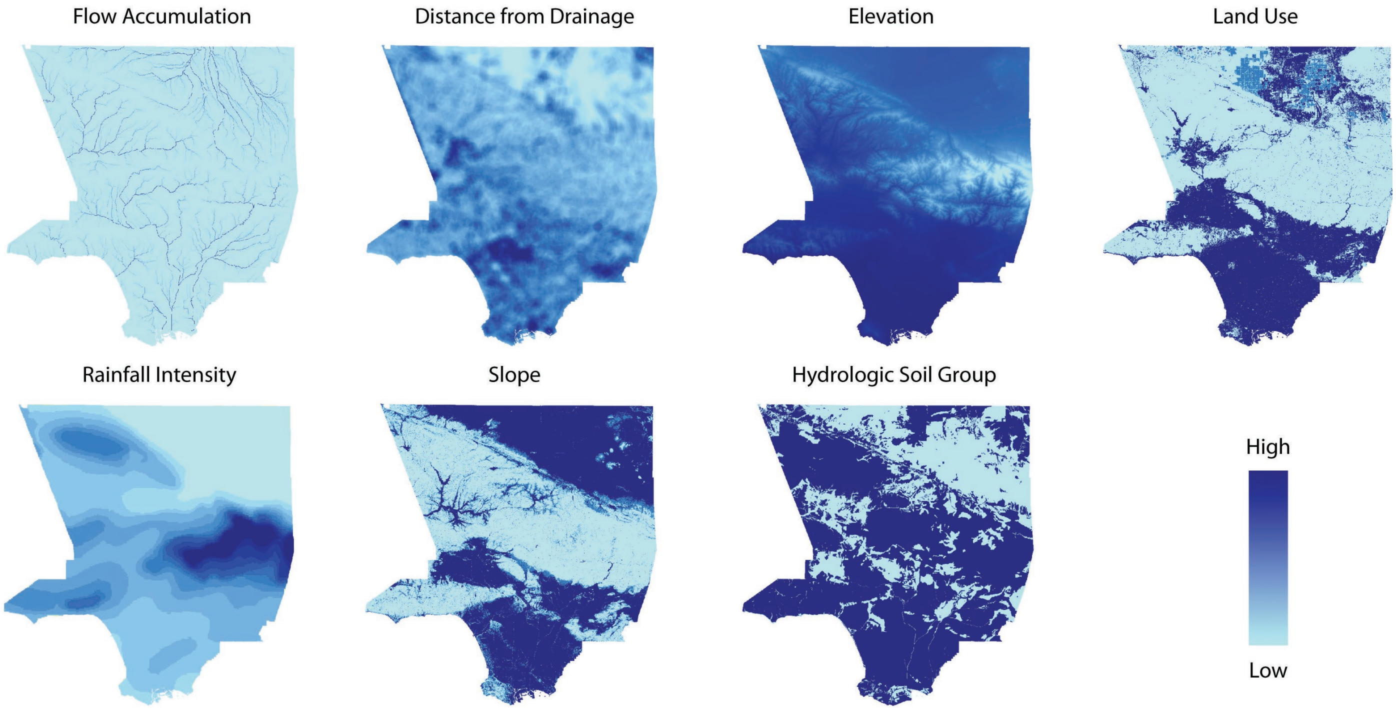

Figure 2.6. Components contributing to stormwater flooding risk.

2.2.5.1 Combined Flooding Risk

Due to the coastal nature of the CoSMoS model and the fact that stormwater flooding modeling used predominately spatial data that occurred over land, partners were interested in looking at the combination of the two models. The final coastal flooding and stormwater risk profiles were combined at the block group level to increase comparability across the study area and to glean a more holistic impression of flooding risk County-wide. By combining outputs from the CoSMoS model with the stormwater flooding model, it is then possible to compare areas at highest overall flooding risk (from these two primary sources) across L.A. County. Combined flooding risk was calculated from an additive index of both models at the block group level, and then re-normalized to 'low to high' (0-1) for comparability.

2.2.6 Erosion Risk

Soil erosion rates are most commonly influenced by water and wind (Breshears et al. 2003). To best approximate water erosion, an erosion hazard dataset that incorporated slope and K Factor was used (USDA NRCS 2017). K Factor is an index used in erosion estimates that quantifies the soil's relative susceptibility to sheet and rill erosion.[20] Soil properties that influence K Factor include texture, organic matter content, structure, and hydrological properties (USDA 2018). Water erosion hazard was combined with wind erosion hazard via the National Soil Survey's Wind Erodibility Index in an additive index to create an overall erosion risk profile for the study area (USDA NRCS 2017).

The two components are shown in Figure 2.7. The final additive index score was normalized to fit a 'low to high' (0-1) range, with block groups closer to 'high' (value of 1) being more at risk.

[20]Sheet erosion results in a thin layer of topsoil being removed universally from an area, typically by rainfall and runoff, whereas rill erosion occurs when runoff water forms small channels as it runs down a slope (Baur 1952; Smith and Wischmeier 1957).

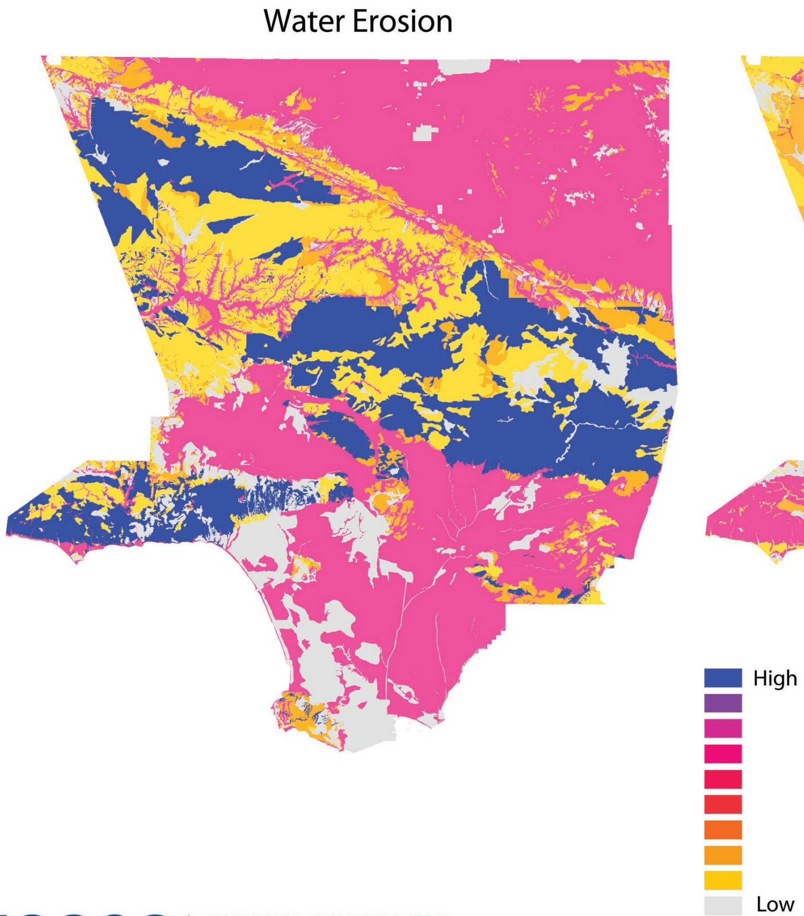

Figure 2.7. Components contributing to erosion risk.

California drought. Credit: Carel Brono, Pixabay

2.2.7 Drought Risk

A drought risk profile for the County was created using data from the U.S. Drought Monitor (USDM) (NDMC 2017). The USDM releases drought maps each week for the nation, which are jointly developed by the National Drought Mitigation Center, NOAA, the USDA, and other agencies. Data inputs and indicators used to develop the USDM vary by region, but primarily incorporate measures accounting for precipitation, soil moisture, relative humidity, temperature, water levels (reservoirs, surface water, and groundwater), crop moisture, fire risk, snowpack, snow water, and similar metrics (USDM 2019). USDM data classify drought conditions into five categories: D0 (abnormally dry), D1 (moderate drought), D2 (severe drought), D3 (extreme drought), and D4 (exceptional drought). To develop a drought risk profile for L.A. County, weekly drought data for the year 2017 were used to calculate the percent area of each drought category within the County. An Accumulated Drought Severity and Coverage Index was calculated based on the methods outlined by the USDM (USDM 2018). The data were aggregated by month, and the aggregated raster datasets were then combined to display aggregate drought risk for the year 2017, shown spatially in Figure 2.8.

The final drought risk aggregate profile for the entire year of 2017 was then further aggregated by mean value to Census block group geography. A higher mean value indicates a higher prevalence of drought in a particular area within the County.

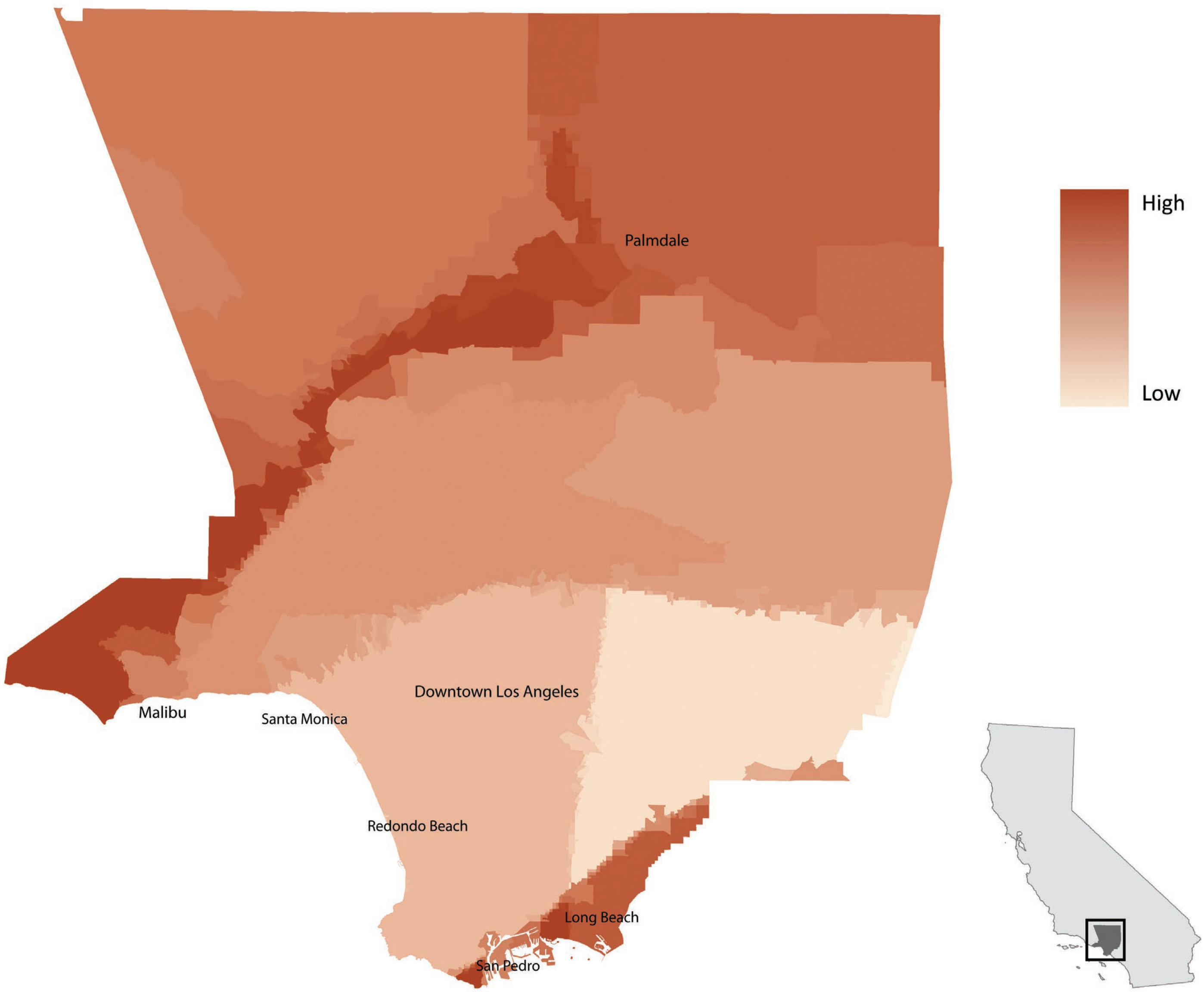

Figure 2.8. Aggregated raster datasets for drought risk.

2.2.8 Heat Risk

Average annual temperature data are collected by NOAA's National Centers for Environmental Information for a 30 year period (1981-2010) from 26 stations across L.A. County (NOAA NCEI 2018b). Heat risk was calculated across L.A. County by performing an inverse distance weighted (IDW) raster interpolation from point locations with projected latitude and longitude, with annual temperature days over 90 degrees Fahrenheit used as an indicator of heat risk. To reduce edge effects, 24 nearby stations from neighboring counties were included for a total of 50 data points. The IDW used in this analysis interpolated data with a linearly weighted combination from all data point locations, and weights were derived as a function of inverse distance. The cell size used matched the national Land Use Land Cover database, and the final raster was clipped to L.A. County. The raster dataset is shown in Figure 2.9. These data were then normalized from 'low to high' (0-1), and the final score was aggregated to block groups, with block groups closer to 'high' (value of 1) being more at risk.

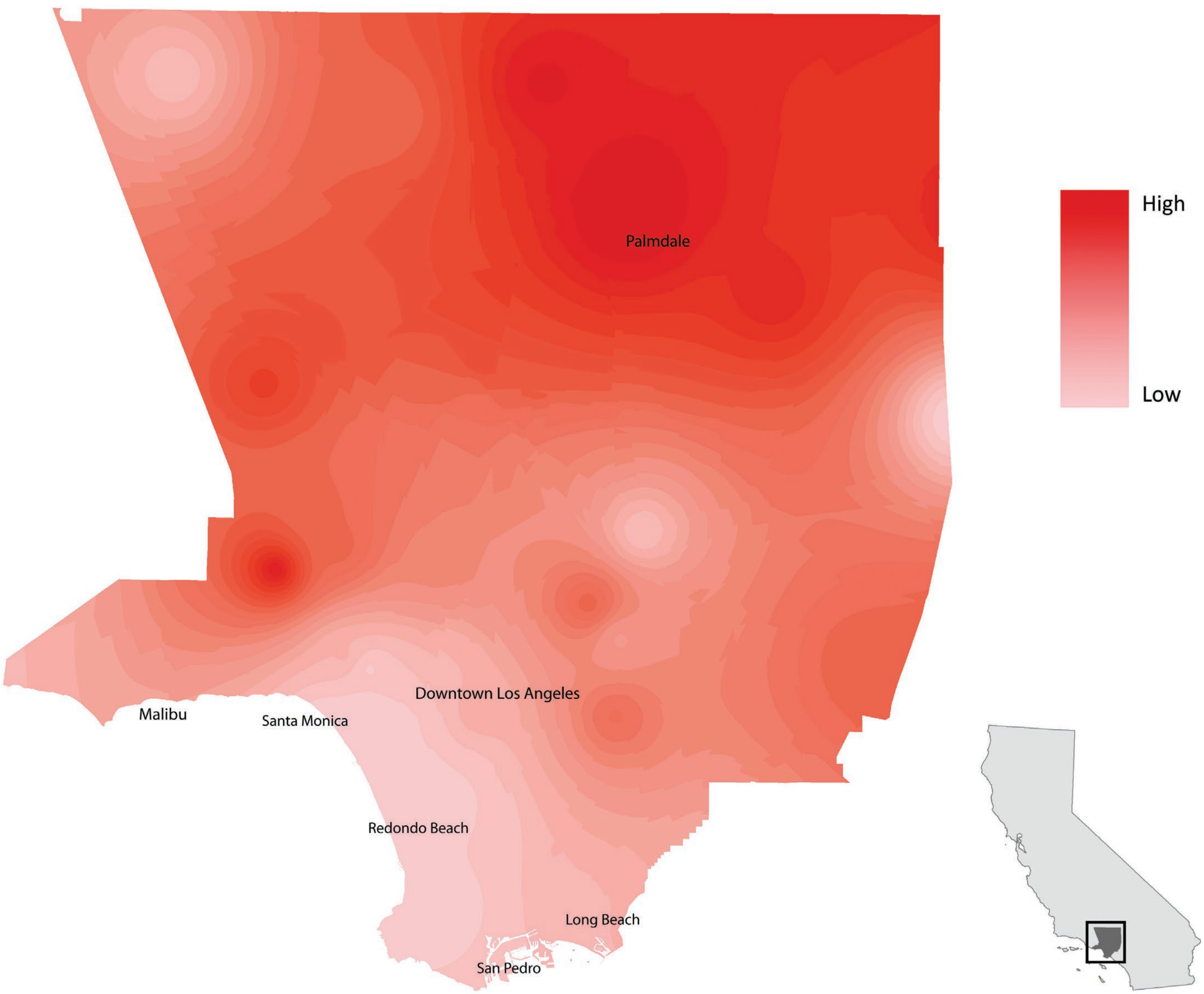

Figure 2.9. Raster dataset for heat risk.

Forest fire in Ventura County. Credit: Pixabay

2.2.9 Wildfire Risk

The wildfire risk profile utilized the Cal Fire dataset from the California Department of Forestry and Fire Protection (CDFFP 2004). Fire threat was calculated by combining two attributes of fire: fire frequency, or the likelihood of a given area burning, and potential fire behavior or hazard. These two factors are combined to create a Cal Fire raster data set with threat classes ranging from 1 to 4, and from moderate to extreme. Fire threat data were used in this analysis to estimate the potential for impacts on various assets and values that might be susceptible to fire. Impacts are more likely to occur and/or be of increased severity in the higher threat class areas. The raster dataset is shown in Figure 2.10. The dataset's final score was normalized to fit a 'low to high' (0-1) range, and aggregated to block groups. Those with higher scores are more at risk.

2.3 INTERSECTING VULNERABILITY WITH RISK

After creating individual vulnerability and risk profiles, the fifth Framework step assesses vulnerability in relation to risk, and risk in relation to vulnerability (Intersect vulnerability and risk). Bivariate choropleth maps (i.e. maps that depict two variables at once; shown in section 4.3) were created to easily compare vulnerability and risk to one another. These maps serve as a visual tool to depict areas where high vulnerability intersects with high risk. Such maps can help prioritize actions and aid in decision making when considering particular aspects of vulnerability and risk. Areas with high vulnerability and high risk would be of primary importance, while areas of low vulnerability and low risk would be of lesser concern.

All risk and vulnerability scores per block group were transformed to a 1 to 3 scale, using a discrete scaling system for each, and scores were broken into three categories of low, medium, and high.

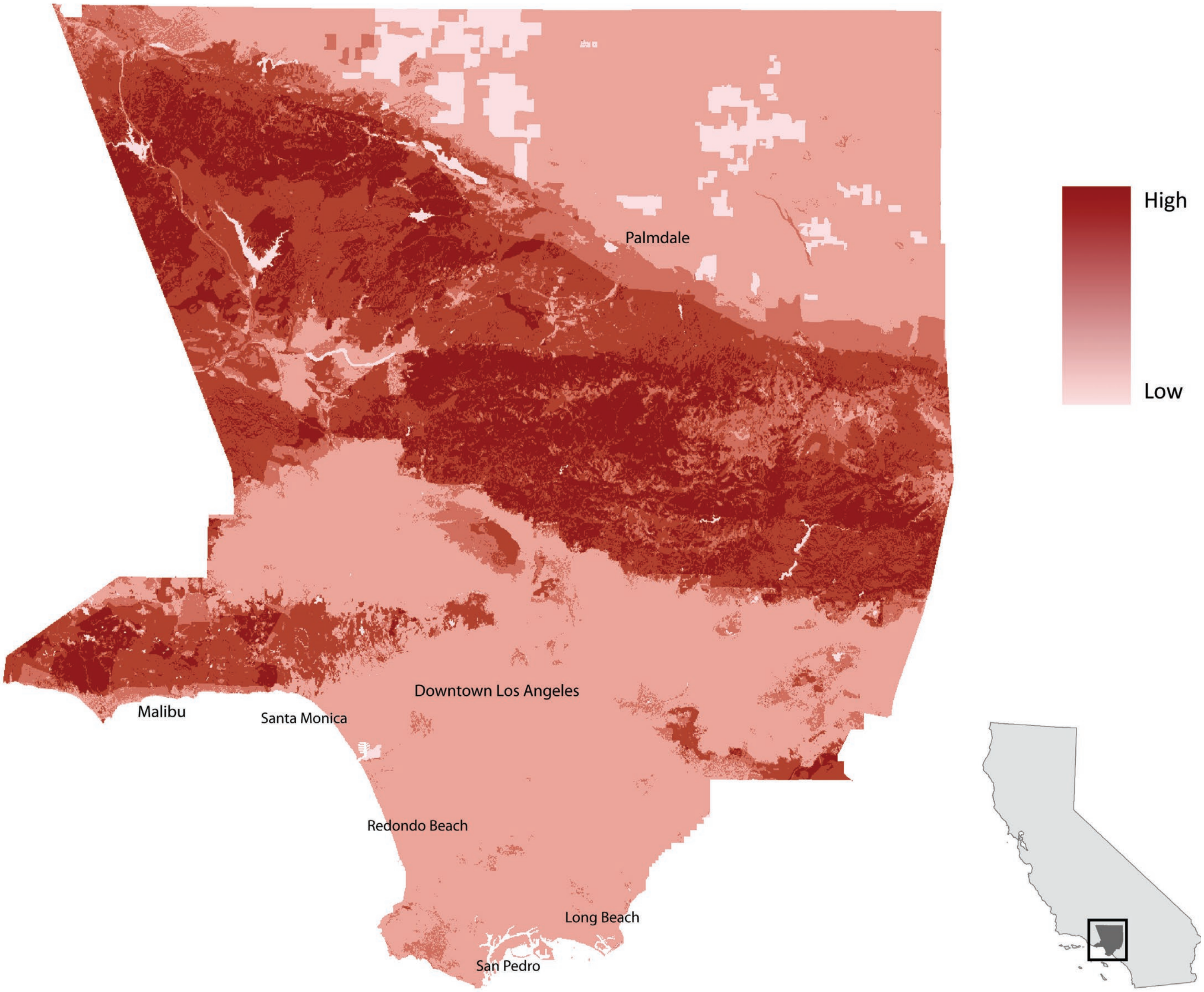

Figure 2.10. Raster dataset for wildfire risk.

2.4 IDENTIFYING ADDITIONAL ASSESSMENT GEOGRAPHIES

Following initial implementation of the Framework in L.A. County, the project team solicited feedback from local partners to identify additional geographies within the study area for application. This was done for four primary reasons. First, the Framework is a relative metric, in which the total data influence the final results. By changing the total number of units analyzed, the relative level of vulnerability or risk of a single block group may change. The inclusion of multiple geographies explores this phenomenon. Second, coastal partners were concerned that the inclusion of inland block groups may be skewing results in coastal block groups. Third, some of the inland block groups are quite large in comparison to inner city block groups due to low population, which may adversely influence results in urban areas. Lastly, the inclusion of multiple assessments results in more refined results for managers and climate adaptation specialists at different scales of jurisdiction.

Drawing upon partner engagement, initial assessment findings, gap analysis, and expert opinion, the team established two additional sub-geographies for Framework implementation: a ten-mile coastal geography and an urban geography.

For each assessment, the team developed social, structural, and natural resource vulnerability profiles using the same additive indices that were implemented in the county-wide assessment. Structural and natural resource vulnerability profiles were clipped to the new study areas. Since the social vulnerability profile was developed using PCA (the results of which depend upon the total n), the factor analysis findings for each new assessment geography are described below. Each assessment also utilized the same metrics for calculating each of the six (modified to seven) identified risk profiles. Similar to structural and natural resource vulnerability, these profiles were also clipped to the new study areas. Assessment profiles were intersected as bivariate choropleth maps using the same implemented methodology (reclassified to a 1 to 3 scale and categorized into low, medium, and high).

The 10-mile coastal band geography, shown in Figure 2.11, is comprised of 2,429 block groups. Any block group for which the centroid was within 10 miles (Euclidean) of the coastline was included for this assessment. Using the same methodology used in the County assessment, the Kaiser-Meyer-Olkin Measure of Sampling Adequacy was .911, and the Bartlett's Test of Sphericity was significant ($p \leq 0.001$). The final social vulnerability index was comprised of 28 variables and resulted in seven factors, labeled Factors 1 through 7. These factors collectively explained 69.80% of the variance in the total variability among data for the blocks groups within the 10-mile coastal band. Table 2.6 shows the variables and factors that explain the majority of variance in the data.

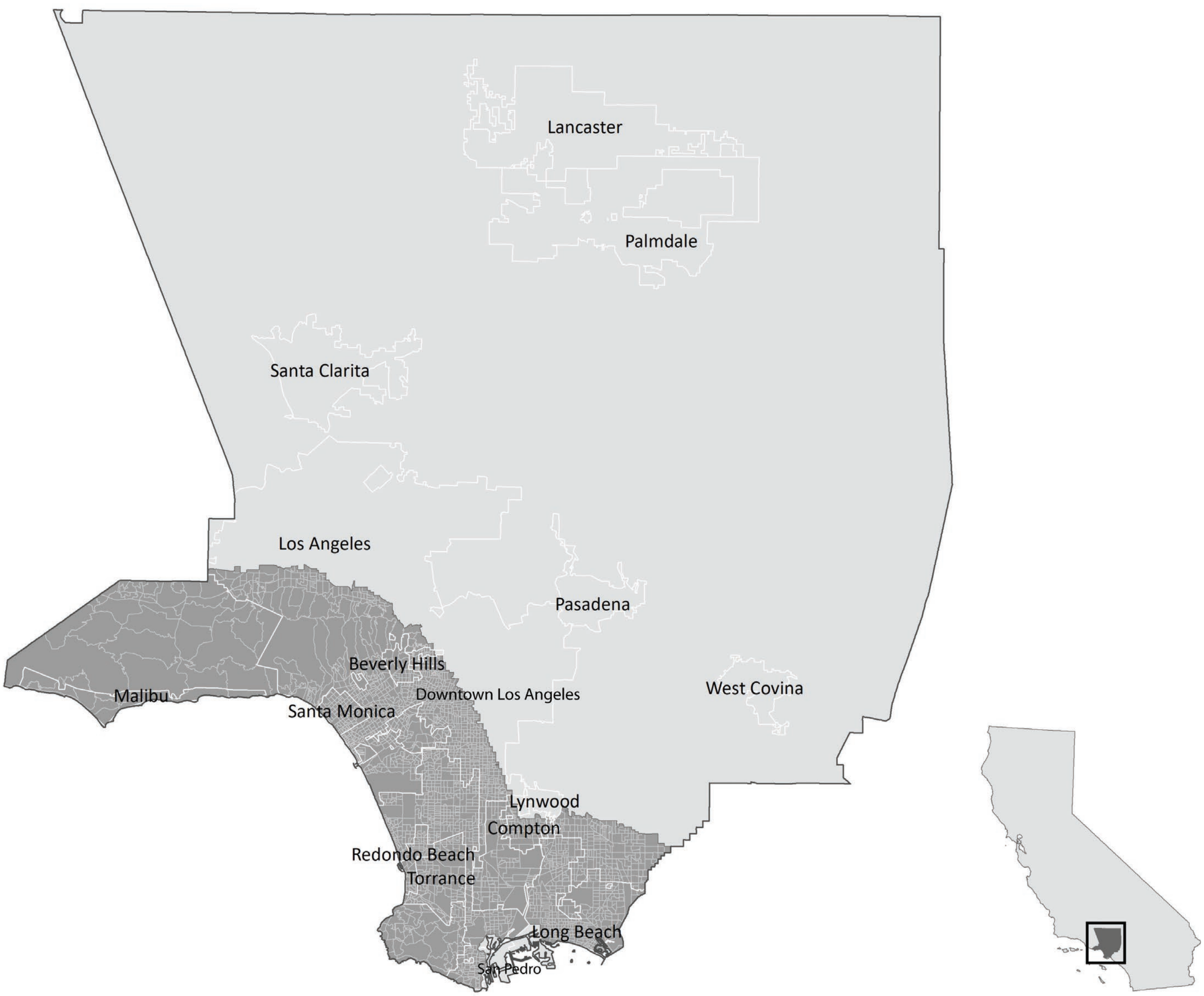

Figure 2.11. 10-mile coastal geography.

Table 2.6. PCA results for the 10-mile geography.

Factor Name	Cardinality*	% Variance Explained	Variables	Loading
Factor 1	+	31.89	% population in poverty	0.785
			% households without a vehicle	0.758
			% households receiving SNAP benefits	0.686
			% female headed households	0.568
			% population unemployed	0.533
			% population without high school diploma	0.517
			Median rent	-0.516
			Median income	-0.540
Factor 2	-	11.54	Median housing value	0.844
			% households with income over $200,000	0.813
			Per capita income	0.756
			Median income	0.667
			% race other than white	-0.611
Factor 3	+	7.57	% households with occupants over age 60	0.897
			% households receiving social security	0.893
			% population over age 65	0.814
			% population in labor force	-0.687
			Median age	0.672
			% rented housing units	-0.568
Factor 4	+	6.45	% family households	0.874
			Average household size	0.866
			% population under age 5	0.512
Factor 5	+	5.20	% foreign born	0.837
			% population with limited English proficiency	0.781
Factor 6	+	3.72	% female	0.893
			% females in labor force	0.864
Factor 7	+	3.39	% population in extractive employment sector	0.718
			% mobile homes	0.566

*Positive = the factor contributes to vulnerability; Negative = the factor contributes to vulnerability inversely.

Experiencing homelessness. Credit: Chloe Fleming, NOAA-CSS

The urban geography is shown in Figure 2.12, and is comprised of 5,986 block groups. Block groups were compared with C-CAP land cover data. Any block group that had 50% or higher land cover of the following categories was included for analysis: high intensity development, medium intensity development, and low intensity development. Using the same methodology employed in the County assessment, the Kaiser-Meyer-Olkin Measure of Sampling Adequacy was .899, and the Bartlett's Test of Sphericity was significant ($p \leq 0.001$). The social vulnerability index was comprised of 25 variables and resulted in seven factors, labeled Factors 1 through 7. These factors collectively explained 67.93% of the variance in the total variability among data for the blocks groups within the urban geography. Table 2.7 shows the variables and factors that explain the majority of variance in the data.

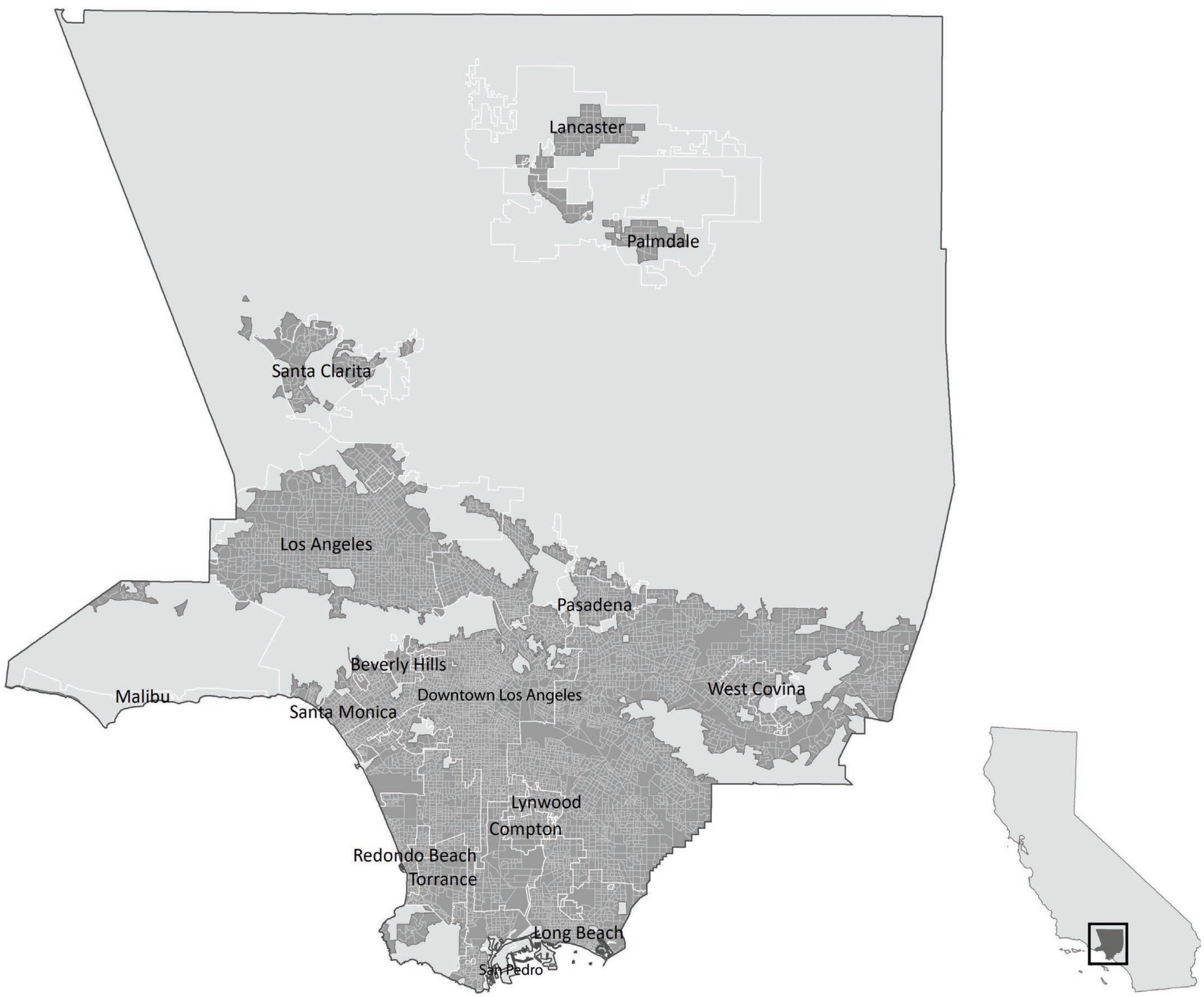

Figure 2.12. Urban geography.

Table 2.7. PCA results for the urban geography.

Factor Name	Cardinality*	% Variance Explained	Variables	Loading
Factor 1	+	29.08	% population in poverty	0.817
			% households without a vehicle	0.758
			Median income	-0.639
			% rented housing units	0.621
			Median rent	-0.580
			% population unemployed	0.504
Factor 2	+	11.07	% rented housing units	-0.513
			% households with occupants over age 60	0.887
			% households receiving social security	0.877
			% population over age 65	0.787
			% population in labor force	-0.701
			Median age	0.627
Factor 3	-	8.79	Median income	0.587
			Median housing value	0.821
			% households with income over $200,000	0.807
			Per capita income	0.762
Factor 4	+	6.27	Average household size	0.873
			% family households	0.829
			% population under age 5	0.533
Factor 5	+	5.13	% foreign born	0.848
			% population with limited English proficiency	0.788
Factor 6	+	4.15	% female	0.874
			% females in labor force	0.845
Factor 7	+	3.40	% population in extractive employment sector	0.686
			% mobile homes	0.586

*Positive = the factor contributes to vulnerability; Negative = the factor contributes to vulnerability inversely.

Venice Canal. Credit: Amy Freitag, NOAA

Chapter 3: Methods for Additional Coastal Analyses

In addition to assessment development, partner engagement throughout the project identified thematic areas for additional analysis within the 10-mile coastal band. The partner and stakeholder prioritization ranking exercise and partner and stakeholder reengagement identified analysis of National Flood Insurance Program (NFIP) claims, access to green space, and access to cultural space. The partner and stakeholder SNAP exercise identified analysis of coastal flooding and erosion impacts to critical infrastructure and blufftop development.[21]

Oceanfront home. Credit: Theresa Goedeke, NOAA

3.1 FLOOD INSURANCE CLAIMS AND PROPERTY VALUE

Since 1980 there have been 32 national major flooding disasters in which damages and costs reached at least $1 billion (NOAA NCEI 2019a). As of October 2019, three major flooding events, each exceeding $1 billion in losses, have occurred. The prevalence and impact of flooding disasters is expected to become increasingly common due to climate change and continual population growth and development in coastal and flood prone areas (Pralle 2019). Flood zone maps are not only vital in communicating risk, but could become integral to influencing risk-averse behavior in some of the nation's most vulnerable communities.

[21]The SNAP exercise also identified concerns regarding access to open space and natural habitat, but these themes are already captured with the access to green space analysis.

King Tide at Naples Island in Long Beach. Credit: California King Tides Project

The Federal Emergency Management Agency (FEMA) implements the NFIP, which provides flood insurance coverage for residential and non-residential/business properties impacted by flooding. This includes flood events resulting from processes such as severe storms and erosion common to coastal L.A. County. Flood insurance coverage under the NFIP is only provided to participating communities, and premium rates are defined by a Flood Insurance Rate Map, which delineates various risk zones, or Special Flood Hazard Areas (SFHAs) within a community (Figure 3.1). Property owners within participating communities are required to purchase NFIP insurance coverage if they have a federally backed mortgage and their property falls within a high-risk flood zone (FEMA 2019a).

The research team analyzed NFIP claims data within the L.A. County 10-mile coastal band geography in an effort to identify where claims commonly occur and to explore relationships between claims, property value, and the vulnerability and risk profiles developed for implementation of the Framework (FEMA 2018b). NFIP data were acquired for L.A. County from 1977 to 2018 (FEMA 2018b). These data include information regarding NFIP policies and claims, including total amounts paid for filed claims or losses. Total dollars paid out for each claim were adjusted to 2017 dollars to account for inflation. L.A. County parcel data were used to calculate a sum of total buildings and property values per block group within the County's 10-mile coastal band geography. Claims and total dollars paid out were aggregated and summed at the block group level,

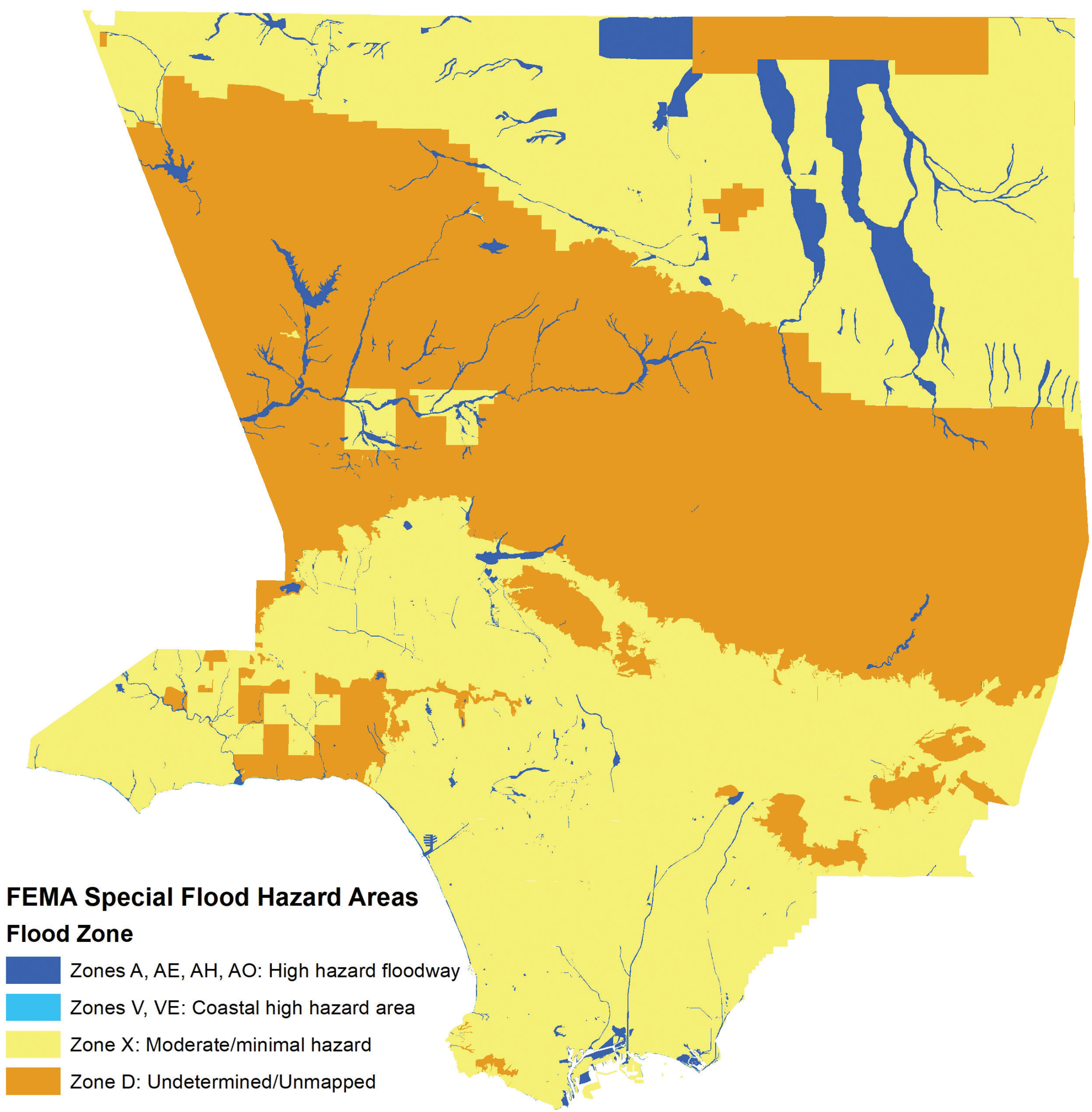

Figure 3.1. Map of L.A. County SFHAs.

and then adjusted to the total number of buildings per block group to account for the variation in rural and urban areas found throughout the coastal area.

The statistical relationships between the NFIP claims dollars paid out and property value, erosion risk, combined flooding risk, and social vulnerability were explored via a correlation analysis completed in R (version 3.4.2) that used the Kendall method after checking the normality, skewness, and modality of the data.

The spatial intersections of NFIP claims dollars paid out and property value, combined flooding risk, erosion risk, and social vulnerability were explored using bivariate choropleth maps following the same methodology employed and discussed in Chapter 2. The significance of these intersections was further explored using the Cluster and Outlier Analysis tool, also known as Local Moran's I, in ArcGIS 10.5. Significant clusters of low and high values for each variable were determined by a 95% confidence interval. The low and high clusters of the claims data along with the property value, erosion risk, combined flooding risk, and social vulnerability low and high clusters were intersected for visualization and comparison.

3.2 ACCESS TO GREEN SPACE

Greenness is a component of the natural resource vulnerability index because of the concept's ability to incorporate a wide variety of natural resources present in a community, from private yards to vast national parks. As an indicator derived from remotely sensed data, it does not rely on political designations or access for a scientific survey, and is therefore an important consideration for regions with large tracts of privately-held land, such as those found in L.A. County. Since it is a measure of photosynthetic activity, however, it omits forms of 'nature' that do not have plants. Some of these forms, such as desert areas, exist within L.A. County. Like all means of measuring nature, each conception is socially constructed, and will be more or less appropriate when considering the context of an area.

Greenness in an urban context is important both because of its ability to account for nature within private lands and because of the documented benefits to the health and well-being of the nearby population. A 2015 review found that greenness is consistently linked with better mental health outcomes, cardiovascular health outcomes, lower mortality, and healthier birth weights (James et al. 2015). In L.A. County, many sustainability and climate action plans include actions to increase the acreage of green space and tree canopy as a strategy for reducing urban heat island effect and improving air quality. Because of these linked health benefits, greenness was the primary indicator used in this analysis; however, there are other common metrics of nature to consider.

In L.A. County, three other metrics are particularly relevant. The first is open space, a management designation of public ownership that generally includes parks and other green spaces important to the community. The second is ecosystem service provision, which takes a utilitarian view of nature in terms of what it provides to the human community around it. In California, areas of important ecosystem service delivery are designated SEAs and offered management to protect provision of those services. Finally, tree canopy cover measures green space that both requires a longer time investment and delivers important ecosystem services such as cooling effects and deep roots to prevent erosion.

In order to compare the areal coverage of different definitions of natural space, similar binary rasters were created for tree canopy, SEAs, and protected areas. Protected area data were obtained from the Protected Areas Database of the United States (PAD-US) (USGS 2019a), and the tree canopy and SEAs data sources were the same as described in section 2.2.3. The SEAs and protected areas layers were converted to rasters with a 30 meter resolution by the Polygon to Raster function. Each raster was then reclassified or assigned a binary value via the Create Attribute Table tool. Forest is defined as 10% or higher tree canopy density, following the guidelines of the USGS; non forest is defined as less than 10% tree canopy density. The binary rasters were merged to compare pixel counts of each binary raster. Each pixel count was then converted to percent of total pixels.

Wetland. Credit: Amy Freitag, NOAA

Within the 10-mile coastal band of L.A. County, 19% of green areas are protected open space, according to the PAD-US database. This means the vast majority of green areas are on private property. Similarly, 27% of green areas are designated as SEAs. The remaining green areas either do not provide enough ecosystem services to qualify for the SEA program or they have not (yet) been designated as part of the program. Finally, 30% of green areas are not forest. This reflects the importance of the forested areas in the Western part of the County in providing greenness, but is also a reminder that non-tree plants are a significant contribution to nature in a desert city.

Green space was defined in this study as having a NDVI of 0.2 or higher, as recommended by the USGS (USGS 2019b). NDVI data were the same as described in section 2.2.3, at a 30 square meter resolution. NDVI rasters were clipped to the 10-mile coastal band and reclassified so each pixel had a binary value of 1 if green (greater than or equal to 0.2 raw NDVI score) or 0 if not green (less than 0.2 raw NDVI score).

The relationship between green space and social vulnerability was tested at the block group scale. The NDVI binary raster was aggregated to the scale of analysis by determining the percent areal coverage of each block group that is green (NDVI score of .2 or higher). Social vulnerability scores were calculated for the 10-mile coastal band as described in Chapter 2. Correlation analysis was completed in R (version 3.4.2) and used the Kendall method after checking the normality, skewness, and modality of the data.

In order to determine areas of overlap between greenness and social vulnerability (or lack thereof), clusters were first identified for each dataset using Cluster and Outlier Analysis in ArcGIS Pro, also known as Local Moran's I. The high-high and low-low clusters for each of the percent green and social vulnerability layers were determined by a 95% confidence interval. The high-high social vulnerability cluster and low-low green cluster were then intersected for comparison to the risk profile layers developed in Chapter 2 due to the policy relevance of low-green but highly socially vulnerable neighborhoods.

3.3 ACCESS TO CULTURAL/HISTORIC SPACE

The number of cultural resources per block group was calculated from the National Register of Historic Places by a point count, using the centroid of any polygons listed in the Register (NPS 2017). The Register is admittedly limited, having a bias toward historical and Caucasian values, but offers the only publicly available georeferenced database covering the entirety of LA County. Should this methodology be repeated in the future or at a smaller scale, local groups have better records of cultural landmarks that aim to be more inclusive, such as the Los Angeles Conservancy.[22]

Since most block groups in the 10-mile coastal band had very few (if any) cultural resources, this variable was treated as a categorical presence/absence variable. Whether social vulnerability varied in block groups with cultural resources was tested using an ANOVA test after assumptions of ANOVA were verified (R 3.4.2). Point locations of cultural resources were also visually compared to risk profiles developed in Chapter 2.

3.4 EROSION, FLOODING, AND CRITICAL INFRASTRUCTURE

For this analysis, critical infrastructure was simplified to disaster and evacuation routes because stakeholders referenced transit interruptions from flood events as the reason for interest in this intersection of risk and vulnerability. The state-designated disaster routes, maintained by the L.A. County Department of Public Works, “are freeway, highway, or arterial routes pre-identified for use during times of crisis. These routes are utilized to bring in emergency personnel, equipment, and supplies to impacted areas in order to save lives, protect property, and minimize impact to the environment. During a disaster, these routes have priority for clearing, repairing, and restoration over all other roads” (LADPW 2015). Disaster routes were overlaid with erosion and combined flooding risk for a visual comparison.

3.5 EROSION AND BLUFFTOP DEVELOPMENT

The research team defined blufftop development as areas on top of coastal bluffs. Since coastal bluffs are inherently prone to erosion (hence the concern from local stakeholders), this phenomenon was examined by looking at development in the coastal geography in high erosion risk areas. Specifically, parcels with development added since 1978 were overlaid with erosion risk (County of Los Angeles 2016). Building code changes and advancements in building technology began to allow for development in marginal areas beginning in 1978. Local partners and stakeholders also suggested that recent development projects are edging closer to erosion-prone bluffs, such as the bluffs above the Bellona wetlands. This visualization tested the theory that newer houses were more likely to be in erosion-prone areas.

Griffith Observatory. Credit: Gary A. Hopkins, Pixabay

[22]https://www.laconservancy.org/explore-la/historic-places

Coastline. Credit: Theresa Goedeke, NOAA

Chapter 4: Assessment Results and Discussion

All profile and bivariate choropleth maps shown in Chapter 4 can be viewed in greater detail within the mapbook found in Appendix D. Due to the complexity of the bivariate choropleth maps, labels have been omitted from those maps; please see Figures 2.1, 2.11, and 2.12 for labeled geography reference maps, or visit Appendix D for full-detail bivariate choropleths.

Beachfront development. Credit: Amy Freitag, NOAA

4.1 VULNERABILITY PROFILES

Figure 4.1, Figure 4.2, and Figure 4.3 show profiles for social vulnerability, structural vulnerability, and natural resource vulnerability at the County geography. While relative vulnerability changes within the urban and 10-mile geographies, as will be shown later in this chapter, the County-level profiles deliver a general understanding of vulnerability trends across L.A. County. For a review of individual index components, please refer back to Chapter 2.

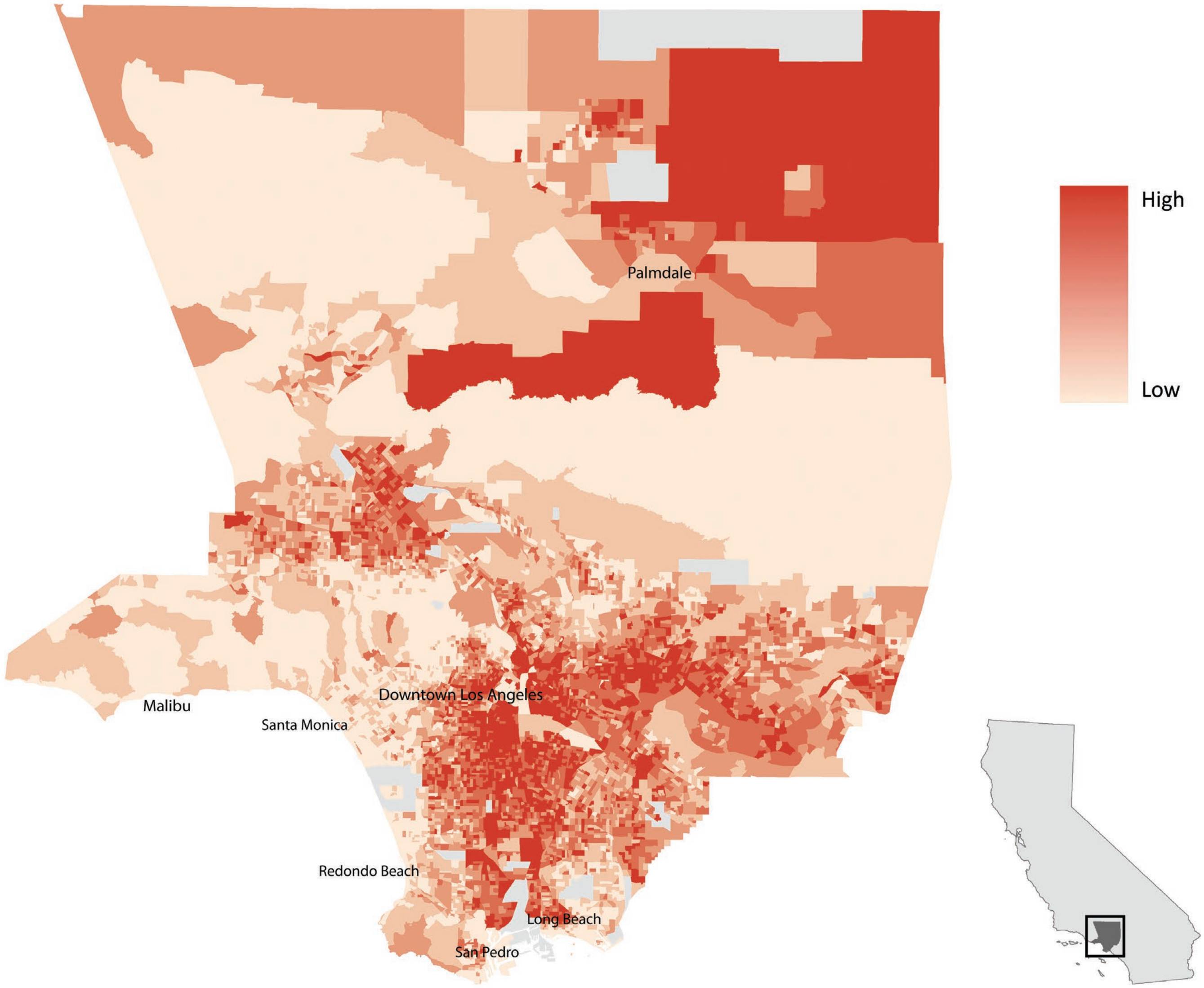

Figure 4.1. Social vulnerability profile for the County geography.

Figure 4.1 shows that social vulnerability is varied throughout the study area, with areas of highest vulnerability shown in dark red. Groups of dark red block groups are observed in the northeastern portion of the County as well as within the heart of the City of L.A. Structural vulnerability is concentrated largely in urban areas, as shown in Figure 4.2, where areas of dark orange are most relatively vulnerable, and areas of pale orange are least vulnerable. The majority of rural areas have low structural vulnerability. Lastly, Figure 4.3 depicts natural resource vulnerability in shades of green. Perhaps unsurprisingly, areas of highest natural resource vulnerability coincide with areas relatively abundant with natural resources. Dark green block groups overlap with the County's mountain ranges and other pockets of vegetation. In some ways, this profile is almost the opposite of structural vulnerability, since urban areas have structures that displaced nature.

When examining these three vulnerability profiles, it is critical to recognize the benefits and limitations of Census geography aggregation. For example, each block group vulnerability score represents the average status within that block group. This means that the individually-lived experience not only varies within each block group, but likely also includes outliers. These are therefore better explained and understood as community metrics, where the block group or a collection of block groups represents a community. Because these are aggregated metrics, it's also important to recognize that vulnerability does not necessarily abruptly change at each block group boundary; despite the combined score within each block group, individual variations are likely to transcend these Census boundaries. Further, there is a noticeable difference in block group size throughout the County, with larger block groups and therefore spatial representation of

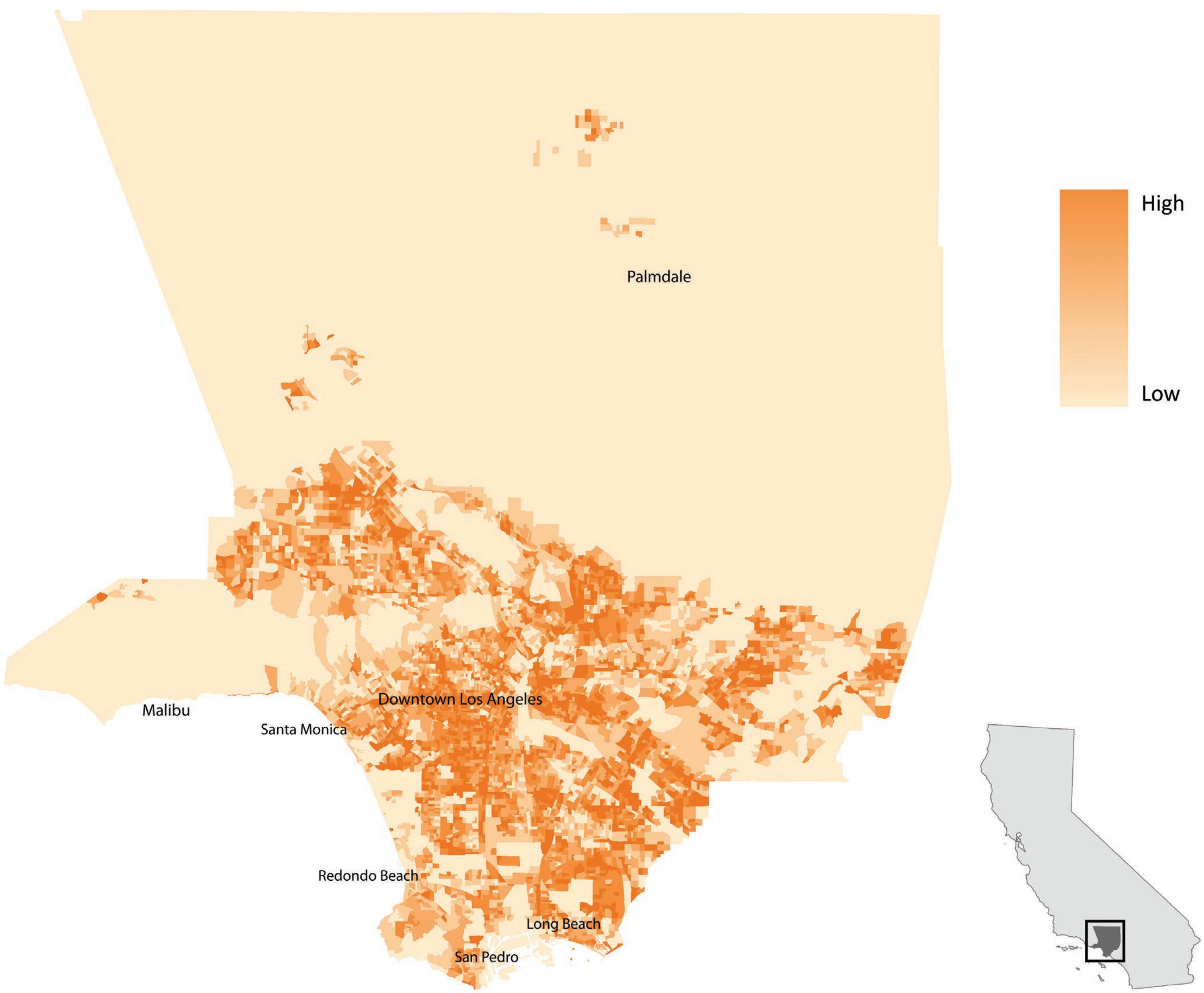

Figure 4.2. Structural vulnerability profile for the County geography.

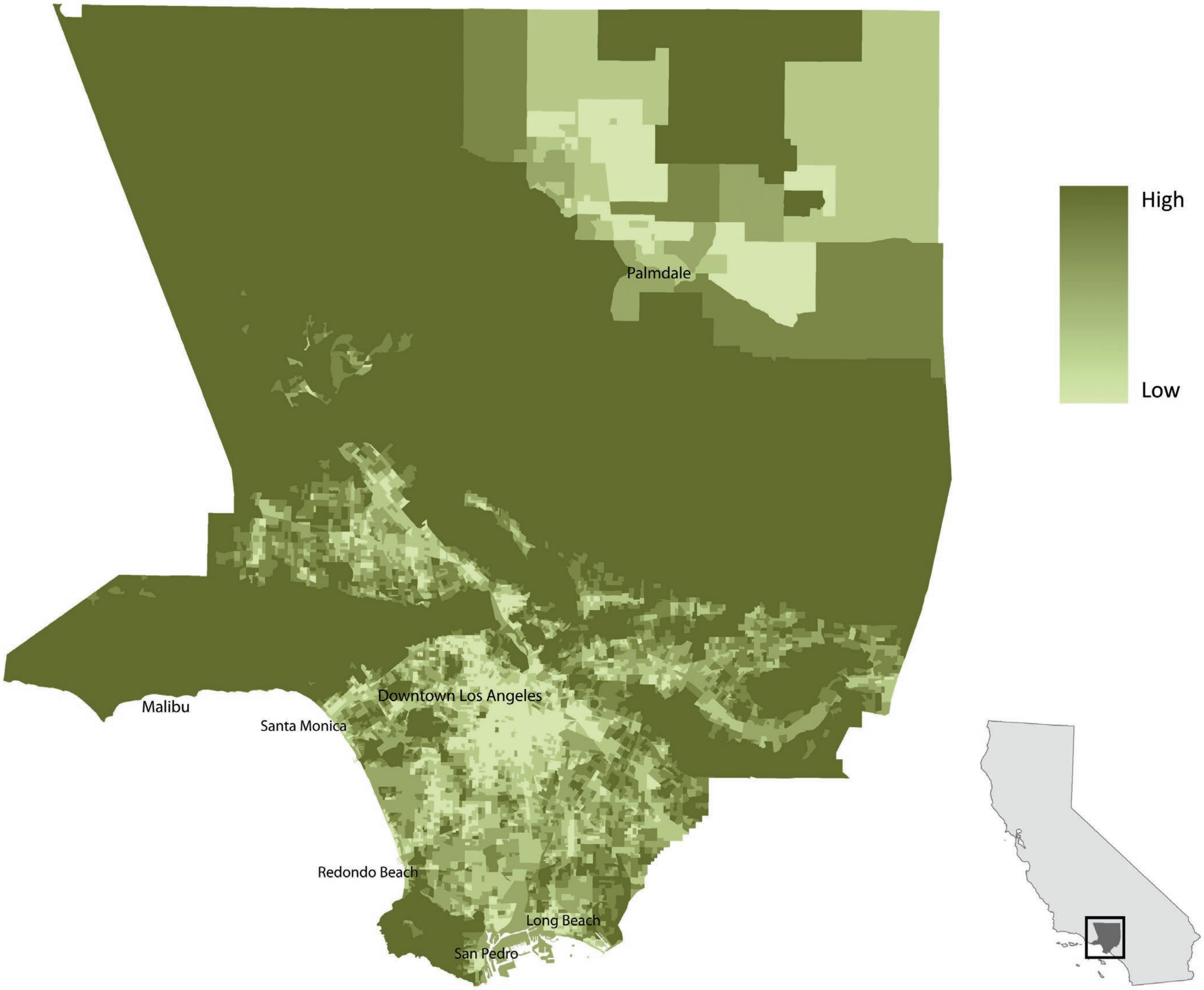

Figure 4.3. Natural resource vulnerability for the County geography.

vulnerability in the northern half and Malibu peninsula region of the County. Block groups are combinations of Census blocks, and are formed by visible features such as roads, streams, and other non-visible geographic features, such as school districts or political boundaries; block groups ideally contain between 500 to 3,000 people. Because rural areas have fewer geographic bounding features, some large block groups exist. For these reasons, caution is advised when interpreting the vulnerability profile scores beyond the community level. These same limitations and insight apply to the risk profiles discussed in the next section.

Flooding mitigation efforts. Credit: Chloe Fleming, NOAA-CSS

4.2 RISK PROFILES

Similar to the vulnerability profiles, risk profiles are shown at the County geography. While relative risk changes within the urban and 10-mile geographies, as will be shown later in this chapter, the County-level profiles deliver a general description of risk trends across L.A. County. Higher risk is depicted in shades of darker pink, while lower risk is shown in pale pink. For a review of individual index components, please refer back to Chapter 2.

Figure 4.4 depicts coastal flooding risk (left) and stormwater flooding risk (right) adjacent to one another. Coastal flooding risk is naturally present along the County's coastline, with non-coastal block groups omitted from the profile (much of the County is grey, as opposed to pink). Areas around the port complex to the south and Venice canals south of the bend are at highest risk of coastal flooding under the high risk-long term scenario from Figure 2.5. Block groups surrounding some of the highest coastal flooding risk areas have some of the highest stormwater flooding risk as well, exemplifying the flooding concerns around these two areas. Stormwater flooding risk is also present further inland, in areas within the City and also in pockets of block groups at the foothills of some of the County's mountainous areas.

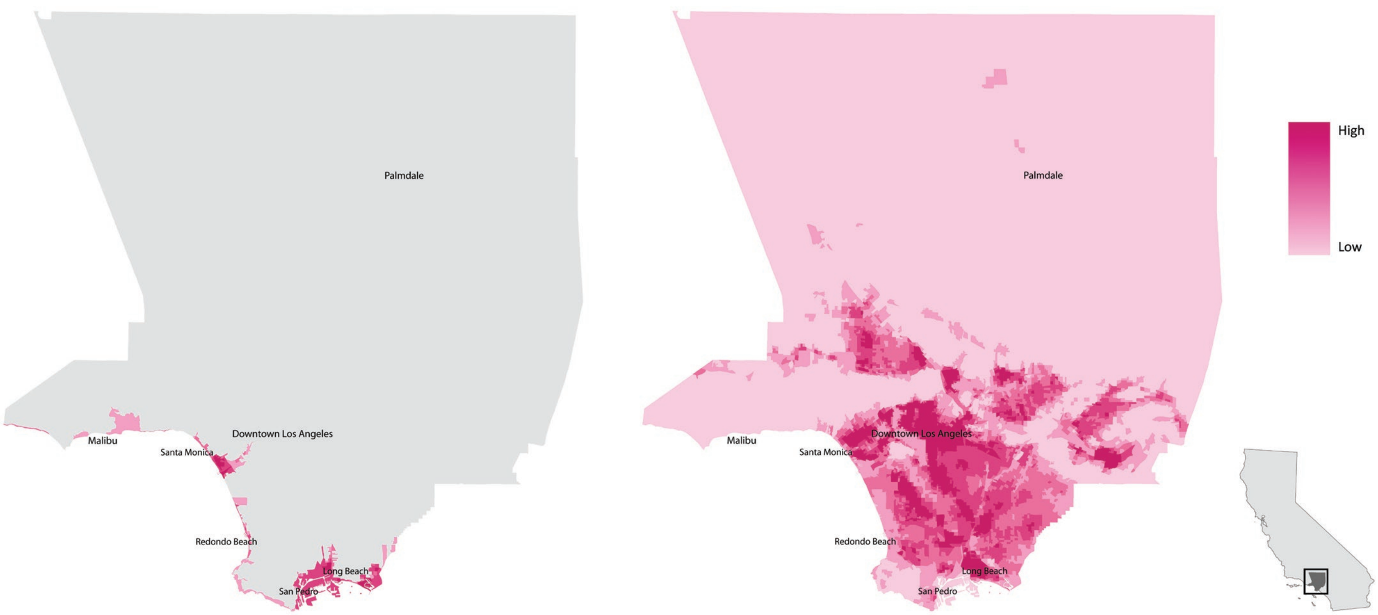

Figure 4.4. Coastal flooding risk (left) and stormwater flooding risk (right) profiles for the County geography.

While coastal flooding is a serious concern for coastal communities, the areas at risk are relatively few and logically focused in coastal areas. In addition to this nuance, local partners were interested in understanding flooding risk across the full country, and in looking at coastal flooding and stormwater flooding simultaneously. For these reasons, the research team drafted a seventh risk profile that combines coastal and stormwater flooding risks, named combined flooding (Figure 4.5). This profile appears similar to the stormwater flooding profile, but also includes areas at risk of coastal flooding. Overall, areas at risk of combined flooding are typically characterized as urban areas with a high percentage of impervious surface and/or low lying coastal areas. One example of an area that shares both stormwater and coastal flooding risk is near the Port of Long Beach and along coastal portions of the Los Angeles River.

Related to flooding risk is risk of erosion, shown in Figure 4.6. As erosion of the underlying soil from water and wind were both taken into account, mountainous and arid regions of the County are most at risk. Some coastal areas are also at elevated risk, as are southeastern parts of the County. Coupled with a flooding event, areas at risk of erosion are also at risk of mudslides.

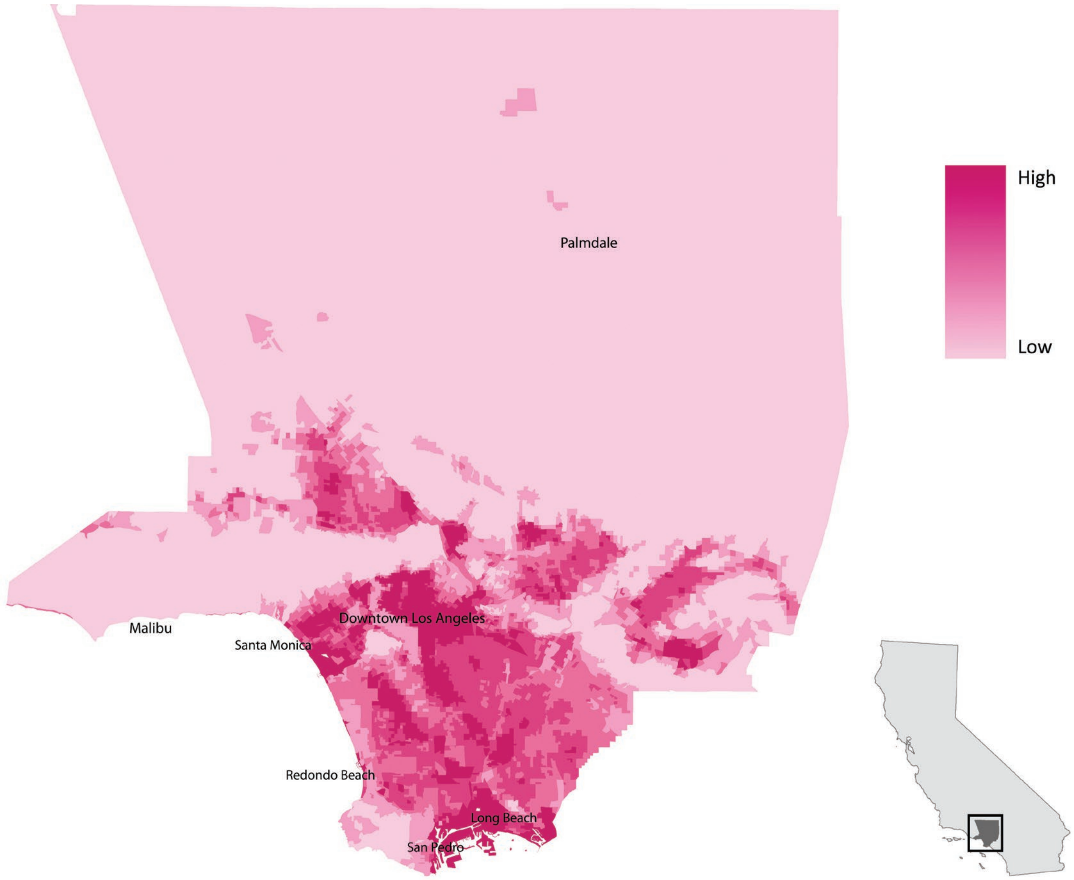

Figure 4.5. Coastal and stormwater combined flooding risk profile for the County geography.

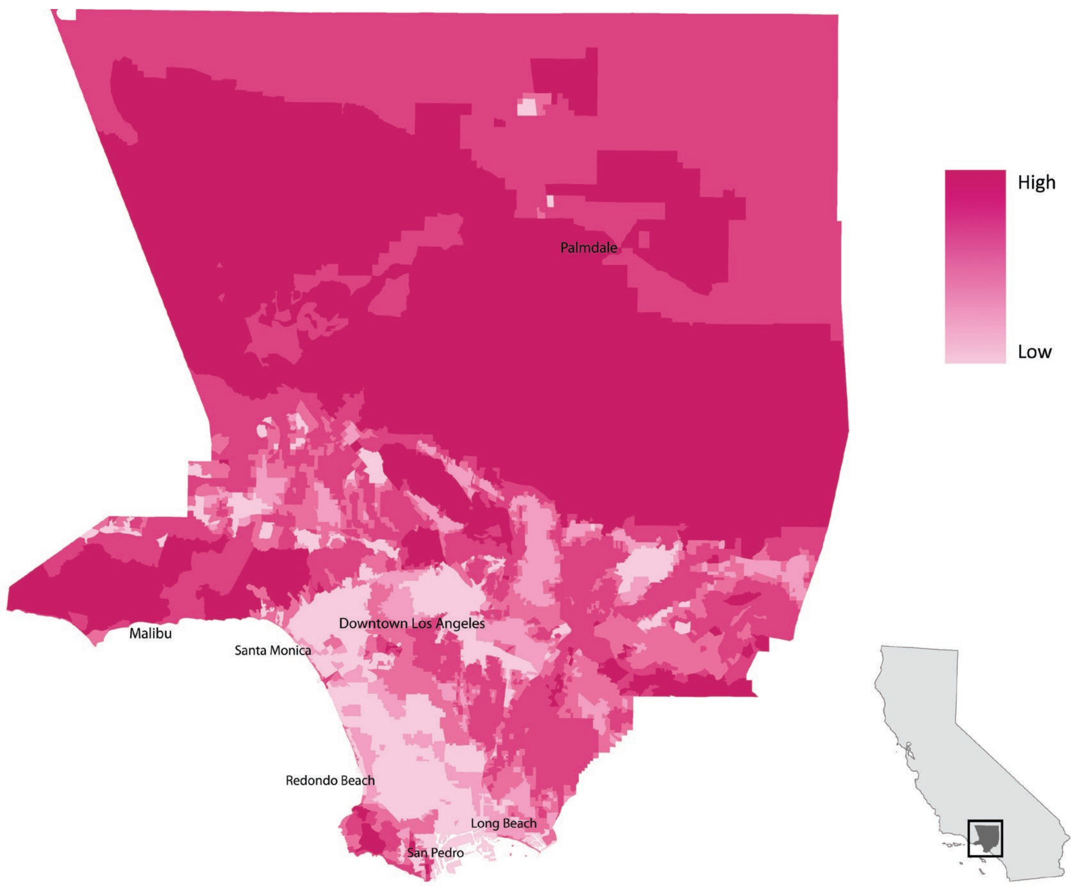

Figure 4.6. Erosion risk profile for the County geography.

Figure 4.7 displays heat risk (left) and drought risk (right) profiles for the County geography. Heat risk becomes more prevalent farther from the cooling effects of the coast, with some pockets of high risk located centrally within the County. Drought in 2017 was most prevalent in the desert region of the Antelope Valley northeast of the San Gabriel Mountains, along the western reaches of the Santa Monica Mountains, and also in a small area along the southern coast bordering Malibu. During this time, L.A. County as a whole was slowly coming out of an exceptional drought (USDM 2019). Although the County experienced significant drought in the 2011-2019 time period, less severe drought conditions depicted in Figure 4.7 in the San Gabriel Valley may be explained by variations in soil, vegetation, and, perhaps of primary influence, precipitation inputs, such as rainfall and snowmelt, from the San Gabriel Mountains, which have historically seen the highest measures of rainfall frequency and intensity within the County (LACDPW 2006). The northeastern region of the County is susceptible to both heat and drought.

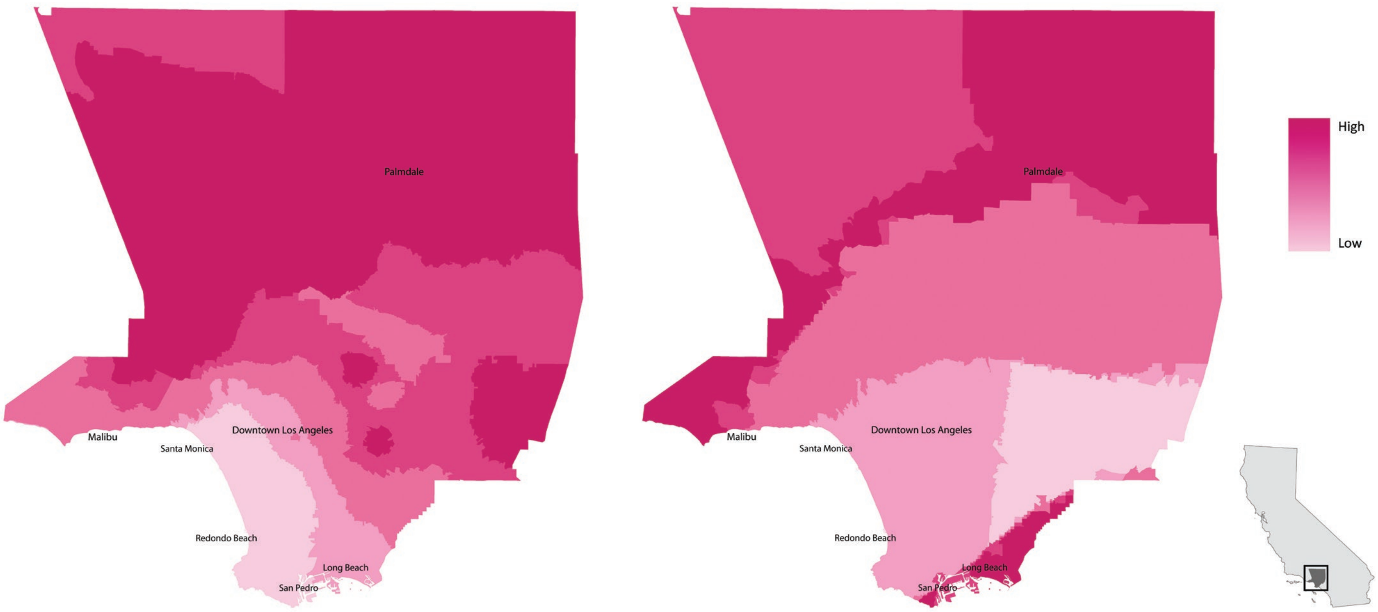

Figure 4.7. Heat risk (left) and drought risk (right) profiles for the County geography.

Lastly, Figure 4.8 displays wildfire risk. This risk is highest in areas of higher fuel availability, and therefore, is increased in forested and mountainous areas. There are pockets of block groups along the periphery of urban areas that also have increased risk of wildfire.

Forest fire in Ventura County. Credit: Pixabay

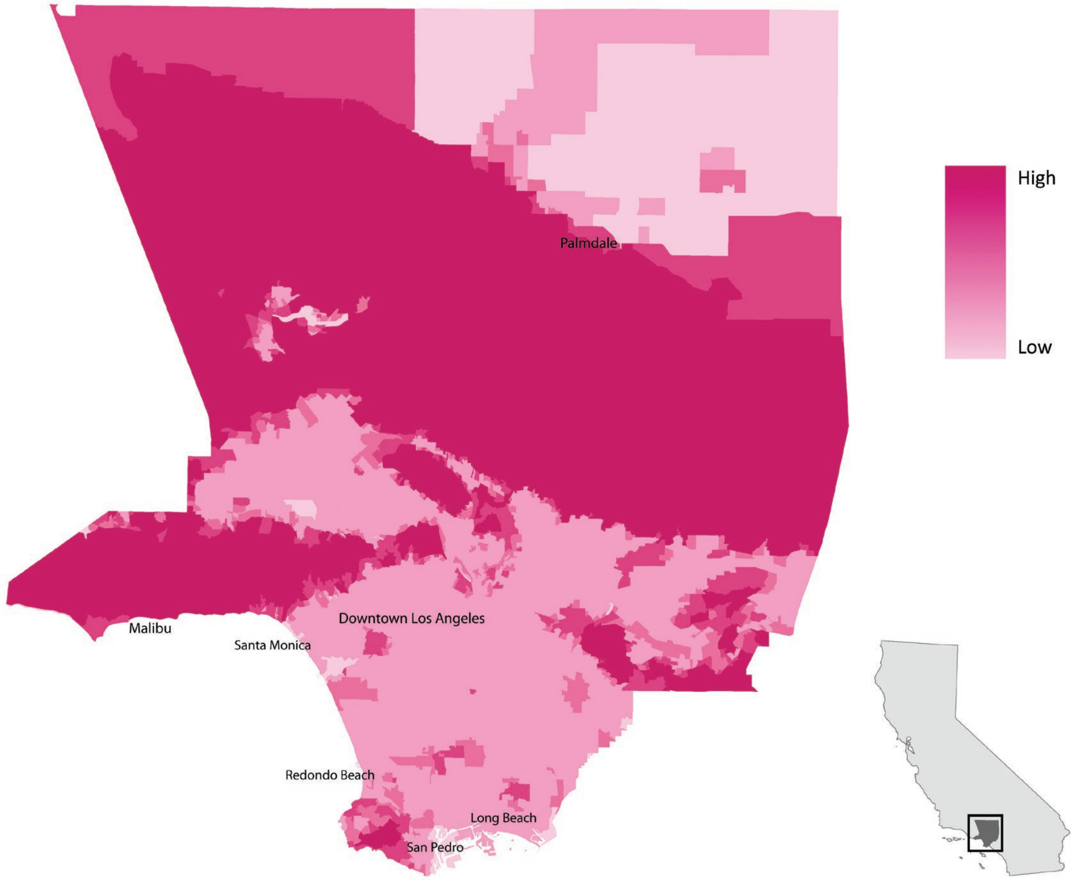

Figure 4.8. Wildfire risk profile for the County geography.

4.3 INTERSECTION OF VULNERABILITY AND RISK

Figure 4.9 displays the legend for reading bivariate choropleth maps. It shows that as vulnerability increases from left to right (in blue), risk increases from bottom to top (in pink). Each corner of the matrix represents a different extreme in terms of variable scoring. Dark blue block groups on each map indicate areas with both high risk and vulnerability, while light grey block groups indicate the opposite. Similarly, magenta block groups indicate areas with high risk, but low vulnerability, and teal block groups indicate areas with low risk, but high vulnerability.

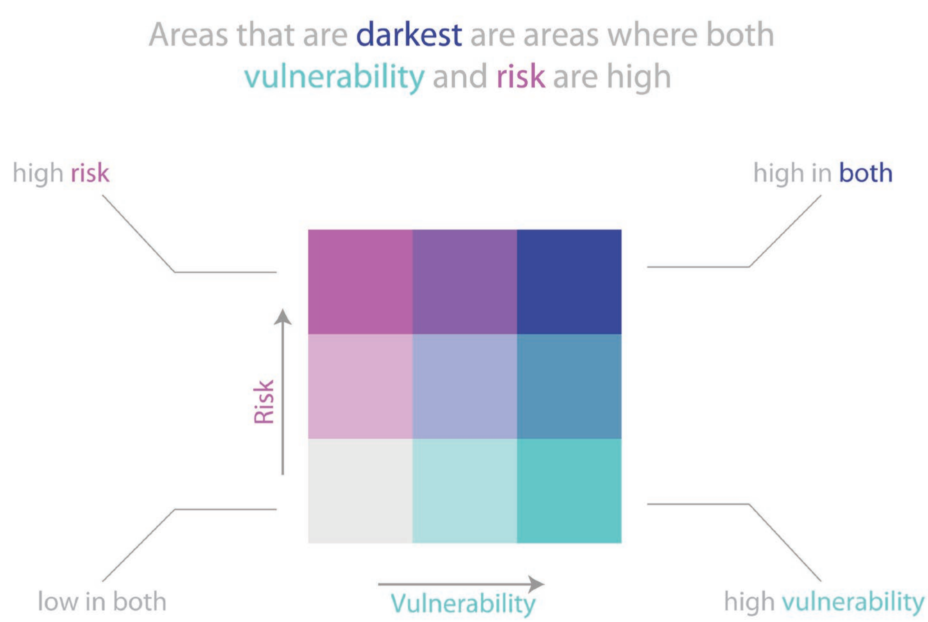

Figure 4.9. Bivariate choropleth map legend.

Across the three assessments, there are numerous potential risk and vulnerability combinations and at various geographies. While the complete series of maps can lay the foundation for step 6 of the Framework (Engage local partners and stakeholders for prioritization of adaptation areas and next steps to mitigate climate-driven impacts), this section of Chapter 4 initiates the process by highlighting key findings and stories of interest across the geographies by risk type.

4.3.1 Drought Risk Key Findings

Given the broad manner in which drought impacts an area in addition to the scale of data used to develop this profile, drought findings are most applicable at the County geography. Figure 4.10 displays intersections of drought risk with natural resource vulnerability (left) and social vulnerability (right). While drought impacts the likelihood of wildfire risk and the severity of stormwater flooding, both of which interplay with structural vulnerability, these analyses were beyond the scope of this study; therefore, drought risk is not shown with structural vulnerability below.

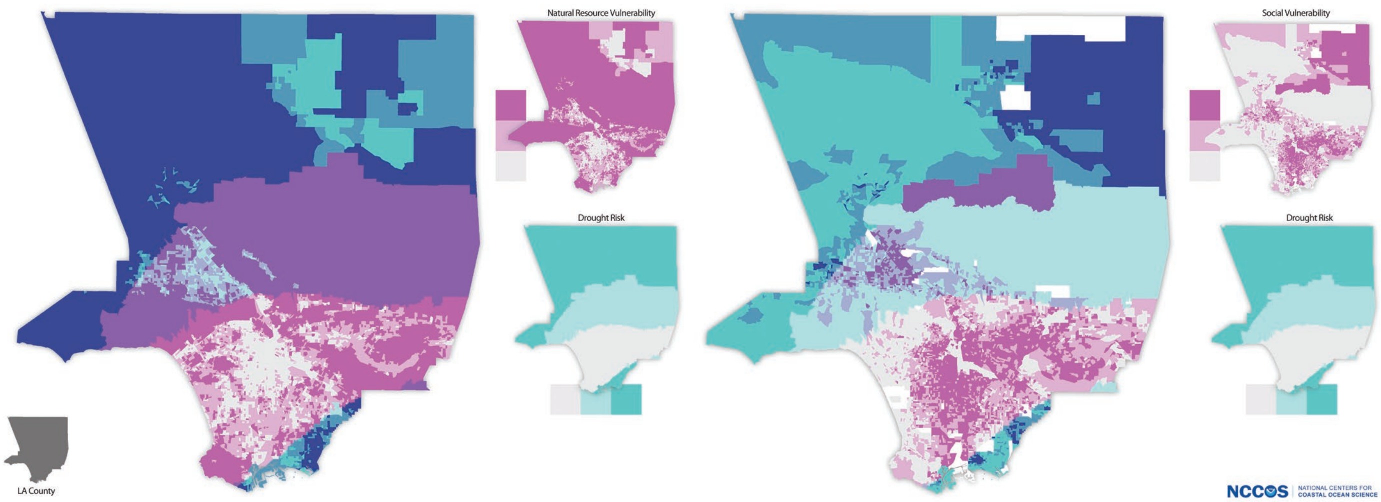

Figure 4.10. Drought intersected with natural resource vulnerability (left) and social vulnerability (right) at the County geography.

Areas of highest drought risk and social vulnerability occur in the dark blue block groups in the northeast portion of the County. This region is arid and rural, and is comprised of large block groups. There are also some overlapping pockets of high risk and vulnerability in the southern portion of the County. Areas of overlapping high risk and natural resource vulnerability follow a similar pattern, but extend farther west.

Drought has long been thought to impact social vulnerability and economic security in rural agricultural regions (e.g., Hill and Porter 2017; Mahajan 2017; van Dijk et al. 2013), and these impacts are possible in the northeastern portion of the County. Desbureaux and Rodella (2019) conducted a study in urban Latin American cities, however, that challenges the notion that drought impacts are smaller in urban areas. They found that prolonged drought in urban areas decreases the probability of being employed, especially for informal workers. Further, they suggest that drought impacts on labor market outcomes may actually be larger and/or prolonged in comparison to labor impacts from floods (Desbureaux and Rodella 2019). Since the present study used Census data to derive its social vulnerability metric, informal labor is likely under or misrepresented, possibly increasing felt social vulnerability in L.A. urban areas in the face of drought risk.

Los Angeles hiking trail. Credit: Eva C., Pixabay

4.3.2 Heat Risk Key Findings

Similar to drought risk, heat risk results appear most striking at the County level geography, and are shown for natural resource vulnerability (left) and social vulnerability (right) in Figure 4.11. Heat risk and natural resource vulnerability overlap throughout much of the County, north of the highly urbanized areas of the City of L.A. There appears to be an isolated pocket of high risk and high natural resource vulnerability in the center of the County, which may be due to urban heat island effects. County-wide, areas of highest social vulnerability and highest heat risk occur in the northeastern arid region of the County, but also in two pockets towards the inland empire and in the eastern portions of downtown L.A.

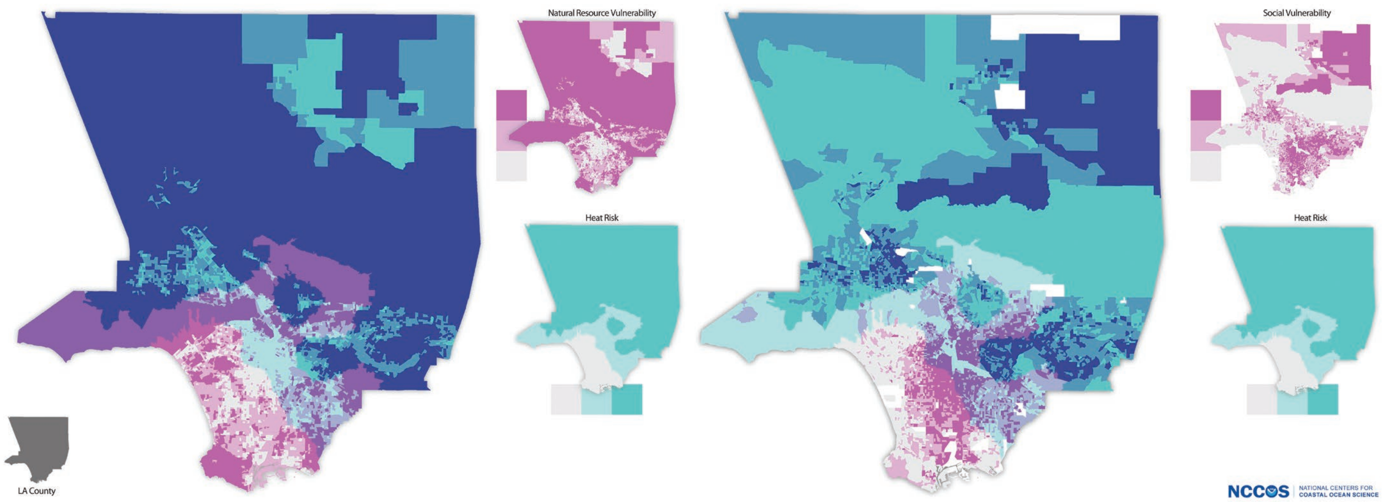

Figure 4.11. Heat risk intersected with natural resource vulnerability (left) and social vulnerability (right) at the County geography.

Intersections of areas of highest heat risk and highest social vulnerability tell a slightly more nuanced story. First, heat risk increases farther inland, away from the cooling effect of the Pacific Ocean, which is consistent with results from downscaled climate modeling efforts undertaken in the region. Future projections also indicate that this trend may continue while precipitation amounts may slightly decrease in the coming decades (Berg et al. 2015). Furthermore, many of the coastal areas that feel less impact from stifling heat are also more prosperous, less socially vulnerable, and contain highly valuable real-estate. The “inland empire” east of the City of L.A. also happens to be consistently ranked as one of the poorest air quality regions in the United States (American Lung Association 2019). The present research suggests areas of compounding vulnerability, heat risk, and poor air quality.

Parking area heat mitigation efforts. Credit: Chloe Fleming, NOAA-CSS

4.3.3 Wildfire Risk Key Findings

Wildfire is not a new threat to L.A. County and its inhabitants, but climate change and development into previously 'natural' areas, or areas that were once allowed to burn without disrupting human settlements, have exacerbated wildfire risk. Figure 4.12 shows a snapshot of peripheral development by age of structure, where light blue is development through 1950, dark blue is development from 1950 to 1980, purple is development from 1980 to 2000, and pink is development from 2000 on. The inset map shows development slowly encroaching on historically undeveloped land (and also the smoke from the 2017 Rye fire). These areas where development encroaches upon undeveloped wildlands and vegetation, often called the wildland–urban interface, are key in zones where environment conflict occur. L.A. County has recently and repeatedly seen the destruction of homes by wildfires (Radeloff et al. 2005), and this trend is likely to continue.

Forest fire. Credit: Pixabay

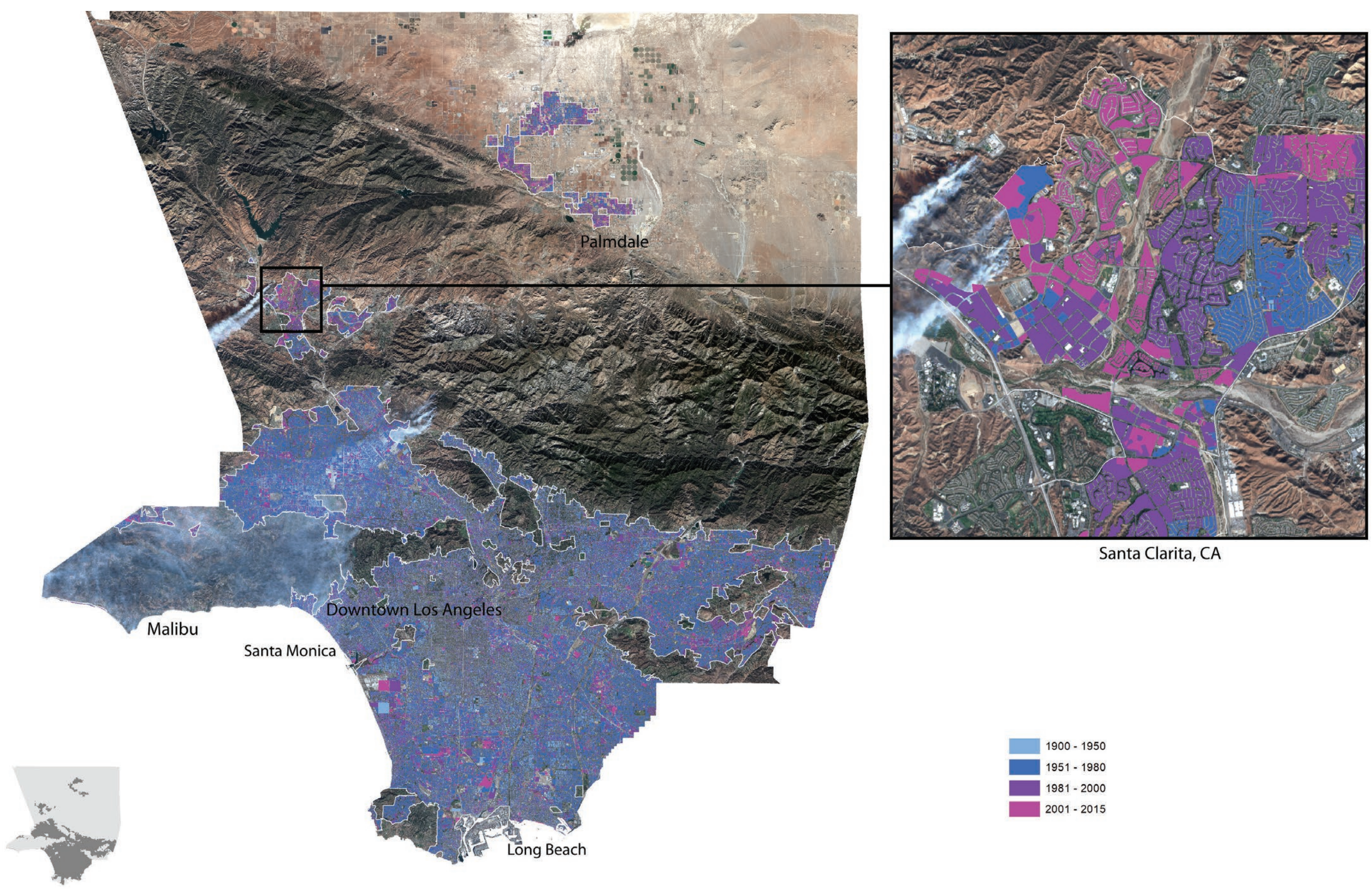

Figure 4.12. Peripheral urban development from the 1950s to present.

At the County geography, wildfire risk and social vulnerability are highest in a few large block groups in the northeastern portion of the County, as well as in a few pockets in central L.A (Figure 4.13). When reviewing the urban geography assessment (right), the majority of high risk and high social vulnerability overlap areas are on the outskirts of the urban boundary (Figure 4.13). A similar trend is shown in Figure 4.14, which examines structural vulnerability and wildfire risk at the County (left) and urban (right) geographies. Structural vulnerability and wildfire risk are highest along the periphery of urban areas.

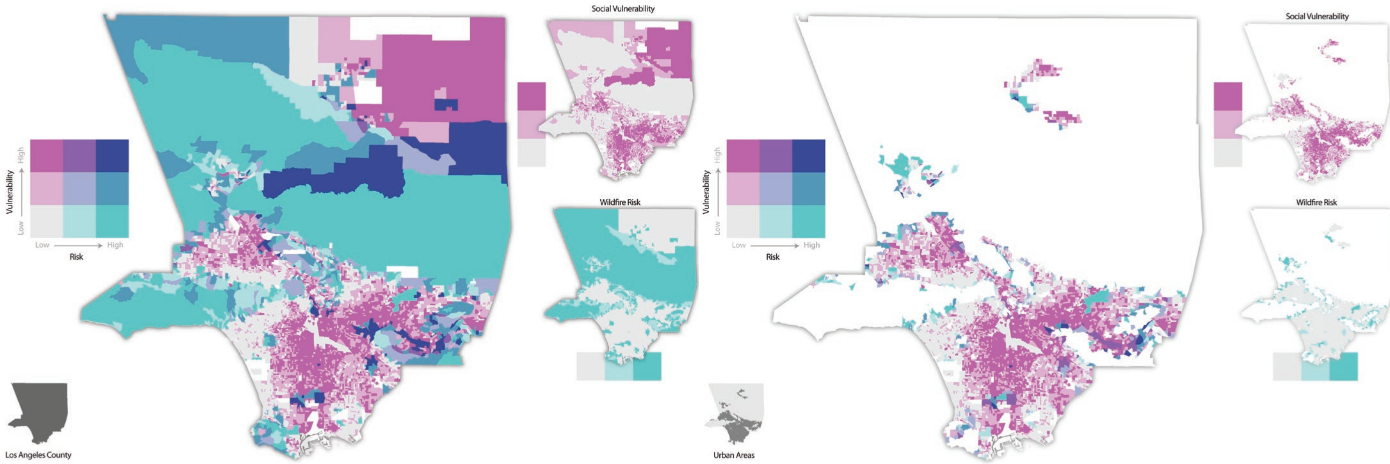

Figure 4.13. Wildfire risk and social vulnerability at the County (left) and urban (right) geographies.

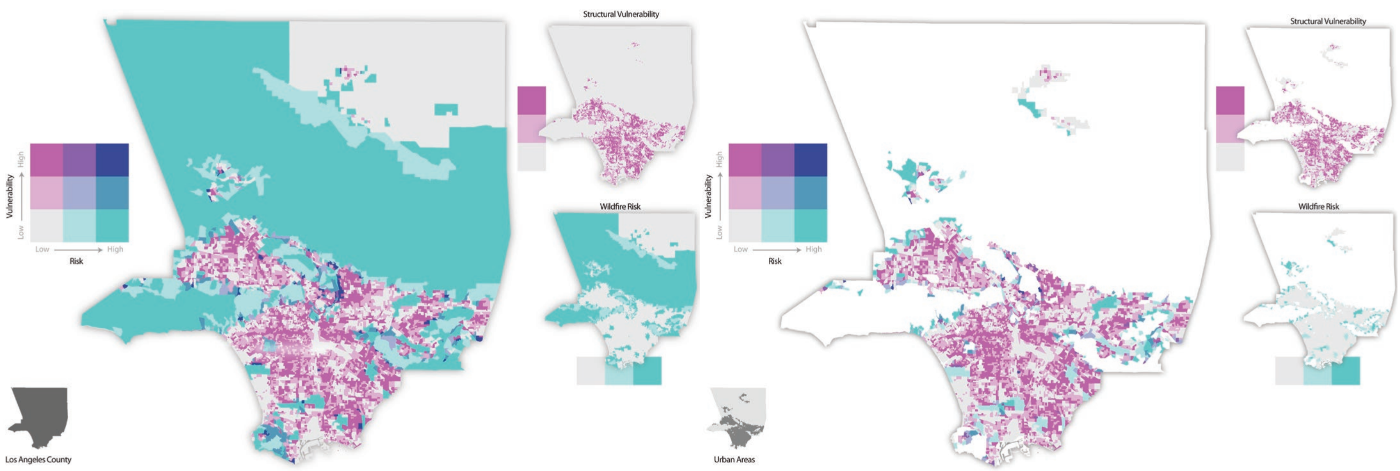

Figure 4.14. Wildfire risk and structural vulnerability at the County (left) and urban (right) geographies.

Cactus. Credit: Jackie Harder, Pixabay

Wildfire risk, however, interacts very differently with natural resource vulnerability (Figure 4.15). Areas of highest wildfire risk coincide with areas of increased vegetation, which in turn translates to areas of highest natural resource vulnerability. Large swaths of dark blue are shown in the forested and mountainous areas of the County.

The natural resources that are counted in the index as positive attributes sometimes serve as the fuel for wildfire that is ignited by lightning or anthropogenic sources. The Gabrielino and Tongva people that once inhabited the L.A. region actively managed the landscape with prescribed burns in order to maintain coastal grasslands and shrublands suitable for their communities and agricultural activities. Since urban development and European settlement, forests (and their capacity for hot crown fires) as well as non-native grasslands now dominate the natural areas, and both of these plant communities have a higher tendency to perpetuate wildfire (Keeley 2002; ESRI n.d.). Recent droughts that stress or kill vegetation also create fuel for increased, hotter wildfires, creating a feedback loop of increasing risk.

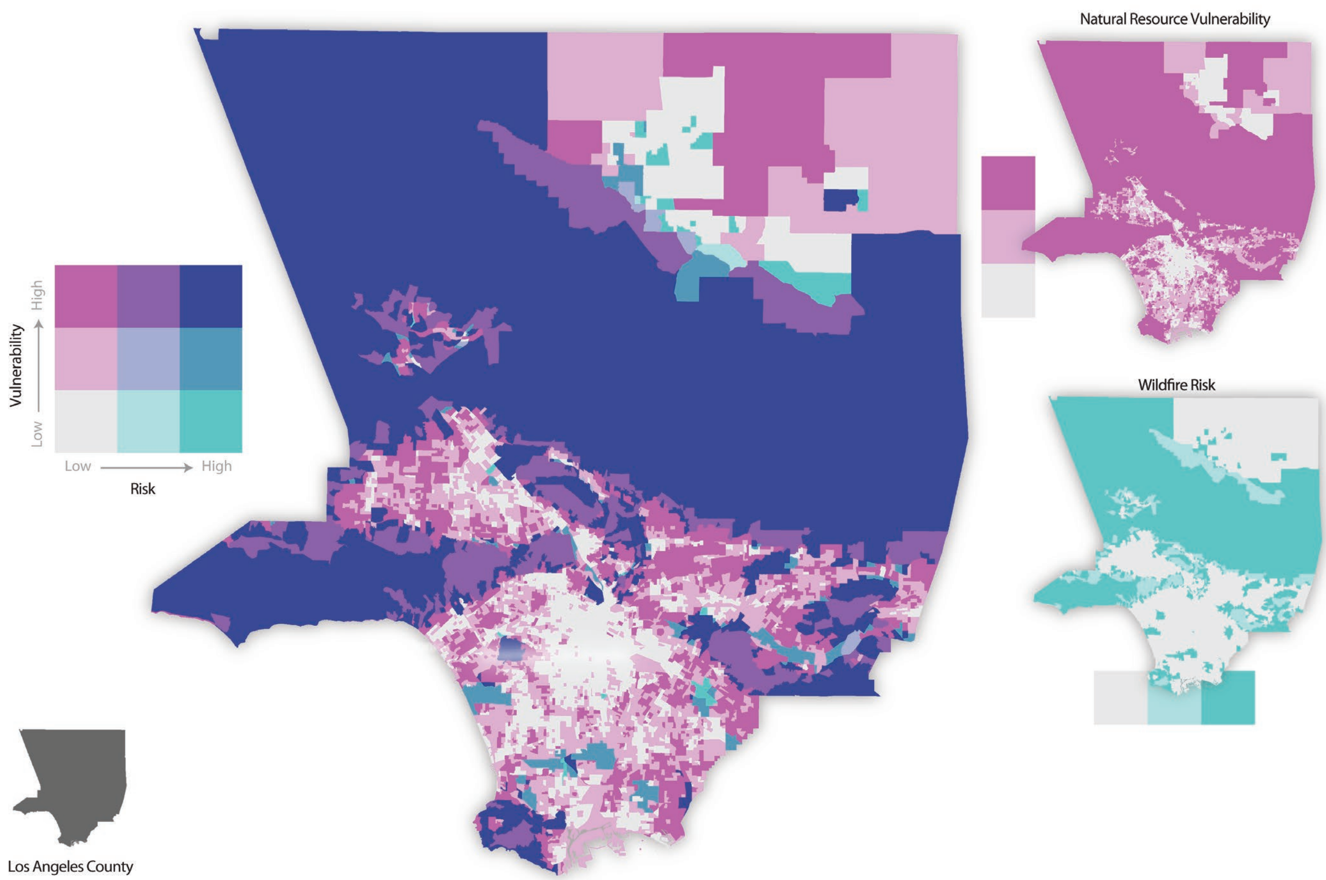

Figure 4.15. Wildfire risk and natural resource vulnerability at the County geography.

Landscape. Credit: Heidi Burkart, NOAA-CSS

4.3.4 Erosion Key Findings

Risk of erosion within the coastal zone was a top concern for local partners, and as a result, erosion risk intersected with social vulnerability (left) and structural vulnerability (right) within the 10-mile coastal band are shown in Figure 4.16. Most of the western region has high erosion risk, but moderate social vulnerability and low structural vulnerability. Pockets of block groups on the northernmost, southernmost, and easternmost edges of this geography have overlapping high erosion risk and high social and structural vulnerability. While there are many dark blue block groups located within central L.A., this erosion profile is reflective of underlying soil characteristics, and is less certain in highly urban environments. Nonetheless, social and structural vulnerability are both high for central L.A.

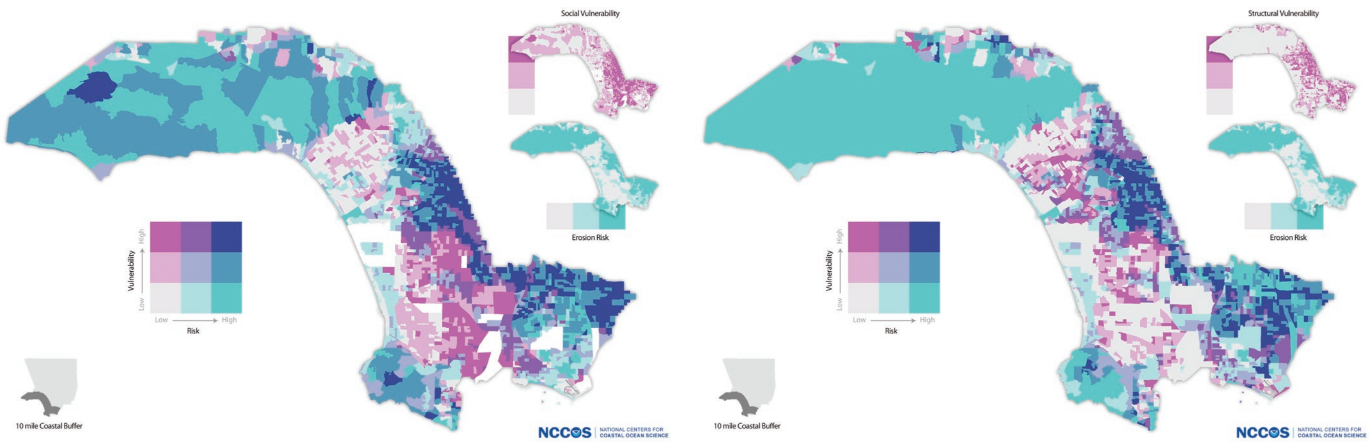

Figure 4.16. Erosion risk intersected with social vulnerability (left) and structural vulnerability (right) for the 10-mile geography.

Erosion risk and natural resources themselves share a delicate relationship, in which the presence of some natural resources can act as a physical deterrent to erosion while other natural resources can increase erosion rates. A more detailed exploration of specific species and other factors would be necessary to draw conclusions on the interactions between natural resource vulnerability and erosion, and are therefore omitted from these findings.

Throughout much of the County, erosion risk is tightly interwoven with risk of flooding and flooding impacts. Figure 4.17 shows structural vulnerability intersected with erosion risk (left) and with stormwater flooding risk (right) for L.A. County. While there are large areas of teal blue, highlighting high erosion risk, on the left map, the areas of dark blue on both maps occur in relatively similar areas. These overlapping areas occur northeast of the Malibu peninsula and hug the south side of the Angeles National Forest, as well as scattered across central and south L.A.

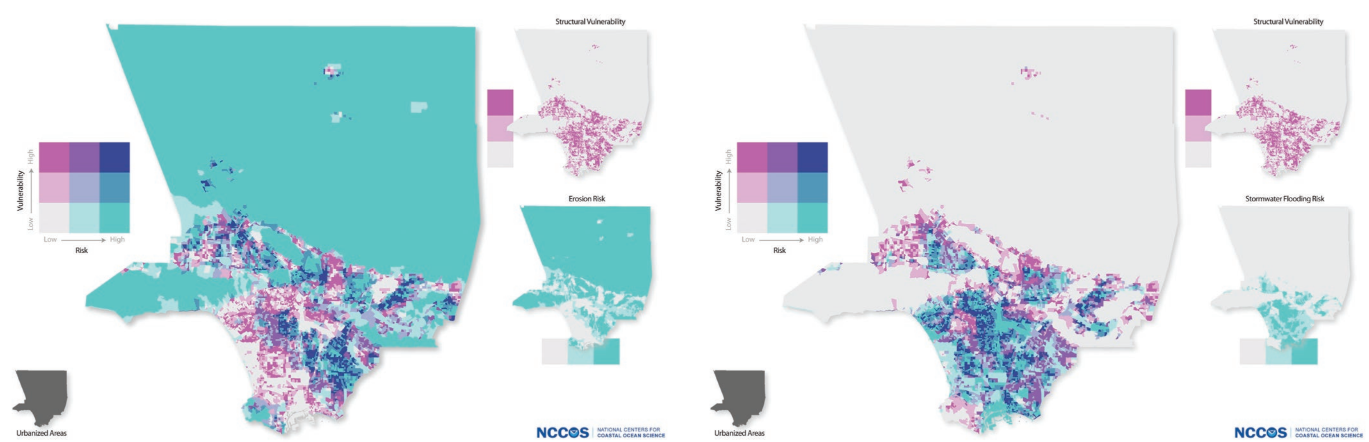

Figure 4.17. Structural vulnerability intersected with erosion risk (left) and stormwater flooding risk (right) for the County.

The similarity in high risk areas for both erosion and stormwater flooding is intuitive since factors such as coastal flooding, precipitation, and wind have been shown to increase erosion potential. Throughout the entirety of the County, erosion risk is impacted by rainfall frequency and intensity, soil conditions, and wind strength and direction (Grifman, Newton Mann, and Sadrpour 2016; Noble Consultants 2016; USDA 2013; Finzi Hart et al. 2012; Breshears et al. 2003). The relationship between stormwater flooding and erosion is complicated, since changes in each influence the magnitude of the other. Increased erosion can lead to more severe stormwater flooding, while increased stormwater flooding can result in increased erosion. Further, mudslides and other forms of gravity erosion can be triggered by intense rain events and the underlying erosion potential (Tchekmedyian, Mejia, and Livingston 2018; Xu et al. 2015).

Erosion risk has great potential to adversely impact built infrastructure in L.A. County. Areas of higher erosion risk and their accompanying infrastructure are more prone to mudslides and landslides, especially when these areas are further subjected to earthquakes, winter storms, or intense or prolonged rainfall (USGS 2019c). Slip soil maps for southwestern California highlight the inherent dangers to infrastructure throughout much of L.A. County. These maps show “relative susceptibility of hill slopes to the initiation sites of rainfall-triggered soil slip-debris flows” (Morton, Alvarez, and Campbell 2003). Many of the mapped susceptibility areas correspond with locations of dark blue block groups in Figure 38 (Morton, Alvarez, and Campbell 2003), as do USGS accounts of historical and often fatal debris flows in the Santa Monica Mountains and surrounding area (Campbell 1975). Erosion risk and debris flow susceptibility are further exacerbated following a wildfire, and the rainfall required to trigger a landslide is greatly reduced. Following L.A. County’s Colby Fire in 2014, USGS completed a preliminary hazard assessment, and found increased probability of debris-flow generation within the burn footprint (USGS 2019c; USGS 2014).

In addition to the exacerbated impacts that stormwater flooding (and wildfire) can have on erosion-prone areas and the structures dependent on those soils, the initial precipitation itself can also impact structures through wind-driven rain surface erosion. Wind-driven rain impact has been shown to erode historic masonry building façades (Erkal, D’Ayala, and Sequeira 2012). Areas of cultural significance in L.A. County may therefore be exposed to additional risk from extreme precipitation events (see other reference to historic spaces in section 5.3).

Blufftop infrastructure. Credit: Heidi Burkart, NOAA-CSS

4.3.5 Coastal and Stormwater Flooding Key Findings

While flooding impacts large portions of the County, social vulnerability is intersected with coastal flooding risk (left) and stormwater flooding risk (right) for the 10-mile coastal geography in Figure 4.18. When considering coastal flooding risk, there are dark blue block groups primarily around the port complex and the southeastern region of the study area. The port complex area increases in its combined vulnerability and risk when stormwater flooding is examined. Further, there is a corridor of intersecting high social vulnerability and high stormwater flooding risk in the center of the study area adjacent to the L.A. River, likely in part due to the lack of permeable surfaces, lower elevations, flatter slopes, and historical context of this area (i.e., much of this area was wetlands, historically).

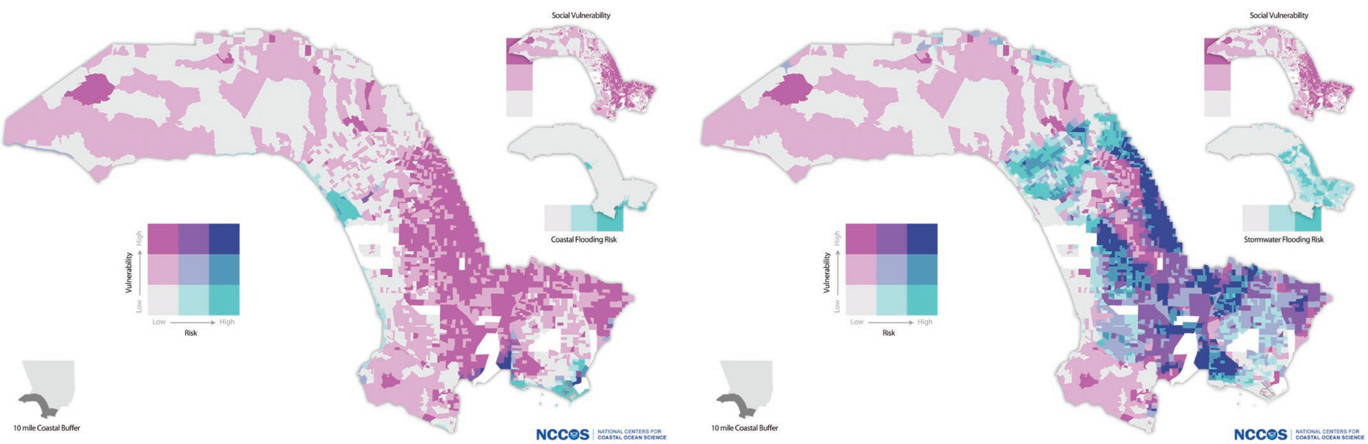

Figure 4.18. Social vulnerability intersected with coastal flooding risk (left) and stormwater flooding risk (right) for the 10-mile coastal geography.

Figure 4.19 portrays a more holistic flooding profile with combined flooding risk (see section 4.2 for profile details). This profile is similar to the right image in Figure 4.18, but pulls some of the flooding risk closer to the coast.[23] The dark blue block groups around the port complex in Figure 4.19 are further contextualized in Figure 4.20, which shows a detailed view of high social vulnerability around the L.A. port complex. The "Westside neighborhood" stands out as highly vulnerable, and is bordered by the L.A. River to the East and

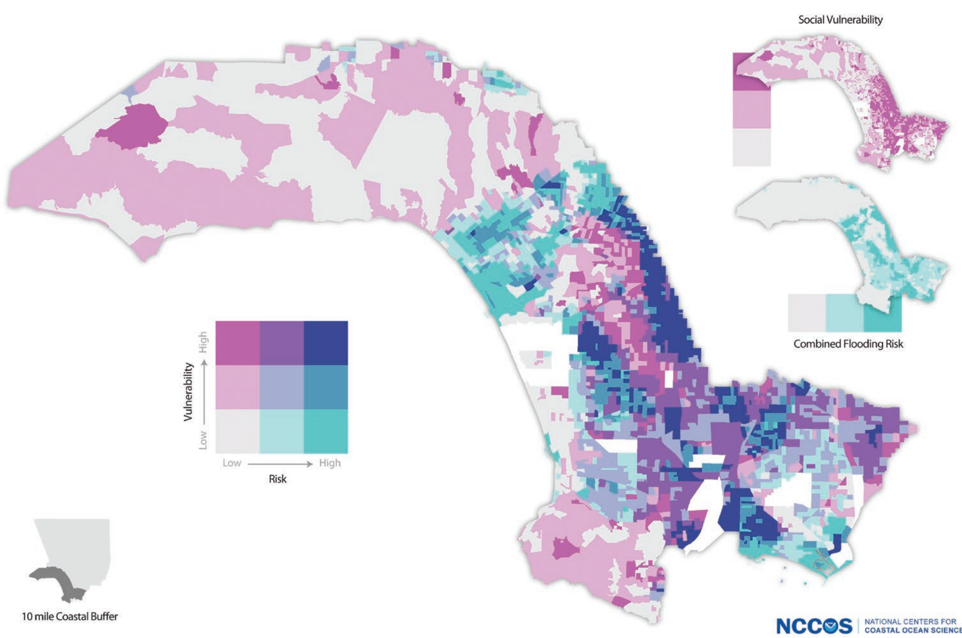

Figure 4.19. Social vulnerability intersected with combined flooding for the 10-mile coastal geography.

[23]For a more detailed comparison among coastal flooding, stormwater flooding, and combined flooding, see Appendix D.

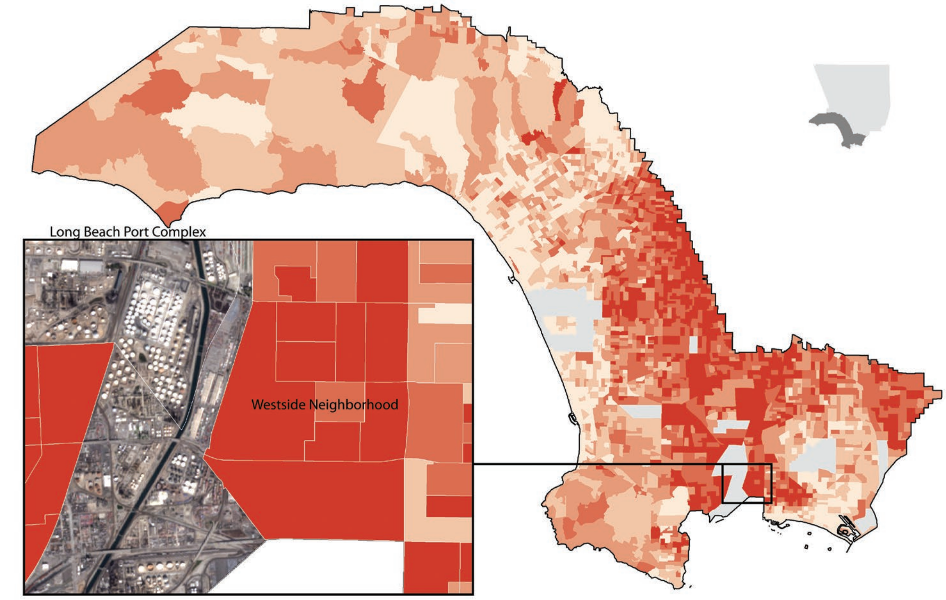

Figure 4.20. Inset map of social vulnerability around the port complex.

the port complex to the West, leaving it susceptible to flood risk. While at risk of flooding, this same area has high structural vulnerability and natural resource vulnerability as well (Figure 4.21 and Figure 4.22). These findings align well with the conclusions of previous vulnerability analysis for the City of L.A. (Ekstrom and Moser 2013; Grifman et al. 2013).

In addition to the port complex area described above, there are other pockets of high structural vulnerability and high combined flooding risk within the 10-mile coastal geography, including many of the same block groups that are highlighted for combined flooding and social vulnerability. The high risk/high vulnerability block groups are concentrated within the highly urbanized City areas, but also occur closer to the coast within roughly five miles (Figure 4.21).

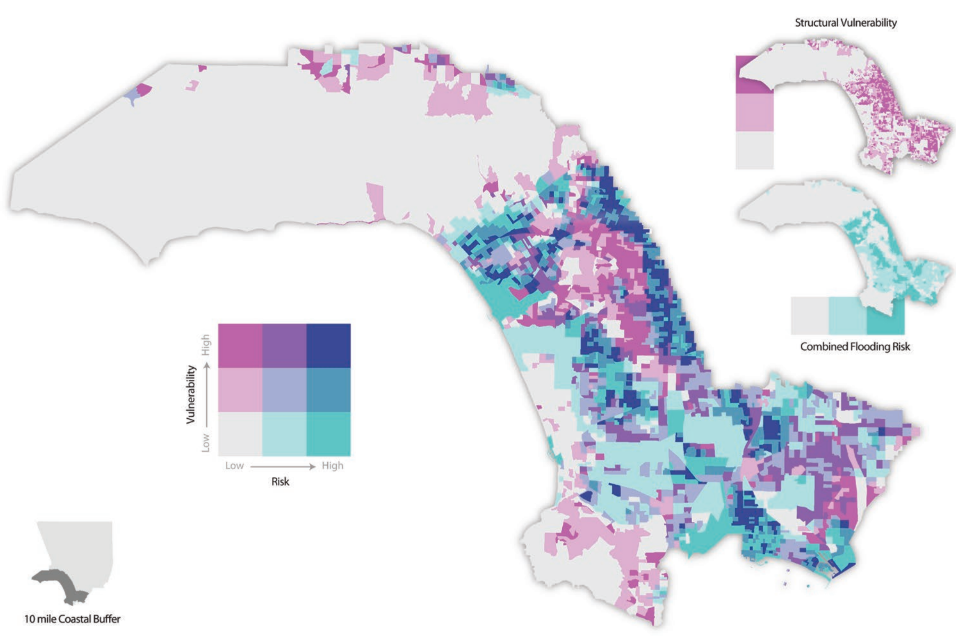

Figure 4.21. Combined flooding risk intersected with structural vulnerability for the 10-mile geography.

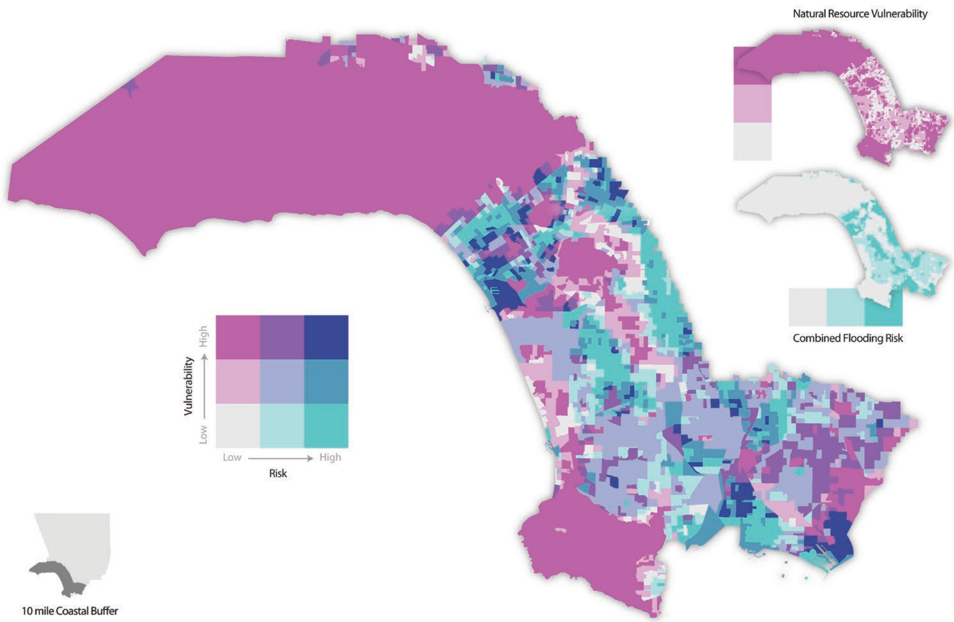

Figure 4.22. Combined flooding risk intersected with natural resource vulnerability for the 10-mile geography.

Overlapping areas of high natural resource vulnerability and high combined flooding risk follow a different pattern despite sharing overlap within the port complex area. Figure 4.22 shows areas of high risk and high natural resource vulnerability occurring farther from the highly urban corridor and instead scattered more sporadically throughout the eastern half of the study area. Some notable areas include around the Venice canals, Santa Monica, and northeast of there, as well as the southeastern tip of the geography.

The spatial correlation between high social vulnerability and flood risk is a phenomenon that likely extends to the history of the settlement of L.A., and will likely continue into the future. Before recent gentrification, impoverished parts of L.A. tended to be marginal land within the confines of existing development, such as the historic parts of the City along the L.A. River (Hanson and Marty 2012), and this was enabled by a lack of central planning (Cuff 2002). Worldwide, settlement around water tends to trade off small, daily risks (such as the need for water in desert conditions) with large, longer-term risks (such as 100-year flood storms) – and also depends on the societal needs and demands of the moment (Nelson et al. 2010). Looking forward, as the impacts of sea level rise become more apparent, housing markets are demonstrating the demand for houses at elevation, a process recently named climate gentrification (Keenan et al. 2018), but a process that is far from new (Pinke et al. 2016). The higher prices for houses outside of a flood zone mean that they can become out of reach for more socially vulnerable parts of the population.

Los Angeles city with hills and mountains. Credit: David Mark, Pixabay

Wetlands southeast of Venice Canals. Credit: Chloe Fleming, NOAA-CSS

Chapter 5: Coastal Analysis Results and Discussion

All maps shown in Chapter 5 can be viewed in greater detail within the mapbook found in Appendix D. Again, due to the complexity of the bivariate choropleth maps, labels have been omitted from those maps; please see Figures 2.1, 2.11, and 2.12 for labeled geography reference maps, or visit Appendix D for full-detail bivariate choropleths.

5.1 FLOOD INSURANCE CLAIMS AND PROPERTY VALUE

Out of the over 30,000 NFIP records for L.A. County dating back to 1977, there were 2,941 claims filed, and the majority (83%; 2,454) of those fell within the 10-mile coastal band geography (Table 5.1). There is a primary concentration of claims occurring in the northern portion of L.A. County's coast around the City of Malibu (Figure 5.1). This area also happens to have a high potential risk of erosion and some of the highest total property values per block group in the County.

Table 5.1. NFIP claims count and total dollars paid out for each assessment geography.

Geography	Count	Count (%)	Total Paid Out (2017 Dollars)	Total Paid Out (2017 Dollars) (%)
Coastal 10 mile	2,454	83%	$45,822,436	92%
Urban	986	34%	$19,924,706	40%
L.A. County	2,941	100%	$50,029,962	100%

There is a weak, yet statistically significant positive correlation between the claims amounts paid out and property value (Kendall tau = 0.22; $p<2.2e-16$). Areas with higher claims amounts paid out are more likely to have some of the highest property values found within the 10-mile coastal band. Although it is expected to see a proportionality between the cost of losses incurred and the value of the property damaged, the data indicate that the large majority of claims are occurring in the northern portion of the coastal band. A significant cluster ($p<0.05$) of block groups around Malibu has the highest incidence of claims amounts paid out and property value in the coastal band. Alternatively, a significant cluster of block groups around the south-central

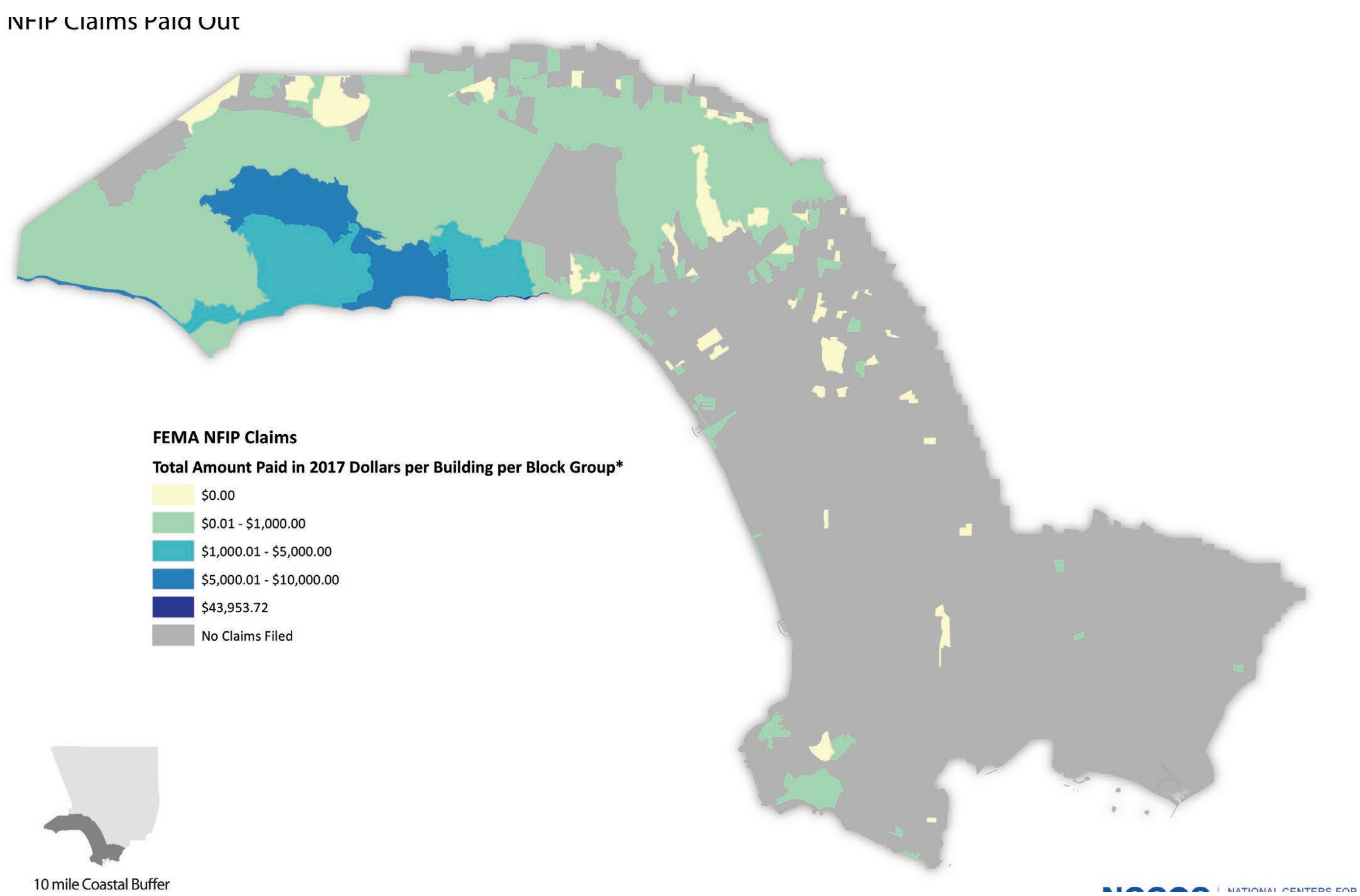

Figure 5.1. NFIP claims paid out.

area of the coastal band (i.e., Inglewood, Compton, Paramount, etc.) has the lowest amount of claims paid out and low property value (Figure 5.2).

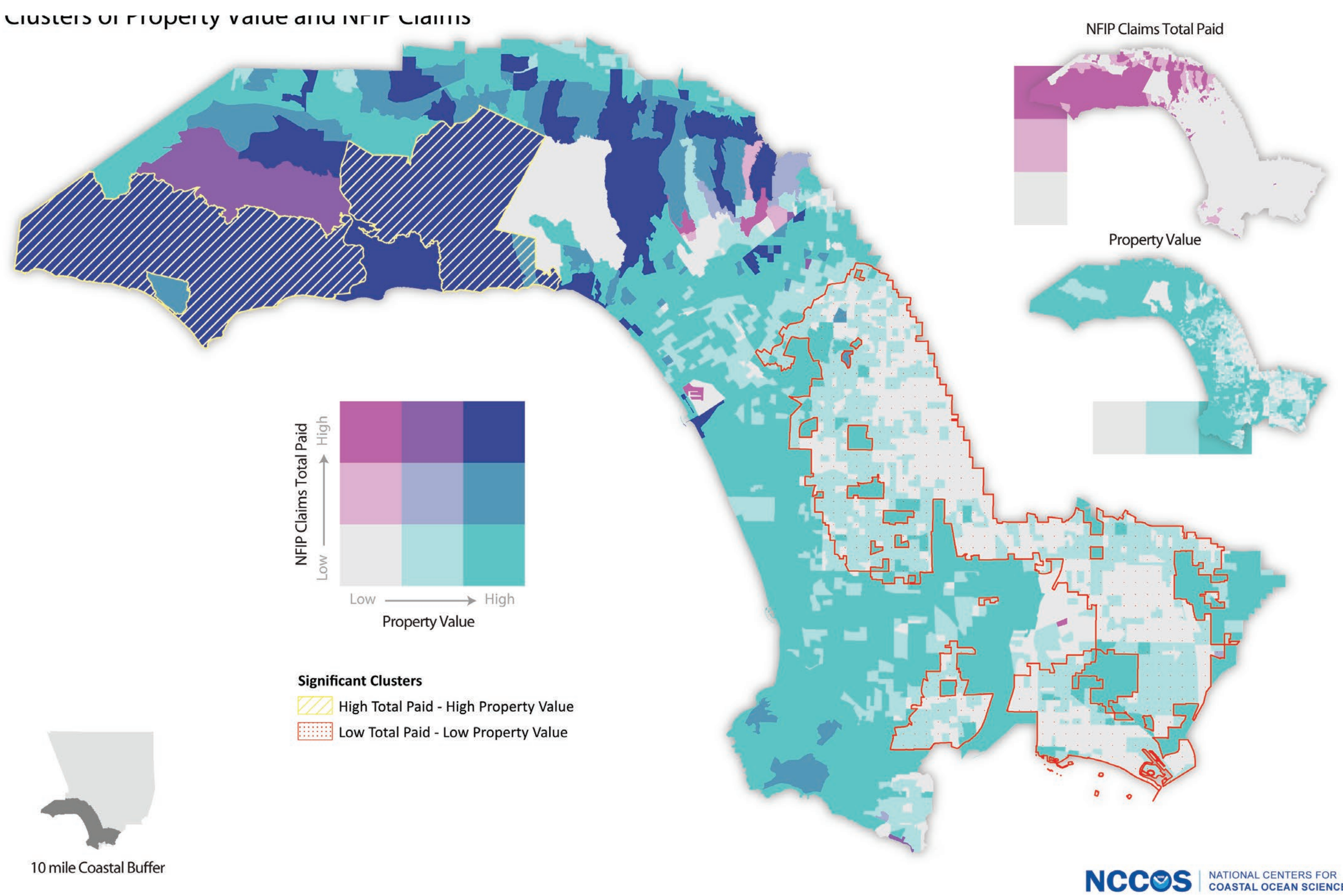

Figure 5.2. Clusters of property value and NFIP claims.

A weak, yet statistically significant positive correlation also exists between the claims amounts paid out and erosion risk (Kendall tau = 0.08; p=2.59e-6). Areas with higher claims amounts paid out are more likely to have high risk of erosion. A significant cluster (p<0.05) of block groups representing high claims amounts paid out and high erosion risk can be seen around the Malibu area. Alternatively, there is also a statistically significant cluster (p<0.05) of block groups that has low claims amounts paid out, yet high erosion risk; this cluster falls within the same southern area of the coast where lower property values are found (Figure 5.3).

There is a weak, yet significant negative correlation between the claims amounts paid out and combined flood risk (Kendall tau = -0.216; p<2.2e-16). Areas with lower claims amounts paid out are more likely to have high flood risk. A significant cluster (p<0.05) of block groups is seen in the southern area of the coastal band, including near the L.A. port complex, where low claims amounts have been paid out, yet there is a high risk of flooding (Figure 5.4). Areas around Malibu also show significant clusters (p<0.05) that have high claims amounts paid out, yet low combined flood risk. This suggests that perhaps the majority of claims filed in the Malibu area are the result of flooding exacerbated by erosional processes, and are likely also influenced by the increased social capacity to obtain insurance and file claims successfully.

Finally, there is a weak, yet significant negative correlation between the claims amounts paid out and social vulnerability (Kendall tau = -0.108; p=4.79e-11). Areas with lower claims amounts paid out are more likely to have high social vulnerability. As seen in Figure 5.5, there is a significant cluster (p<0.05) of block groups that has low claims amounts paid out and high social vulnerability. This cluster occurs in the same vicinity where lower property values, high erosion risk, and high flood risk are observed; yet, fewer NFIP policies and claims are filed and paid out in this region of the County's coast. Most of these areas identified as having high social

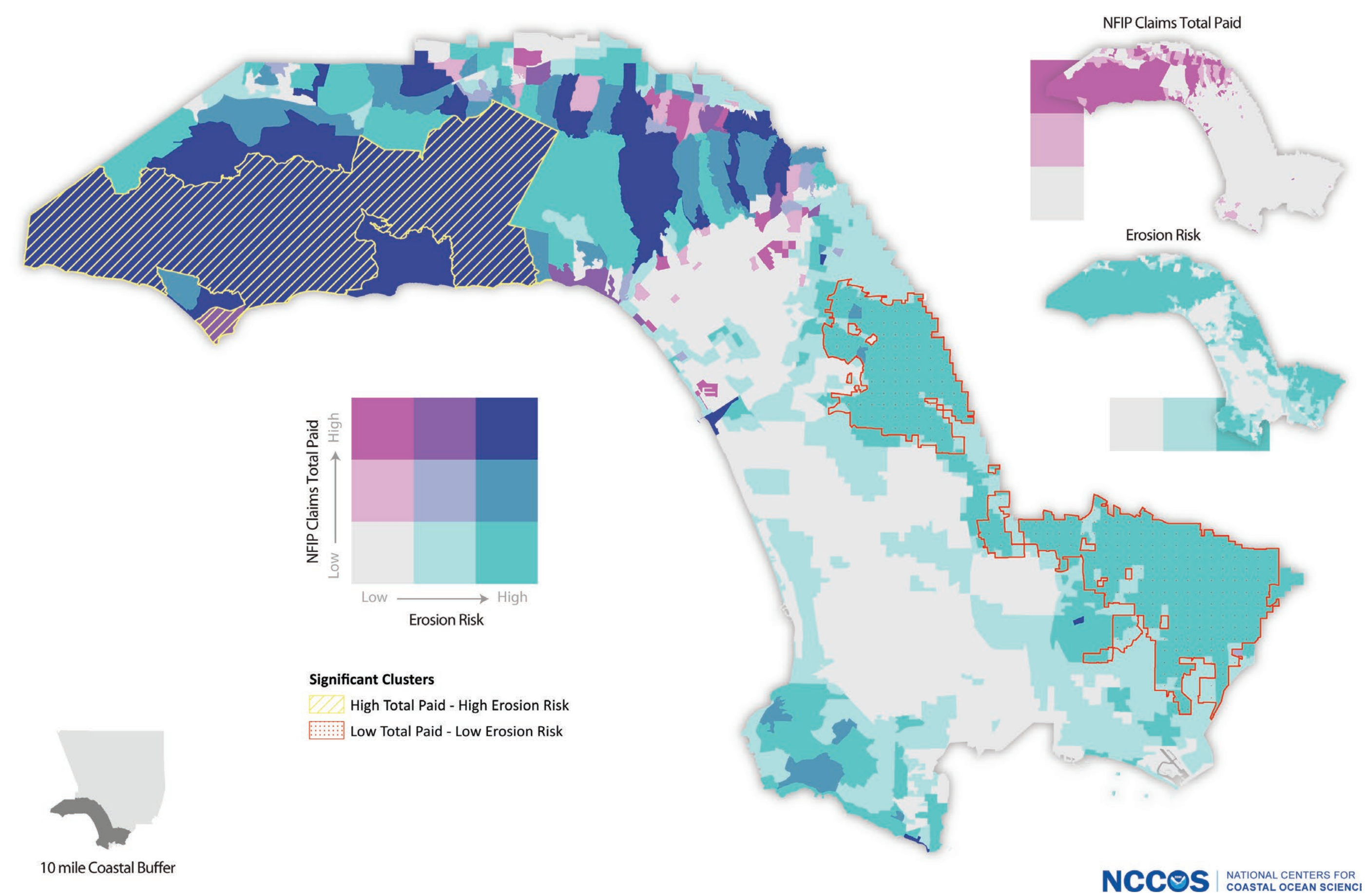

Figure 5.3. Clusters of erosion risk and NFIP claims.

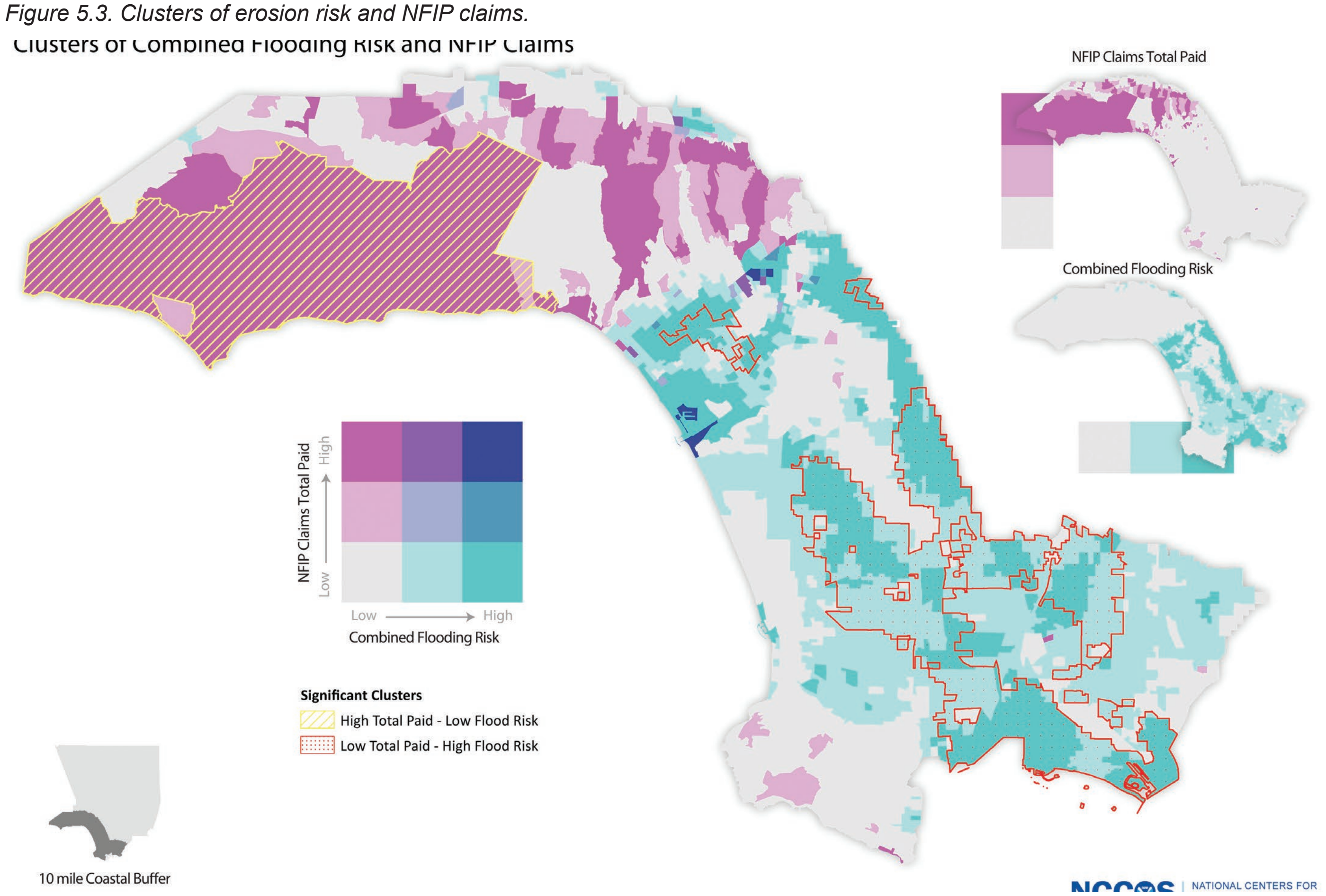

Figure 5.4. Clusters of combined flooding risk and NFIP claims.

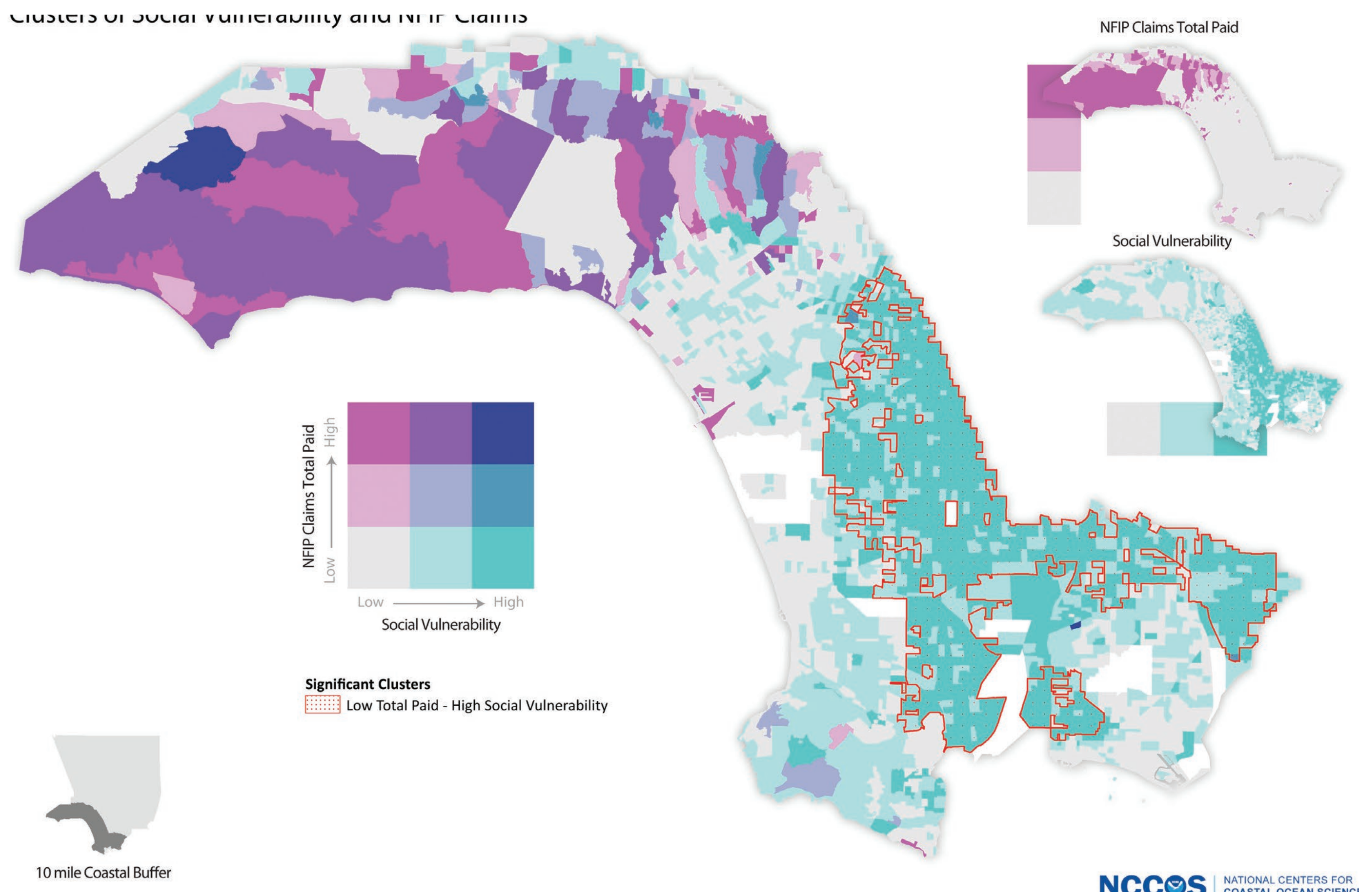

Figure 5.5. Clusters of social vulnerability and NFIP claims.

vulnerability and high flood risk do not fall within a FEMA-designated high hazard floodway (Figure 3.1), which would require property owners with federally backed mortgages to purchase flood insurance coverage. Without the pressing concern of flooding impacts, property owners with fewer resources are perhaps less likely to accept the added expense of flood insurance coverage, especially if it is perceived to be unnecessary.

Across these maps, there are overlapping clusters of lower property values, high erosion risk, high flood risk, low claims paid out, and high social vulnerability in south-central L.A. While these findings are not necessarily surprising, they do speak to a larger phenomenon of equity and means in a natural hazards context. Federal law requires homeowners with a federally backed mortgage to acquire flood insurance in FEMA-designated high-risk flood areas (SFHA zones A, AE, AH, AO, V, and VE in Figure 3.1 in Chapter 3) (FEMA 2019a). Communities or individual property owners are allowed to challenge flood risk zone delineations via a Letter of Map Amendment, but this process can be costly as it may require expensive services, such as the hiring of an engineering firm (FEMA 2019b). As such, this process can be challenging for lower income property owners and communities to implement. Outside of the high-risk zones, flood insurance is optional, although some lenders may still require it (FEMA 2014). There is often a false belief that flood risk changes abruptly at SFHA lines (ASFPM Foundation 2004), rendering voluntary flood insurance futile. Several studies have found that as education of homeowners and home values increase, the likelihood of coverage also increases (e.g., Brody et al. 2016; Atreya, Ferreira, and Michel-Kerjan 2015; Kousky 2011); therefore, it is logical that the inverse of these metrics result not only in fewer paid out NFIP claims, but likely also the decision to forego optional flood insurance policies in the first place.

Some critiques of FEMA's flood maps emphasize the shortcomings in how flood zone mapping is prioritized and implemented. For example, FEMA mapping priorities appear to be focused in highly developed areas with a known high risk of flooding (Pralle 2019). This leaves many rural areas unmapped. As seen in Figure 3.1 in Chapter 3, while the majority of L.A. County falls within the designation of SFHA zone X (moderate or minimal flood hazard), most of the rural areas within L.A. County fall within Zone D designation (undesignated or unmapped) (FEMA 2018a; FEMA 2017). An additional caveat to FEMA's flood mapping is that the maps do not account for future risk in relation to climate change and rely primarily on historical data. With flood mapping so tightly integrated with the NFIP, FEMA's ability to efficiently communicate risk through these maps is limited. While the program provides relief to many who experience loss, many communities falling outside of high-risk flood zones may be left with a false sense of security. Likewise, many uninsured property owners and unsuspecting vulnerable communities may be left susceptible to loss in the wake of a flooding event that is not declared a formal Presidential disaster. In the event that the President enacts a Major Disaster Declaration, a variety of federal assistance and emergency services may be made available to both individuals, certain nonprofit organizations, and State, Tribal, and local governments (FEMA 2020a). Although limited, under FEMA's Individuals and Households Program (IHP), federal assistance can be provided to cover uninsured losses due to a major disaster (FEMA 2020b). For instance, Hurricane Harvey made landfall in Louisiana and Texas in 2017, causing unprecedented flooding in the Houston area where the majority of homeowners lacked flood insurance coverage. While a Major Disaster Declaration was declared by the President for the State of Texas, many homeowners faced major out of pocket expenses to repair damages; those expenses included low interest loans provided via federal assistance (Condon and Sweet 2017).

The City and County of L.A. have both employed mitigation plans which identify and evaluate the various risks and vulnerabilities as well as potential solutions or methods of increasing preparedness and resilience (County of Los Angeles 2019; City of Los Angeles EMD 2018). These plans meet a core requirement of FEMA's Community Rating System (CRS), a voluntary program within the NFIP which incentivizes risk adverse floodplain management activities within a community (FEMA 2020c). Both the City and County are participants of the CRS, thus achieving the goals of the CRS by reducing future flood damage, aiding in the successful implementation and improvements of the NFIP, and adopting a comprehensive approach to floodplain management. As a result, the L.A. community is rewarded with discounted flood insurance premium rates and an improved approach to floodplain management activities. The CRS program is designed to encourage communities to actively promote awareness of flood insurance, maintain flood maps, and improve regulations such as zoning codes in an effort to reduce the potential future threat of major flooding events to a variety of property owners and individuals at risk.

King Tide at Alamitos Bay shore in Long Beach. Credit: California King Tides Project

5.2 ACCESS TO GREEN SPACE

Tested statistically, greenness is negatively correlated with social vulnerability (Kendall tau = -.165 and p=2.2e-6), where areas with low greenness are more likely to have high social vulnerability. Variability of social vulnerability is also much greater in the low greenness areas than in the high greenness areas, so there is a wide range of social experiences in the low greenness areas. This finding supports similar findings looking at median income level in L.A. (Wilson and Belonis 2004) as it relates to greenness derived from NDVI, including the high variability. Both of these findings can be partially explained by documented inequalities in park and recreation expenditures in L.A. County, where middle-income neighborhoods are preferentially given grants, land, and other resources necessary for creating and maintaining parks (Joassart-Marcelli 2010).

While the statistics are compelling, they indicate a correlation, not causation. The causation likely runs in both directions. Greenness is associated with increased property values at both the individual property and neighborhood scale (Bark et al. 2011); therefore, people with less means likely choose houses elsewhere. Conversely, high social vulnerability may mean fewer resources and time to spend on landscaping and caring for green plants, especially in arid environments. Of note, 19 block groups do not follow the trend and have both high greenness values and high social vulnerability scores. These are almost entirely due to green public spaces in schools or small city parks, emphasizing the importance of public investment in green space.

These important areas of low greenness and high social vulnerability are geographically clustered and therefore also have a risk profile associated with that geography. Figure 5.6 shows block groups in the low greenness/high social vulnerability clusters outlined over the combined flood risk profile, which is the most striking of these comparisons. This relationship makes sense given the settlement pattern of L.A., with low-lying river valleys settled first and now constituting the urban core.

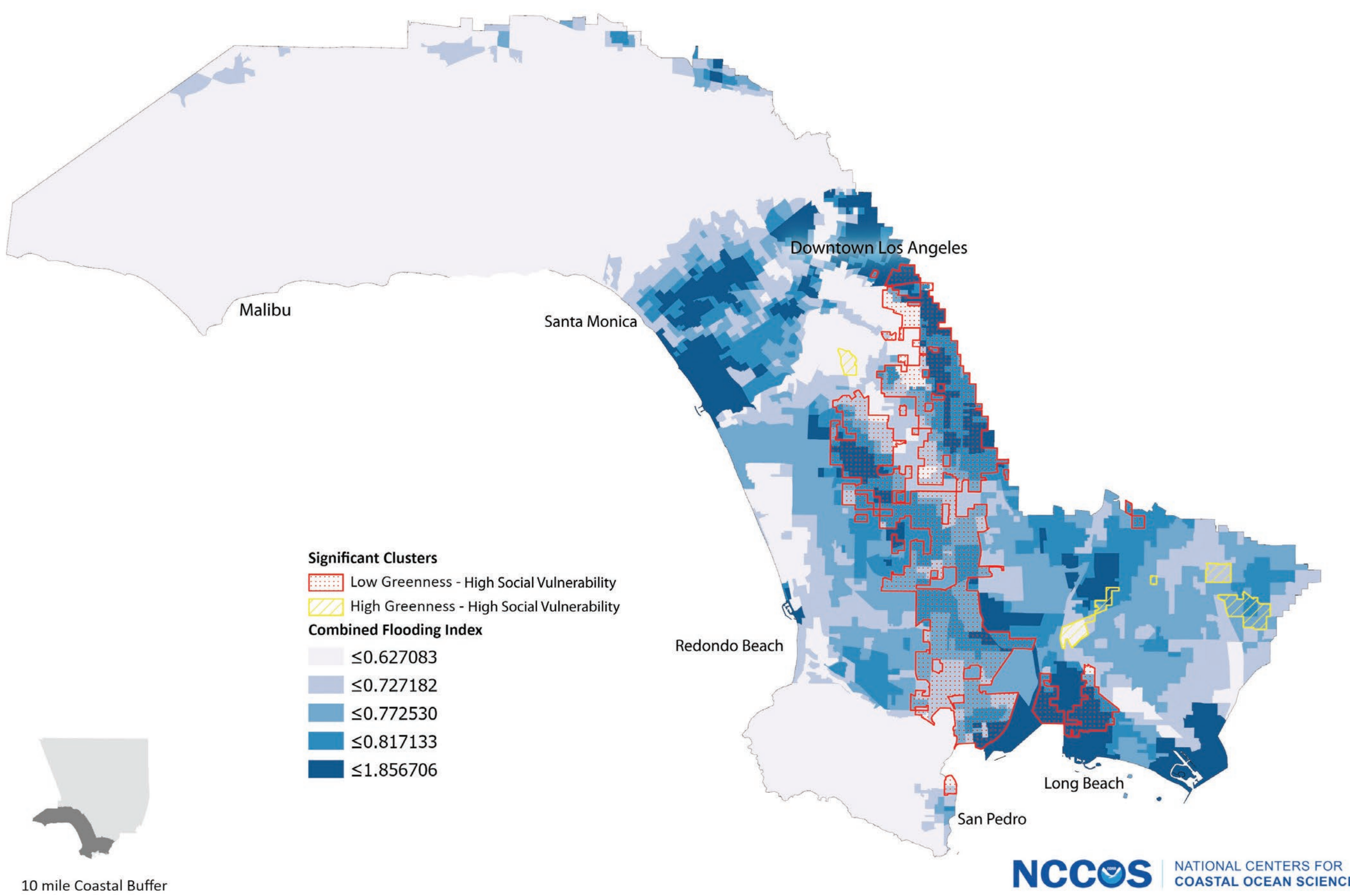

Figure 5.6. Areas of low greenness/high social vulnerability with combined flooding risk.

The highlighted areas are largely the densely populated areas of the City of L.A., many of which border the L.A. River, and are therefore largely impacted by concrete construction. This concrete would both increase flooding and limit opportunities for plant growth. That said, river-focused programs are already active in the sustainability arena, such as the L.A. River Revitalization Project (City of Los Angeles 2020), and this finding supports the need for efforts like theirs. The areas of high social vulnerability also stand to gain the most from public programs or community development grants aimed at increasing capacity to respond to environmental concerns. Areas of high social vulnerability that also have low greenness represent an opportunity to optimize investments by helping both greening efforts and social resilience efforts. For example, a rain garden placed in a highly vulnerable neighborhood can reduce flood risk and increase psychological well-being simultaneously.

From a policy and management perspective, there is a network of Sustainability Plans and Climate Adaptation Plans that fit together like puzzle pieces to address concerns of resilience in L.A. County. These plans are emerging and evolving rapidly, but the Los Angeles Regional Collaborative (LARC) has a summary and map on their website to track new plans as they become available.[24] For the areas of high social vulnerability and low greenness that also have high flood risk, three existing Sustainability Plans might be leveraged as a place to find resources for addressing the nexus of concerns: Hawthorne, Long Beach, and the City of L.A.

The 2019 Sustainable City pLAn, L.A.'s Green New Deal, has a section dedicated to greenness and equity concerns. Excerpts from the section, titled "Urban Ecosystems and Resilience", are found in Exhibit 2 (City of Los Angeles 2019).

Exhibit 2: Excerpts from L.A.'s Green New Deal "Urban Ecosystems and Resilience" section

"Reduce urban/rural temperature differential by 1.7 degrees by 2025; and 3 degrees by 2035" (p. 122) with milestones and initiatives that include:

- "pilot 6 cool neighborhoods in vulnerable communities by 2021; and 10 by 2025" (p. 122)
- "install cool pavement material on 250 lane miles of City streets, prioritizing neighborhoods with the most severe heat island effect" (p. 122)
- "all new roofs must be cool roofs by 2020; and install 13,000 additional cool roofs by 2021" (p. 122)

"Ensure proportion of Angelenos living within ½ mile of a park or open space is at least 65% by 2025; 75% by 2035; and 100% by 2050" (p. 124) with milestones and initiatives that include:

- "add at least 8 parks by 2021; and 30 parks by 2025" (p. 124)
- "establish 25 joint-use parks in underserved communities" (p. 124)

"Increase tree canopy in areas of greatest need by at least 50% by 2028 to grow a more equitable urban forest that provides cooling, public health, habitat, energy savings, and other benefits" (p. 120) with milestones and initiatives that include:

- "plant and maintain at least 90,000 trees citywide" (p. 120)
- "complete citywide tree inventory by 2021; and an Urban Forest Management Plan by 2025" (p. 120)
- "update and align City policies and procedures to grow and protect public and private trees" (p. 120)

The 2010 City of Long Beach Sustainable City Action Plan contains initiatives that address greenness and social vulnerability. Relevant sustainability goals from the section, titled "Urban Nature," are highlighted in Exhibit 3 (Long Beach Office of Sustainability 2010).

Exhibit 3: Excerpts from City of Long Beach's Sustainability Plan

"Urban Nature" (p. 25) lists sustainability goals, including:

- "plant at least 10,000 new trees in Long Beach by 2020" (p. 25)
- "create 8 acres of open space per 1,000 residents by 2020" (p. 25)
- "create 100 miles of green linkages by 2020" (p.25)

[24] http://www.laregionalcollaborative.com/la-cap-map/

The City of Hawthorne Plan, known as the ‘Green Initiative’, was rolled into their Climate Action Plan. Two goals within the climate plan address greenness, and are outlined in Exhibit 4 (South Bay Cities Council of Governments 2017). Additionally, many of these goals include several GHG reduction measures.

Exhibit 4: Excerpts from City of Hawthorne’s Climate Action Plan

Energy Efficiency: “Decrease energy demand through reducing urban heat island effect” (p. 50) with specific measures to include:

- “promote tree planting for shading and energy efficiency” through encouraging tree planting, working with community to develop a tree-planting group, and developing a City tree planting program
- “incentivize or require light-reflecting surfaces” through requiring or incentivizing cool roofs and cool pavements

Urban Greening: “Increase and maintain urban greening in the community” (p. 66) with specific measures to include:

- “increase community gardens” (p. 67) through establishing and maintaining a community garden, promoting gardening and composting, and organizing a tool lending program and bounty exchange
- “increase rooftop gardens” (p. 68) through incentivizing rooftop gardens and promoting rooftop gardens for residential and commercial buildings
- “restoration/preservation of landscapes” (p. 69) through landscape, open space, and tree maintenance
- “increase open space” (p. 70) through creating new green or open spaces

While there is not a unified plan for the whole County, these individual plans point to the potential for some win-win-win scenarios for natural resource preservation, flood protection, and reduction of social vulnerability. The recommendations tend to be small-scale projects that affect a single neighborhood, but many of those neighborhoods are likely the least able to provide the necessary resources for such a project. This suggests an opportunity for regional grants or capacity building efforts to participate in leveraging multiple types of benefits that result from a single investment. In addition to local initiatives to address greenness, flood protection, and social vulnerability, L.A. County has attempted to mitigate stormwater flooding concerns through implementation of a large-scale stormwater property tax. This tax, enacted in 2019, taxes parcel property owners within the County’s Flood Control District (slightly over one fourth of the County’s total land area) (LACPW 2020) 2.5 cents per square foot of impermeable space in an effort to raise funds to better capture and clean stormwater, improve water quality, and provide community benefits through parks and wetlands (Agrawal 2018).

Echo Park in Los Angeles. Credit: Betsy M. Hall, Pixabay

5.3 ACCESS TO CULTURAL/HISTORIC SPACE

When examining the relationship between the presence of cultural resources (as registered with the National Register of Historic Places) and social vulnerability, there is a significant difference between those with historic places and those without (p=.000747 from ANOVA): block groups with historic places have lower social vulnerability. While for the County as a whole this would be a counterintuitive finding, this relationship in the 10-mile coastal band includes a large number of historic waterfront properties, and waterfront tends to have lower social vulnerability.

Since the National Register of Historic Places is a conservative and limited inventory of cultural resources, and because the relationship between cultural resources and social vulnerability was counterintuitive, further analysis looked at all cultural resources in the 10-mile coastal band and how they overlaid with risk. The cultural resources are spread throughout different levels of risk for most of the risk types, except for flooding (Figure 5.7). This conclusion mirrors the priority areas of low greenness/high social vulnerability, but adds waterfront areas, and therefore supplies more evidence of the need to focus on flood prevention.

Perhaps the confluence of historic structures and cultural spaces with flood prone areas is less surprising when discussing the historical context of L.A. Like many early settlements, historic life in L.A. County revolved around rivers. The L.A. and San Gabriel rivers provided water for early settlers, and later the San Pedro Bay allowed for trade. Much of the development that followed was concentrated in now-downtown L.A. with linkages to coastal ports and access points (LATCB 2019). Unfortunately, as a result, many of the corresponding historical sites are now either at risk of stormwater flooding, coastal flooding, or both. Finding adaptation strategies will require some creative thinking particular to each cultural landmark, but adaptive strategy plans including risk management, emergency planning, and building design will be critical to protect these cultural resources in future flooding events (as suggested by a USC Sea Grant Regional Stakeholder Working Group in Grifman et al. 2013).

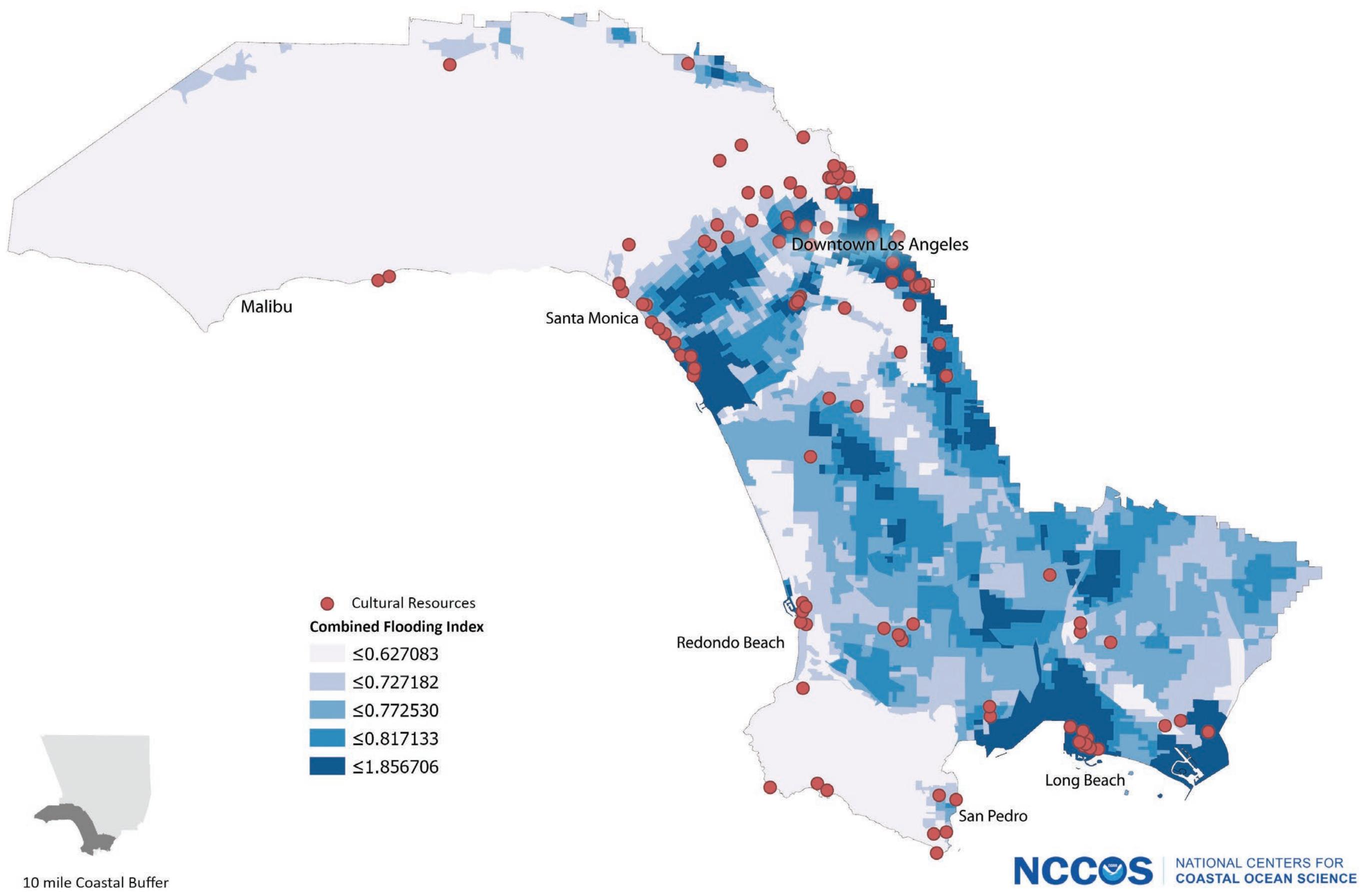

Figure 5.7. Cultural resources and combined flooding risk.

Hollywood sign. Credit: David Mark, Pixabay

5.4 EROSION, FLOODING, AND CRITICAL INFRASTRUCTURE

Figure 5.8 and Figure 5.9 show that the grid-like network of disaster (and often evacuation) routes is fairly evenly spread throughout the 10-mile coastal band, thinning out where mountains limit road-building abilities. It is precisely in these mountainous areas where erosion risk is highest (the western part of the County), but where route redundancy is not guaranteed (Figure 5.8). During disaster situations, routes in high erosion-prone areas are limited. Analysis suggests that the opposite is true in high flood prone areas (Figure 5.9).

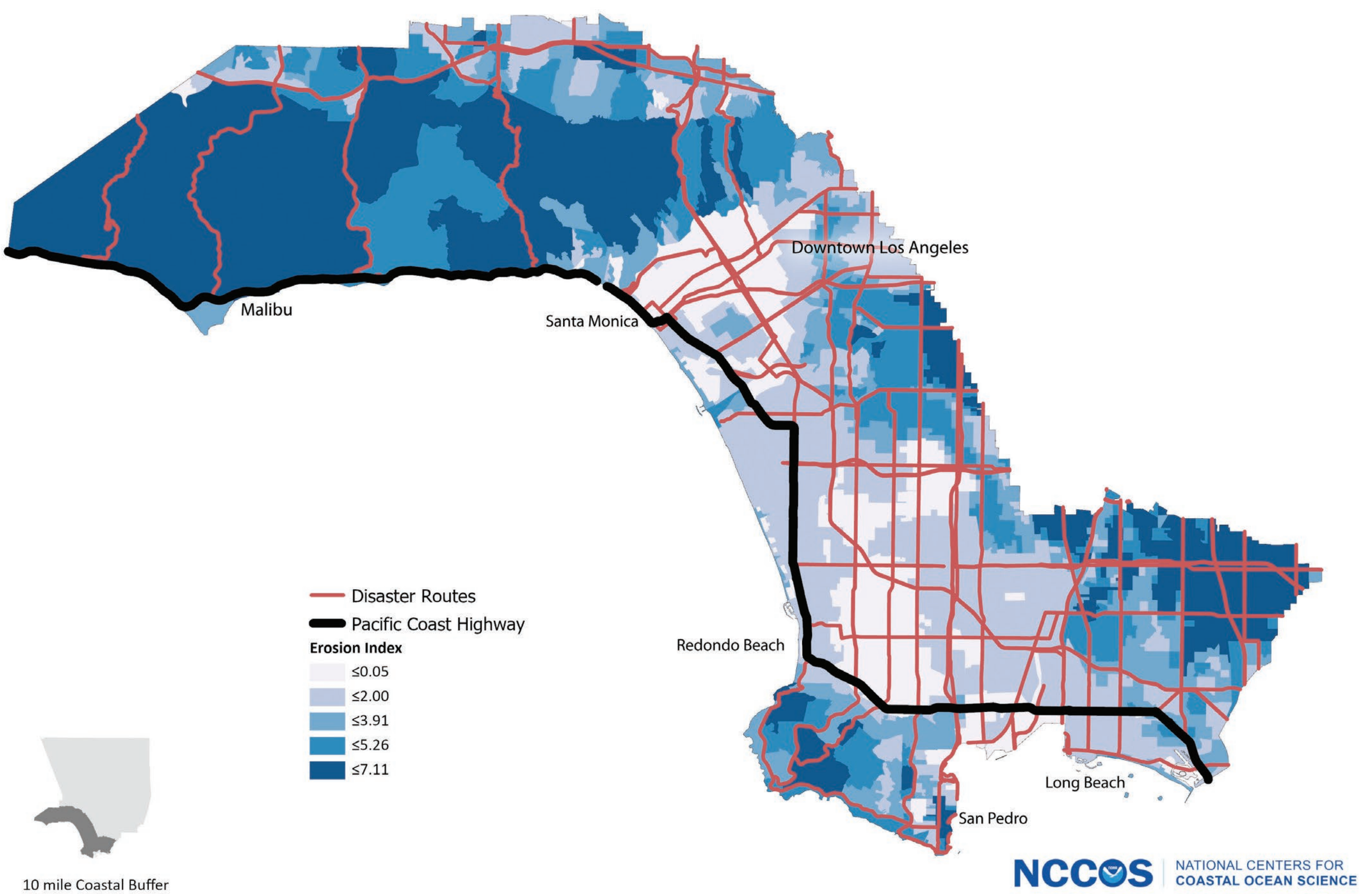

Figure 5.8. Disaster routes and erosion risk.

Figure 5.9 demonstrates that areas of high flood risk generally have various disaster route options. This is positive for redundancy of route options and safety for commuters (i.e., there are multiple routes to take if one of the main routes is unavailable due to flooding or another disruption). If an extreme event results in the damage of all infrastructure within this flood prone area, however, the County, State, and local municipalities may face higher repair costs due to the sheer number of routes affected. These maps show not only the locations of the most at-risk roads in the face of flooding and erosion concerns, but potentially also the locations of the most critical and important roads due to their solitary nature, such as the Pacific Coastal Highway (PCH) that runs along the Malibu coastline.

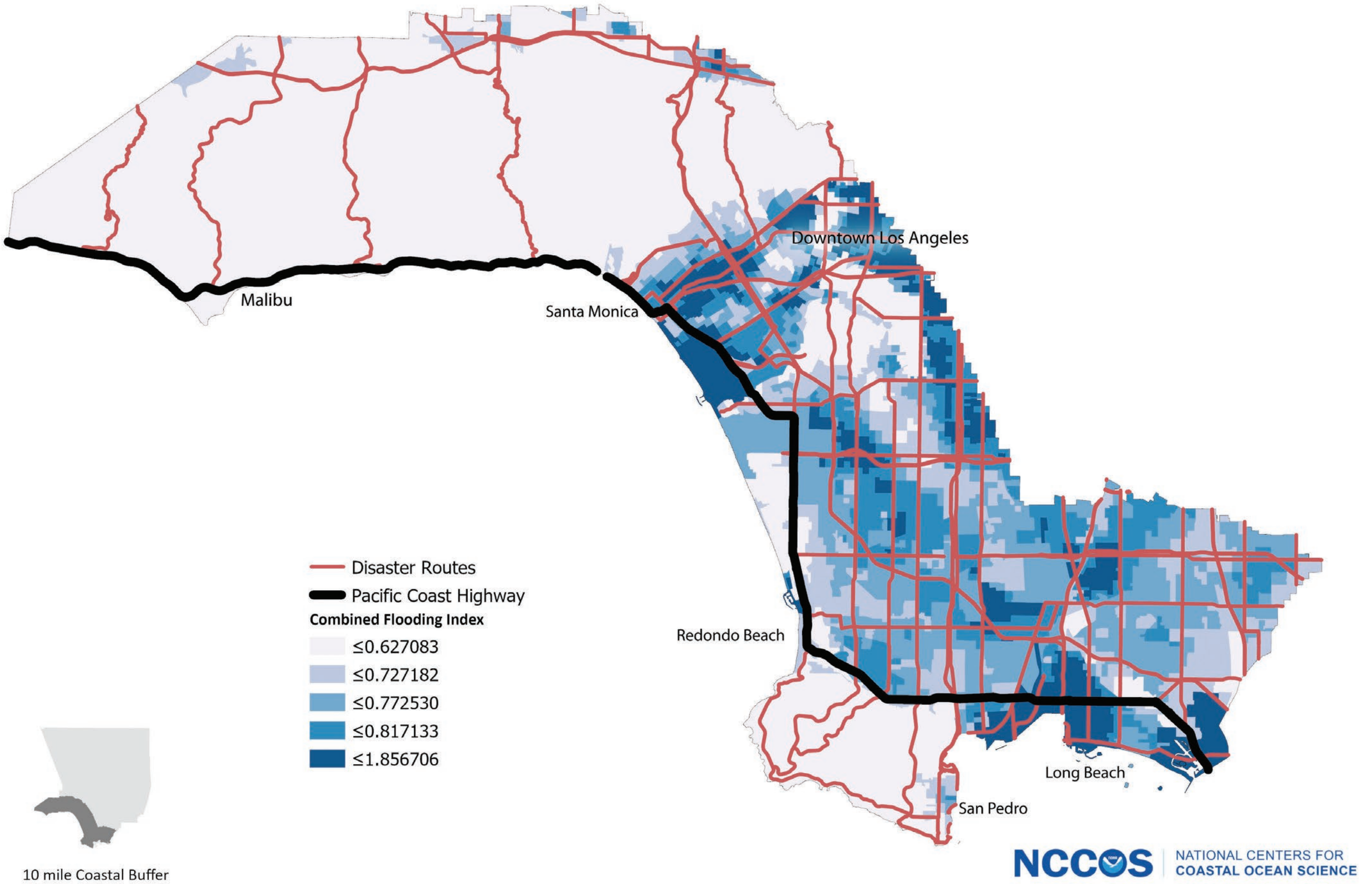

Figure 5.9. Disaster routes and combined flooding risk.

The overlap of disaster routes with high risk areas can be both frightening and challenging in the event of a natural disaster. In 2019, Caltrans assessed potential climate change vulnerabilities to California's State Highway System by district. Their findings for District 7 – Ventura and Los Angeles Counties – suggest not only similar concerns, such as vulnerability to erosion, heat, flooding, and wildfire, but also identify a subset of critical assets for targeted restoration and mitigation efforts. Some parts of the County are already trying to increase their transportation resilience. The City of Santa Monica, for example, proposes to "partner with Caltrans and neighboring jurisdictions on measures to protect critical entry and exit routes such as Pacific Coast Highway (PCH) and Interstate 10" as well as to "work with local agencies to develop contingency plans for operations when the PCH and other roads are inoperable due to coastal flooding or wildfires" (City of Santa Monica 2019, 45).

The challenge becomes even greater when considering the need for rapid evacuations of a large population. Disaster routes are designed to bring in emergency care, rather than to provide residents with evacuation routes. Recent wildfires have raised awareness of the apparent lack of capacity on existing highways to evacuate residents safely. For example, evacuation orders in Malibu during the Woolsey fire in 2018 left people stuck on the PCH for up to seven hours, which could have left them in the path of the fire. Unfortunately, eight of 2018's Camp Fire victims died in their vehicles while trying to evacuate (Walker 2018). The 2019 Caltrans assessment also emphasized a need for greater evacuation planning (Caltrans 2019).

The importance of the PCH in western L.A. County cannot be overstated. In addition to its use during evacuations, many L.A. residents and commuters rely upon the PCH as their main route to and from work, medical appointments, and social outings. Further still, many tourists visit coastal California simply to drive the scenic PCH (National Geographic n.d.). The high erosion risk underlying much of the PCH in western L.A. County (Figure 5.8) could have cascading effects.

5.5 EROSION AND BLUFFTOP DEVELOPMENT

In Figure 5.10, parcels with development added since 1978 are highlighted in red. This newer development is on the outskirts of the historical urban core, spreading generally toward the coastline. In the southern part of the coastal band, this development is primarily in low to medium erosion risk areas; however, there is relatively abundant development in the mountainous Western portion of the County, which is also the most erosion prone. Figure 5.11 shows an example of blufftop development near Loyola Marymount University, on a bluff overlooking the Ballona wetlands. Given that blufftop development occurs at a small scale, a higher resolution study with analytical means of identifying bluffs within the high erosion areas may be helpful.

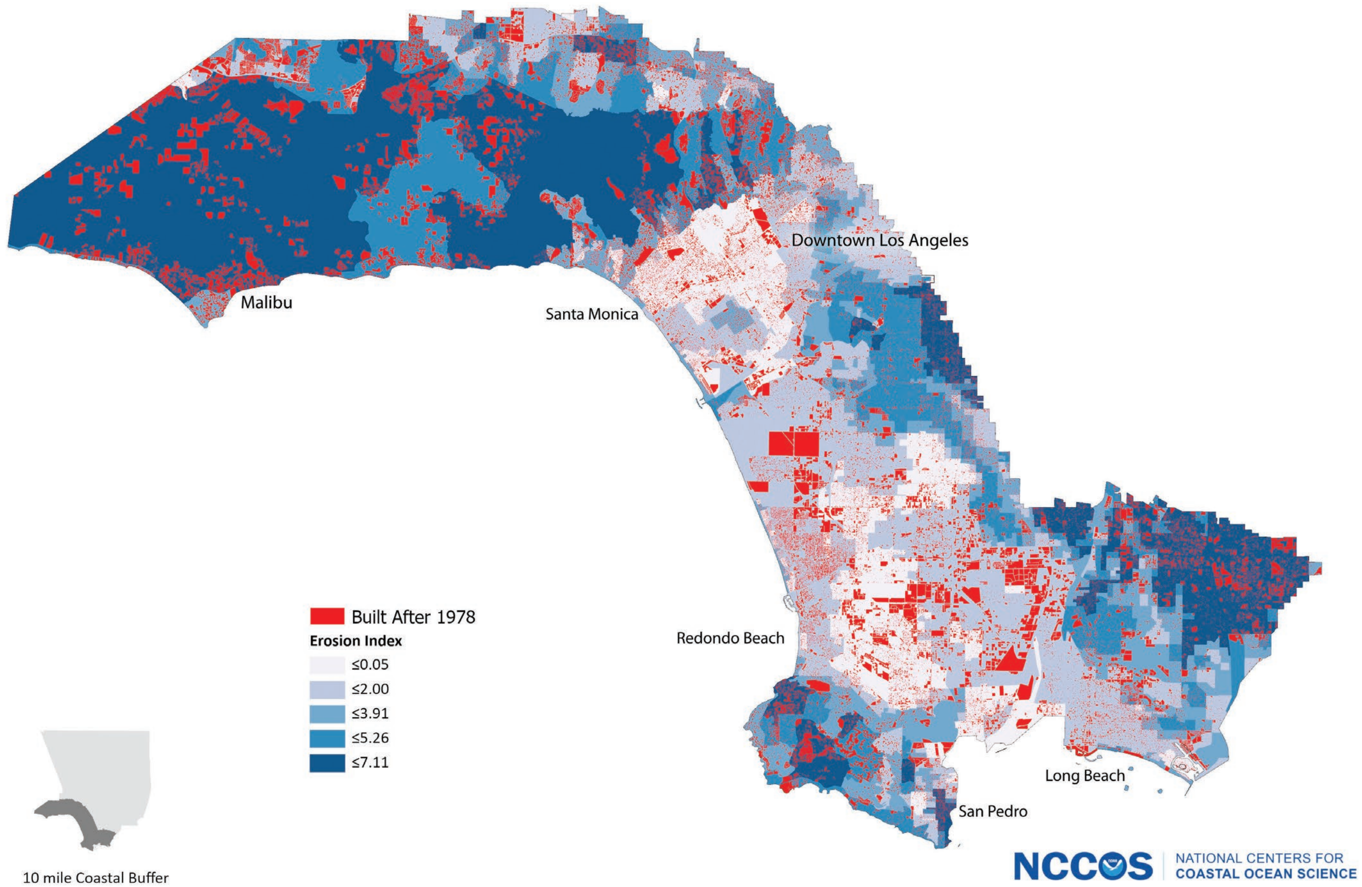

Figure 5.10. Erosion risk with new coastal development.

Blufftop development provides beautiful views and offers more space for housing in a city with very high demand, but can be costly given coastal hazards. Section 30253 of the California Coastal Act mandates that new development shall “minimize risks to life and property in areas of high geologic, flood, and fire hazard” and shall “assure stability and structural integrity, and neither create nor contribute significantly to erosion, geologic instability, or destruction…along bluffs and cliffs” (California Coastal Act Section 30253). To ensure consistency with the Coastal Act, some cities in L.A. County have incorporated policies into their land use plans. The City of Malibu, for example, provided land use plan provisions in its 2002 Land Use Plan that facilitate development while minimizing impacts from hazards and impacts to coastal resources. Some of these policies are included in Exhibit 5 (Quality Code Publishing 2002).

Figure 5.11. Marymount University. Credit: Amy Freitag, NOAA

Exhibit 5: Excerpts from City of Malibu's Local Coastal Program Land Use Plan

- "New development on a beach or oceanfront bluff shall be sited outside areas subject to hazards (beach or bluff erosion, inundation, wave uprush) at any time during the full projected 100-year economic life of the development" (p. 66)
- "All new development located on a blufftop shall be setback from the bluff edge a sufficient distance to ensure that it will not be endangered by erosion for a projected 100 year economic life of the structure plus an added geologic stability factor of 1.5 " (p. 66)
- "No permanent structures shall be permitted on a bluff face, except for engineered stairways or accessways to provide public beach access" (p. 67)
- "All new beachfront and blufftop development shall be sized, sited and designed to minimize risk from wave run-up, flooding and beach and bluff erosion hazards without requiring a shoreline protection structure at any time during the life of the development" (p. 68)

County-wide, efforts are already being made to reduce construction-induced erosion and runoff along bluffs and elsewhere. The L.A. County Department of Public Works developed a program to protect water quality through the reduction of runoff from construction sites that requires contractors to follow a number of best management practices (BMPs). Some examples of the 2010 Construction Site BMPs related to erosion control are outlined in Exhibit 6 (LACDPW 2010).

Exhibit 6: Excerpts from L.A. County's Construction Site BMPs Manual

- Soil Stabilization – "Erosion from disturbed soil and concentrated flows shall be prevented by implementing appropriate BMPs, such as limiting grading and excavation during the wet season, diverting run-on, controlling runoff, slowing and spreading flows, breaking up disturbed areas with linear barriers and covering erosion susceptible areas" (p. 1)
- Wind Erosion Control – "Prevent wind erosion and dust by applying water or other dust palliatives or by covering as necessary" (p. 1)

In part due to the fact that bluffs and blufftops are dynamic, geologic, and ecologic landforms in addition to being attractive residential locations, establishing responsible development setbacks has been challenging. These policies on new blufftop development and general construction regulations demonstrate that progress is being made to minimize erosion and flooding-accelerated erosion impacts where possible in L.A. County. These efforts are undeniably important, but new development regulations do little to influence existing blufftop infrastructure. As bluffs continue to erode, older buildings may become bluff-adjacent and increasingly more susceptible to risk.

Raised lawn garden for water retention. Credit: Chloe Fleming, NOAA-CSS

Chapter 6: Summary of Key Findings

This chapter provides brief summaries of the key findings highlighted in Chapters 4 and 5. For greater detail and contextualization, please refer back to the appropriate chapter and/or section.

Drought risk may impact both rural and urban areas. Drought risk is most prevalent in the northern and western portions of the County, and therefore overlaps with many of the County's natural resources, but there are some areas in southern L.A. that share high drought risk, high social vulnerability, and high natural resource vulnerability. This supports literature that discusses drought's impact on social vulnerability and economic security in rural agricultural areas, but also recent findings that drought impacts can be strongly felt in urban areas as well (see section 4.3.1).

Heat risk occurs further inland. Heat risk is greater in inland areas, impacting the "inland empire" and rural parts of the County. Coastal breezes may reduce heat effects in more prosperous and less socially vulnerable populations along the coast, but may also provide relief in southwestern L.A. (see section 4.3.2).

Wildfire threatens rural and newly suburban areas. Wildfire risk is highest in rural areas, and is especially threatening to people and structures along the interface between natural and urban areas. Development boundaries have steadily expanded into historically natural areas that used to experience periodic burn events. Drought and extreme heat increase the risk of wildfire in these already at-risk areas (see section 4.3.3).

Bioswale for water rention. Credit: Chloe Fleming, NOAA-CSS

Erosion risk is tightly interwoven with flooding impacts. Increases in either erosion or flooding risk can result in increased risk of the other. Together, mudslides and other forms of gravity erosion can be triggered. Erosion risk and debris flow susceptibility are further exacerbated following a wildfire event, and the rainfall required to trigger a landslide is greatly reduced. The confluence of these risks can place people and property in danger, especially in socially and structurally vulnerable areas (see section 4.3.4).

There are many areas of high social vulnerability and high combined flooding risk. Two particular areas experiencing high social vulnerability and high combined flooding risk include central L.A., adjacent to the L.A. River, and south L.A., close to the port complex. This is likely due to impermeable surfaces, lower elevations, flatter slopes, historical land cover type (i.e., much of this area was previously wetland that has been subsequently developed), and the socioeconomic settlement of L.A., where impoverished parts of the City tended to be marginal land within the confines of existing development. Higher prices for houses outside of flood zones may preclude more socially vulnerable parts of the population from buying or renting in less flood-prone areas (see section 4.3.5).

Parking lot heat mitigation efforts. Credit: Chloe Fleming, NOAA-CSS

Areas of high flood risk in have fewer insurance claims. NFIP claims within the 10-mile coastal band mostly occur in the northwestern region, despite flood risk being higher in south central L.A. This is perhaps driven by high erosion risk and lower social vulnerability in the northwestern region. Further, south central L.A. has pockets of lower property values, lower claims paid out, and higher social vulnerability. This speaks to a larger phenomenon of equity in a natural hazards context. There may be less social capacity to obtain insurance and file claims successfully in south central L.A., in addition to less understanding and receptivity of optional flood insurance for homeowners on the periphery of FEMA-designated flood zones (see section 5.1).

At-risk populations and areas lack green space. Within the coastal band, there is an uneven distribution of green space with clusters of high social vulnerability and low greenness. These clusters also overlap with areas of moderate to high combined flood risk. Areas that have both high greenness values and high social vulnerability scores are due to green public spaces in schools or small city parks, emphasizing the importance of public investment in green space. Areas of high social vulnerability stand to gain the most from public programs or community development grants aimed at increasing capacity to respond to environmental concerns. Areas of high social vulnerability that also have low greenness represent an opportunity to optimize investments by helping both greening efforts and social resilience efforts. For example, a rain garden placed in a highly vulnerable neighborhood can reduce flood risk and increase psychological well-being simultaneously (see section 5.2).

Cultural and historical resources are at risk of flooding. In the 10-mile coastal band, many cultural and historic buildings and landmarks are waterfront-adjacent. To protect these (and other cultural resources not captured with the National Register of Historic Places), finding adaptation strategies will require some creative thinking particular to each cultural landmark. Adaptive strategy plans including risk management, emergency planning, and building design will be critical to protect these cultural resources in future flooding events (see section 5.3).

Tsunami hazard sign. Credit: Chloe Fleming, NOAA-CSS

Many disaster routes are at risk of flooding and erosion. The overlap of disaster routes with high risk areas can be both frightening and challenging in the event of a natural disaster, and the challenge becomes even greater when considering the need for rapid evacuations of a large population. Disaster routes are designed to bring in emergency care, rather than to provide residents with evacuation routes, and recent wildfires have raised awareness of the apparent lack of capacity on existing highways to evacuate residents safely. This is especially true in regard to reliance upon the PCH in western L.A. County. In addition to its use during evacuations, many L.A. residents and commuters rely upon the PCH as their main route to and from work, medical appointments, and social outings, and the scenic views also generate tourism dollars. The high erosion risk underlying much of the PCH in western L.A. County could have cascading effects (see section 5.4).

There are overlapping areas of new development and high erosion risk. This is especially true in the northwestern portion of the 10-mile coastal band. Some of the new development has occurred along bluffs overlooking the coast. Policies on new blufftop development and general construction regulations minimize erosion and flooding-accelerated erosion impacts where possible in L.A. County, but new development regulations do little to influence existing blufftop infrastructure. Given that blufftop development occurs at a small scale, a higher resolution study with analytical means of identifying bluffs within the high erosion areas may be helpful (see section 5.5).

Risks are likely to compound. While the consideration of risks individually is crucial to understanding initial and direct impacts, many risks have the potential to compound with other risks, creating secondary impacts that can be felt immediately or along longer time horizons. The creation of a "combined flooding" risk profile and discussion regarding the relationship between erosion and stormwater flooding are both examples of compounding effects, but other relationships are more complex. For example, severe drought coupled with high heat may assist development of a wildfire; continued drought following the containment of that fire may reduce soil capacity to absorb extreme stormwater flooding; and reduced soil stability could then contribute to land or mudslides. Adaptation strategies that can address multiple risk impacts at once may have greater mitigation influence (see Chapters 4 and 7).

Overlapping vulnerability and risk presents opportunity. Areas that share multiple vulnerabilities and/or risks create the need for adaptation action in the face of a changing climate, but they also present an opportunity to develop and implement innovative strategies that mitigate multiple concerns across multiple sectors at once (see Chapter 7).

Community park. Credit: Chloe Fleming, NOAA-CSS

Chapter 7: Conclusions and Applications

This project represents the third application of the NCCOS Framework focused on coastal areas facing the impacts of climate variability and change, and hinges upon the iterative inclusion of partner engagement and feedback. Like previous iterations, this application has resulted in Framework improvements and advancements while providing actionable information to local partners and stakeholders. First, this was the first time that the Framework was implemented in a highly urbanized environment. This presented an opportunity to overcome challenges in defining "natural resources" in an urban context. Previous applications developed natural resource vulnerability indices surrounding various natural resource spatial distributions (Messick and Dillard 2016) and natural resource-attributed value accrual to property owners (Fleming et al. 2017). In L.A.'s urban environment, neither of those approaches would have properly represented natural resource vulnerability. Considering nature in an urban system versus nature at the ecosystem scale resulted in a fundamentally anthropogenic view of natural resources, and the recognition of the scarcity, specificity, and fragmentation of nature in a city led the researchers to consider much smaller-scale interactions and different types of importance than examined in previous applications.

Coastal Los Angeles. Credit: Chloe Fleming, NOAA-CSS

Second, this was the first time the Framework was applied to a study area with partners interested in climate-driven risks other than flooding and storm surge. The expansion to erosion, heat, drought, and wildfire required forays into new data sources and areas of expertise. It also exposed the extreme complexity of how these and other risks within the study area are closely interconnected. This was made especially apparent during early partner engagement in which USC Sea Grant colleagues drafted a conceptual diagram of local risks (shown in Figure 7.1 and also in Appendix A). The sheer number of risks and the complexity of their interactions could benefit from a study in and of itself. In the context of the present research, the inclusion of chosen risks required the project team to carefully consider the interactions, as well as data availability, when creating final bivariate combinations. Drought risk and stormwater flooding risk, for example, may at first seem to negate one another, but the occurrence of an extreme stormwater flooding event following a period of high drought may actually exacerbate the intensity of flooding due to compacted soil, decreased vegetation, and other factors.

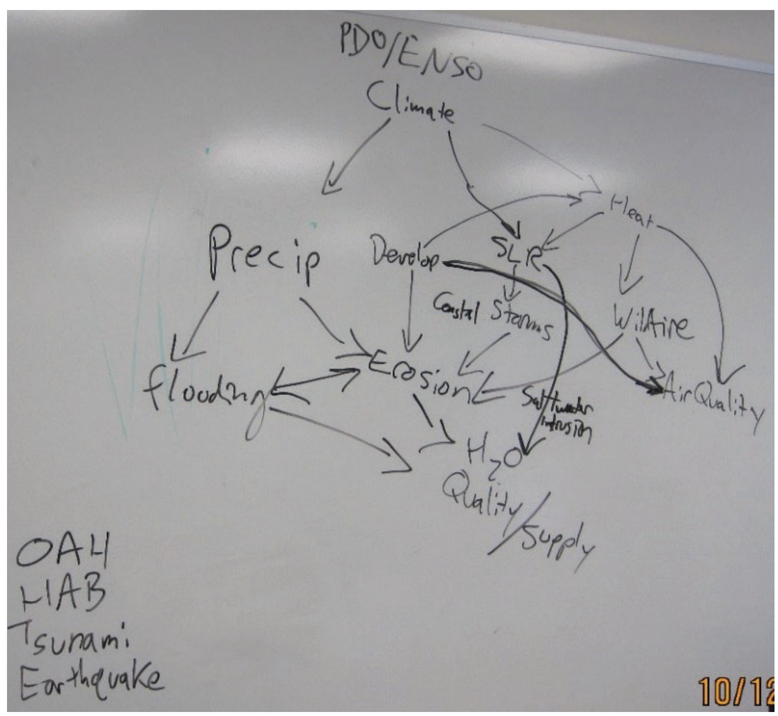

Figure 7.1. Conceptual diagram of local risks by USC Sea Grant colleagues.

Santa Monica Pier. Credit: Bettina Norgaard, Pixabay

Because the goals of this project were to examine the integration of multiple risks and multiple vulnerabilities under current conditions, these causal relationships were omitted from final products; however, future studies could incorporate a temporal component. In addition, this project's expansion into non-flooding risks also demonstrates flexibility of the Framework to adapt to different contexts and local needs.

The L.A. application of the Framework continued to improve and advance this body of work through the expansion of assessments at multiple geographies, the inclusion of additional analyses beyond assessment completion, and the continued refinement of indicators. The stormwater flooding index, for example, now utilized Kazakis et al.'s (2015) FIGUSED methodology, which expanded the index components from the three used in previous applications to seven. The inclusion of new variables, such as slope, precipitation, flow, and drainage, along with those used in previous applications (elevation, land cover, and soil type) provided a more robust consideration of stormwater flooding risk. This is especially true for L.A. County, where there is notable variation in climate and geomorphology in a heavily engineered and constructed landscape. The methodology outlined by Kazakis et al. (2015) also allows for regional customization of a flood hazard index by developing weighting criteria for each index variable by means of performing a sensitivity analysis utilizing historical flood event data. This additional analysis and adjustment to the flood index was not performed for the present research, but could potentially provide a more precise output, and especially so, in a more resolute and downscaled application. Ultimately, the design of the Framework continues to provide a level of flexibility that can be applied to multiple geographies and contexts.

The vulnerability assessments completed for three different geographies within L.A. County can best be used as determined by different management needs. Each assessment provides vulnerability and risk analyses in comparison to other block groups within the assessment. The County-wide assessment provides a holistic understanding of vulnerabilities and risks across the County, and includes both rural and agricultural areas. The 10-mile coastal band geography was driven by USC Sea Grant partners, and informs or reinforces understanding of where vulnerability and risk are most severe in comparison to other areas within the coastal zone. The urban geography provides a more nuanced understanding of the urban areas more or most at risk and vulnerable. Areas of high risk and high vulnerability change as the number and location of total block groups change, and as a result, each of these assessments provides a unique opportunity for planners to make educated trade-offs when prioritizing resources for adaptation and mitigation action.

The bivariate maps included in each assessment serve as visual tools to expose areas where high vulnerability corresponds to high risk. These maps and greater assessments can be used by local partners and stakeholders to establish adaptation priority areas for the coastal and climate-driven risks explored in this research. California Senate Bill 379 (later codified) requires all cities and counties to start incorporating climate adaptation and resiliency strategies into their general plans or hazard mitigation plans. While many local communities in L.A. County already have sustainability or climate action plans in place (e.g., Cities of L.A., Long Beach, Hawthorne, Santa Monica), these assessments may provide information for determining the locations for planned adaptation activities and goals. For communities that are in the process of developing these plans, these assessments and the underlying data may aid these efforts. The project team is already assisting the Cities of Malibu and West Hollywood with data needs. As other communities are identified, NOAA and USC Sea Grant colleagues will be able to share the data and findings from these assessments.

Despite the emphasis on the bivariate map combinations, the individual variables or components of these assessments may also be independently useful for other management and planning purposes. For example, intersecting the ‘no access to a vehicle’ variable of the social vulnerability index with combined flooding risk or wildfire risk may provide insight to emergency response officials during early onset of extreme flooding or encroaching wildfire, respectively. Further, while this research limited bivariate map combinations to a single risk intersected with a single vulnerability, users may find it informative to overlay two risks or two vulnerabilities. Intersecting stormwater flooding risk with erosion risk may highlight potential mudslide zones, for example. Areas that share multiple aspects of vulnerability and/or risk create the need for adaptation action in the face of a changing climate, but they also present an opportunity to develop and implement innovative strategies that mitigate multiple concerns across multiple sectors at once. The flexibility allows for management action based on various time horizons, management needs, levels of political and public support, and availability of funding.

Biodiversity sign. Credit: Amy Freitag, NOAA

The coastal analysis results from this research add to the breadth of information delivered in this report. While the NCCOS Framework largely provided an overview of integrated vulnerability and risk, the additional analyses examined themes of access, flood insurance, and risk-related infrastructure impacts within L.A. County's coastal zone. These analyses utilized vulnerability and risk profiles from the 10-mile coastal band assessment, and could be used to identify areas to implement educational outreach efforts, inform and aid in the creation of emergency preparedness plans, or support further development of coastal management plans in and across local and regional jurisdictions. In addition to providing further information for use by local partners, these analyses also demonstrate the additional ways in which these assessments can be utilized by local management departments and other researchers. The application of the Framework and its results are designed to be used both as final products, but also as foundational pieces for additional research, analysis, and refined adaptation action.

The NCCOS Framework provides a large scale integration of a combination of various vulnerabilities and risks within each assessment geography. The research is intended as a holistic first step to identify priority geographies or intersections that warrant future investments of attention and adaptation funds. In L.A. County, there are a few recommended next steps. First, the unit of analysis was chosen to provide continuity across the entirety of the study area, but this resulted in some very large block groups in some areas of the County (e.g., northern region, Malibu peninsula) that perhaps mask the felt realities in those areas. Those areas could benefit from refined scale analysis to deliver better insight and planning information. Second, homelessness, gentrification, and displacement were all themes of social vulnerability that the authors could not examine adequately in this study. Reliance upon Census data curtails advancements in these areas, and primary data collection could help address these needs. Third, assessment of the everyday movement of people and vulnerability of the population while in transit are current information gaps. Examination of transportation networks and how those networks are disrupted due to natural hazards of varying scales are warranted. Lastly, this research focused on vulnerability, which is but one, albeit important, facet of adaptation planning. Exploration of resilience and perceived vulnerability would result in more robust information to aid adaptation and mitigation efforts in the County.

Ship at port. Credit: Amy Freitag, NOAA

In L.A. County and more broadly, future uses of the Framework could incorporate additional projected datasets, such as land use change data. The Global Climate Explorer Integrated Climate and Land-Use Scenarios (ICLUS) data project changes in land use through 2050 under two population growth scenarios (EPA 2019). If this data stream was coupled with the present research's wildfire risk profile, for example, it may highlight increased vulnerability in areas that are projected to shift from natural to exurban and from exurban to densified urban/suburban. The Framework could also be modified to incorporate trend and projected risk data. With the exception of the coastal flooding risk profile used in this research, all risk data were current and did not project into future time horizons. Where available, projected and estimated changes to risk profiles could be beneficial in understanding possible impacts over time.

Future research should also include the continued improvement of the Framework. For example, methods of spatial refinement of social data to assess risk to human populations and structures are ideal next steps. This might be accomplished through dasymetric analysis using land cover and other spatial data to help determine where populations are distributed as opposed to an assumption of even spatial distribution of social and economic data. Additionally, there is value in scaling the assessment down to smaller geographic units in order to capture the true variability in vulnerability and risk. At smaller geographic scales, future down-scaled studies may also include foundation height for structures to better assess first floor flooding and damage, or building footprint and building material data to better assess likelihood of burn potential. It's possible that future research may also include the assessment of vulnerability in relation to coastal protection (e.g., siting areas for investment in green/gray/hybrid shoreline protection) or new coastal hazards, as well as continued investigation of social vulnerability within coastal communities. Future avenues might also explore vulnerability of transportation systems and how this relates to aspects of social and structural vulnerability. The present research was limited to available secondary data sources, and many of these suggestions would require finer scale data resulting from a primary data collection.

The continuation and refinement of research will provide valuable science to decision makers and planners. Without these types of analyses in multiple locations, coastal communities are at a disadvantage in the face of climate change and related impacts. The L.A. County integrated vulnerability assessments and coastal analyses, as well as past and future iterations of the Framework, provide meaningful information to better protect, advance, and manage climate change impacts within local communities in various coastal geographies of the U.S. and beyond.


Hedgerow Park in Los Angeles. Credit: Christophe Honigschmid, Pixabay

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Los Angeles area beach. Credit: Amy Freitag, NOAA

Appendix A: Kick-Off Meeting Prioritization Exercises

Los Angeles Vulnerability project in-person kick-off meeting on 10/12/17
2 hours

Purpose:
This exercise helped to shape the direction of the Los Angeles Vulnerability (LAV) project. Ranking consensus was accomplished through stakeholder engagement during onset of the project, and was used to structure research throughout the course of the project.

VULNERABILITY RANKING – 45 mins
Purpose:
This session determined partners' prioritization of vulnerability themes for social, structural, natural resource, and "other" vulnerabilities. This ranking aided the research team in implementing the NCCOS assessment Framework, and also provided insight for the development of additional coastal analyses.

Actions:
Existing themes as determined via Framework methodology and questionnaire responses by the project team and project partners prior to the workshop were written under each category (Figures A1-A3), independently. For each vulnerability, partners were asked if there were two-three more themes they felt were missing from the existing lists, and a discussion ensued concerning "other" vulnerabilities. Additional vulnerabilities were added where applicable across the three lists (denoted with an asterisk). Partners were given colored sticky notes that aligned with each office (Table A1), and partners ranked their top three choices via placement of sticky notes under each list. Each partner group was given three sticky notes per vulnerability. Partners with multiple individuals representing their organization were asked to consolidate their prioritization. Following placement, discussion ensued. Final rankings were recorded (Tables A2-A4) and photographed (Figures A1-A3).

Table A1. Participating organizations and corresponding sticky note color.

Organization	Sticky Note Color
University of Southern California Sea Grant	Red
NOAA's Office for Coastal Management – West Coast	Bright Blue
City of Los Angeles, Mayor's Office	Light Blue
University of California Los Angeles	Fuchsia
Bay Regional Foundation and Ballona Wetland Reserve	Teal
National Centers for Coastal Ocean Science	Peach

Results:
Table A2. Social vulnerability theme ranking.

Social Vulnerability Themes	Ranking
*Displacement	5
Well being (economic, health, access to services, etc.)	4
Social/environmental justice	4
*Social cohesion	2
Coastal public access	1
Human health impacts	1

*Additional vulnerabilities were added where applicable across the three lists

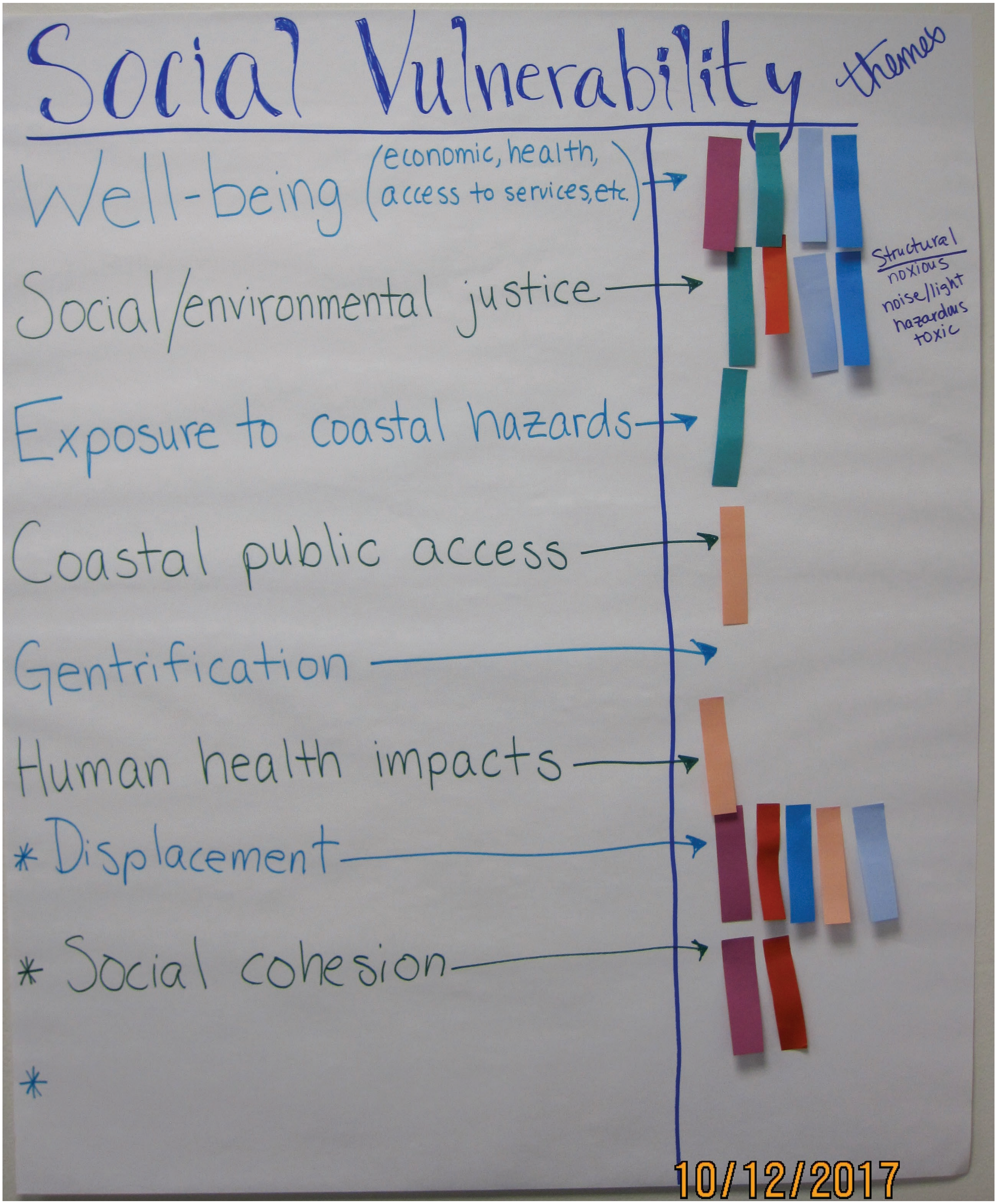


Figure A1. Social vulnerability ranking exercise results.

Notes: Social/environmental justice may fit into structural vulnerability in terms of place-based Environmental Justice cases, including noxious, noise/light, hazardous, and/or toxic sites.

Table A3. Structural vulnerability theme ranking.

Structural Vulnerability Themes	Ranking
City/County infrastructure (incl. services, networks)	6
Residential properties/structures	4
Delivery of/access to emergency services/evacuation routes	2
Port services/delivery of goods	2
Commercial properties/structures	2
Culturally significant places	1

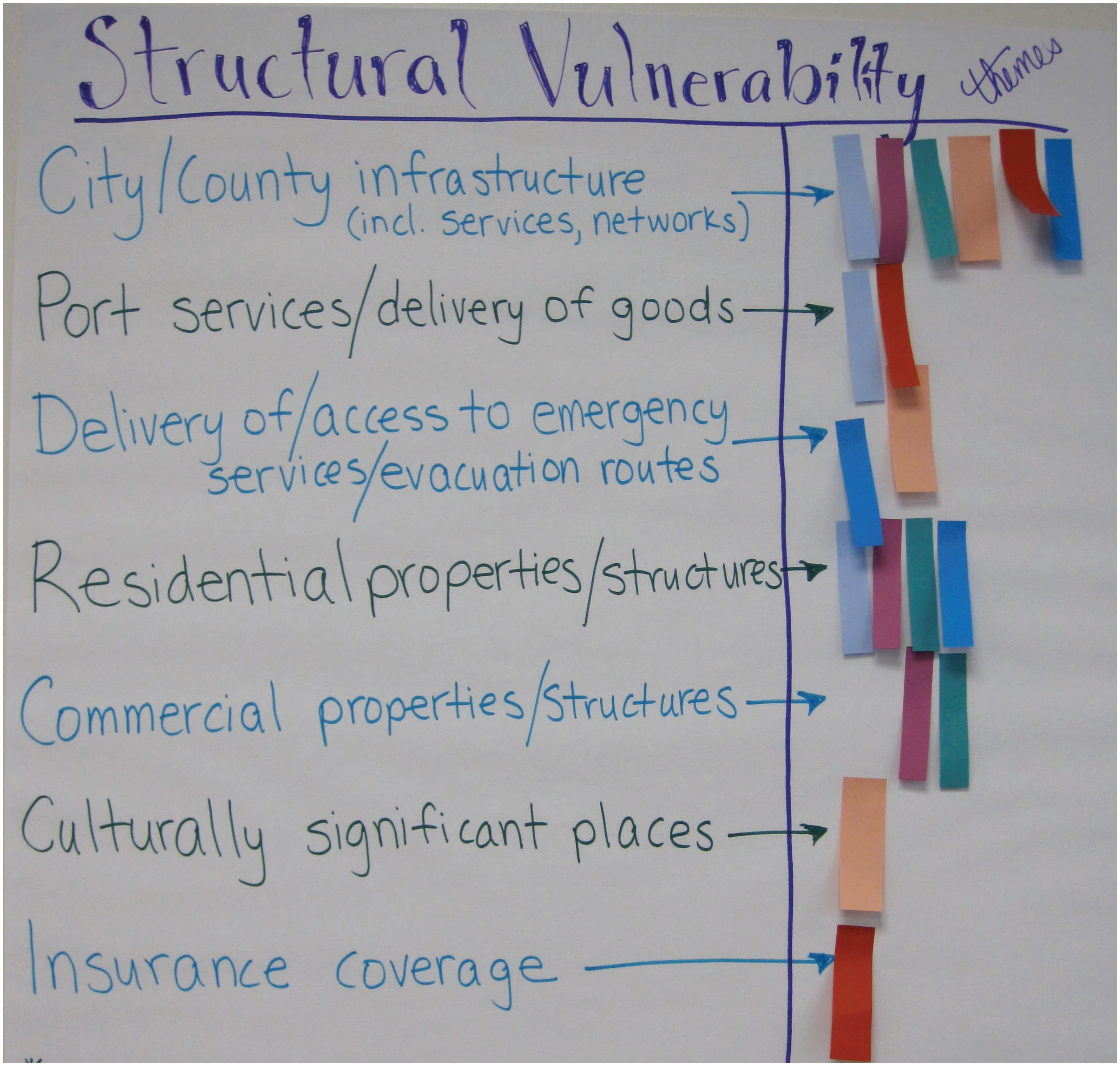


Figure A2. Structural vulnerability ranking exercise results.

Table A4. Natural resource vulnerability theme ranking.

Structural Vulnerability Themes	Ranking
City/County infrastructure (incl. services, networks)	6
Residential properties/structures	4
Delivery of/access to emergency services/evacuation routes	2
Port services/delivery of goods	2
Commercial properties/structures	2
Culturally significant places	1

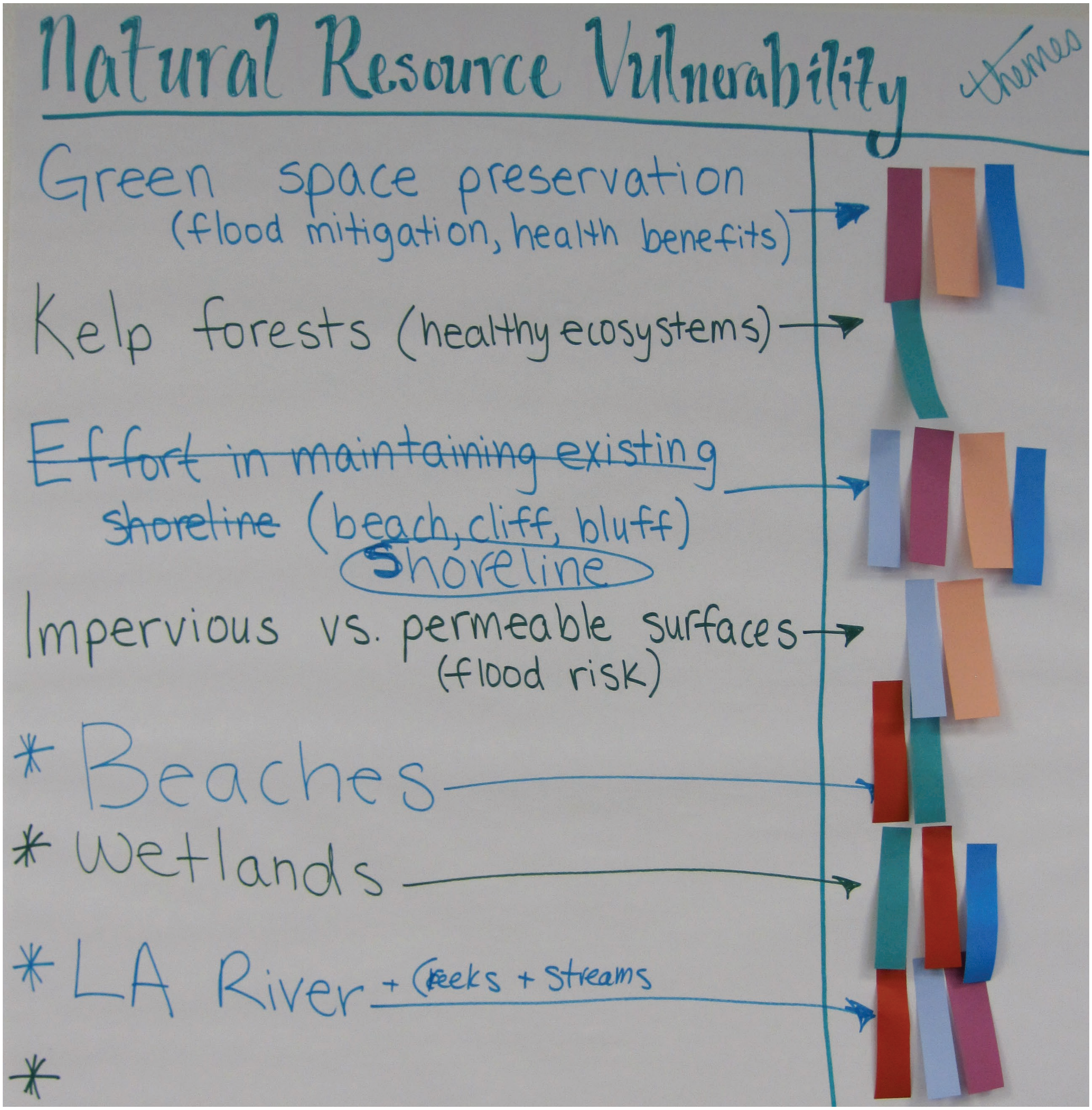


Figure A3. Natural resource vulnerability ranking exercise results.

RISKS RANKING AND DEVELOPMENT – 30 mins

Purpose:

This session determined partners' prioritization of coastal hazards/risks, and then further developed the coastal risks chosen. This ranking and development directed the risks analyzed in the assessments and additional coastal analyses.

Actions:

Existing climate risks as determined via Framework methodology and questionnaire responses by the project team and project partners prior to the workshop were written on the white board (Table A5 and Figure A4), and partners were asked if there were 2-3 more risks they felt were missing. These were added if applicable (denoted with an asterisk). Next, partners ranked their top five choices via placement of sticky notes. Partners with multiple individuals representing their organization were asked to consolidate their prioritization. This only occurred for USC Sea Grant and NCCOS. Following placement, discussion ensued. Final rankings were recorded (Table A5) and photographed (Figure A4). For each of the top ranked risks, the group worked to further develop the risk specifics and targeted levels or measures where applicable.

Results:

Table A5. Coastal risk/hazard ranking.

Coastal Hazards/Risks	Ranking
Erosion (beach, cliff, bluff)	6
Precipitation (drought, stormwater flooding)	5
Heat (temperature/advisory days)	4
Coastal flooding (storm surge, tides, wave driven run- up)	4
Sea Level Rise	4
*Water quality/availability (incl. HABs, OA, etc.)	4
*Wildfire	2
*Air quality	1
*Tsunami/earthquake	1

*Additional vulnerabilities were added where applicable across the three lists

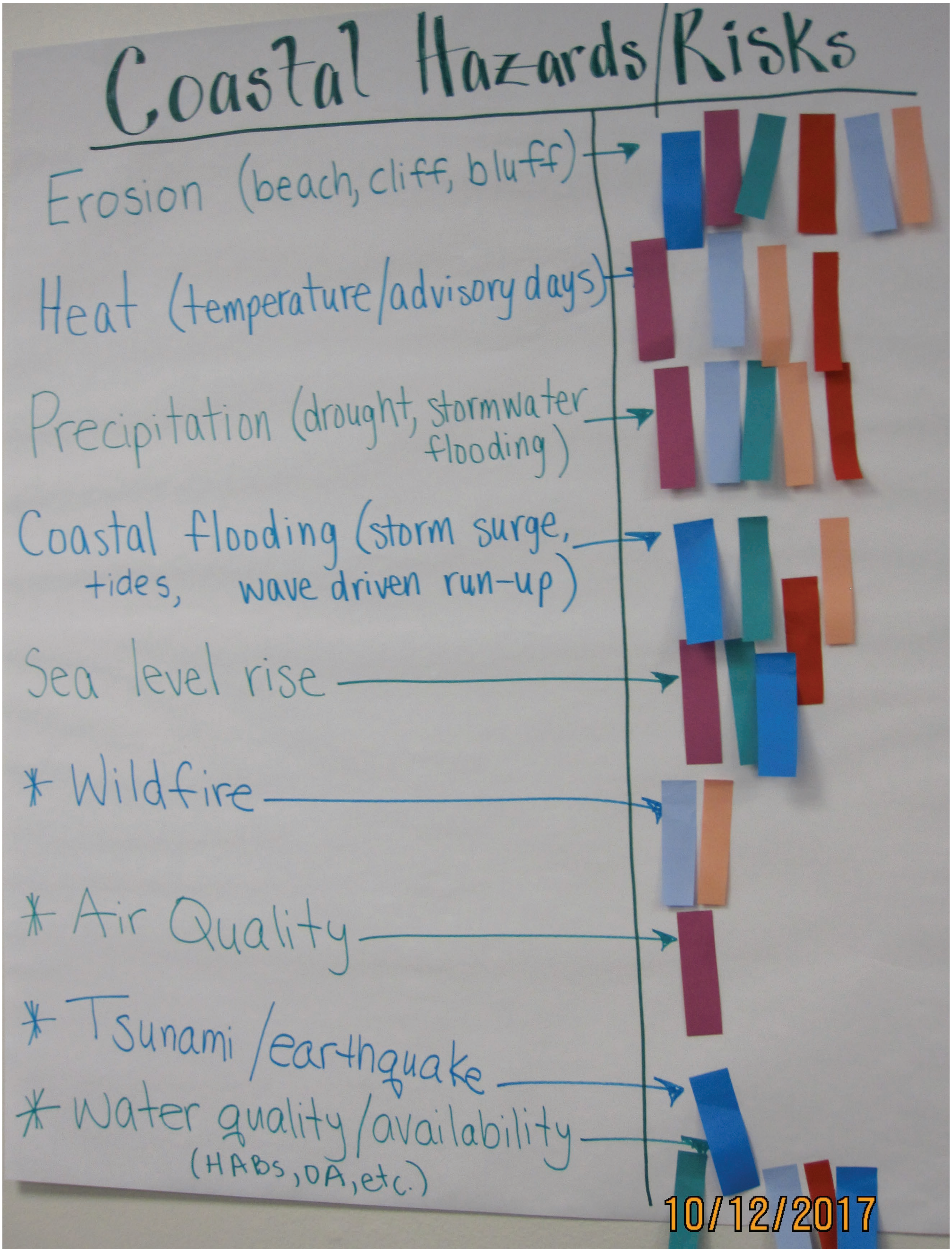


Figure A4. Coastal risk/hazard ranking exercise results.

USC Sea Grant also chose to draw a coarse conceptual model, showcasing the complicated relationships amongst local risks and hazards (Figure A5).

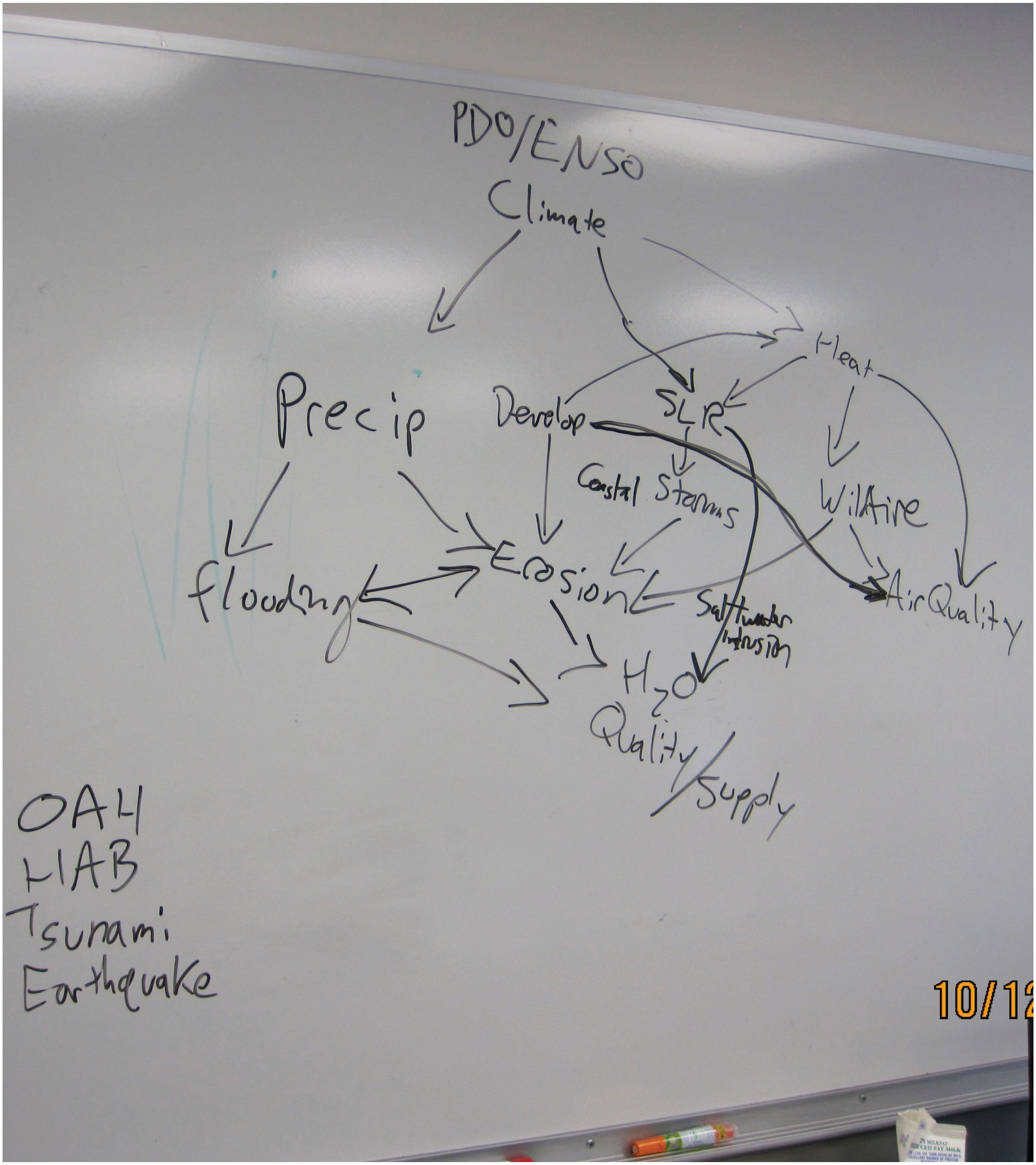


Figure A5. Coastal risk conceptual model showcasing risk interconnectedness

ECONOMIC ANALYSIS THEMES RANKING – 20 mins

Purpose:

This session determined partners' prioritization of economic themes/analyses for additional coastal analysis, if applicable. Partners were asked to consider the following questions when prioritizing: "What do you need this information for? Who needs or could benefit from this information? How can the resulting information be used?" The top three ranked themes were also used for fodder during an economic methods and approaches call later that afternoon.

Actions:

Existing themes as determined via Framework methodology and questionnaire responses by the project team and project partners prior to the workshop were written on the white board (Figure A6), and partners were asked if there were two-three more themes that they felt were missing. These were added if applicable (denoted with an asterisk). Next, partners ranked their top three choices via placement of sticky notes. Partners with multiple individuals representing their organization were asked to consolidate their prioritization. This only occurred for USC Sea Grant and NCCOS. Following placement, discussion ensued. Overlapping themes were then grouped together where appropriate. Final rankings were recorded (Table A6) and photographed (Figure A6).

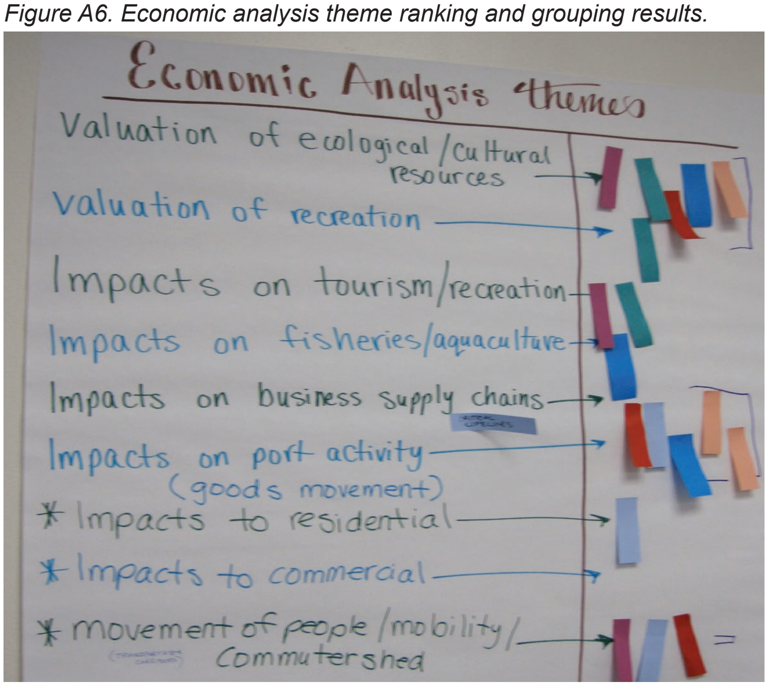
Results:

Table A6. Economic analysis theme ranking.

Economic Analysis Themes	Ranking
Valuation of ecological/cultural assets	5 (grouped with below)
Valuation of recreation	2 (grouped with above)
Impacts on business supply chains (critical lifelines)	3 (grouped with below)
Impacts on port activity	2 (grouped with above)
*Movement of people/mobility/ commutershed/transportation corridors	3
Impacts on tourism/recreation	2
*Impacts to residential	1
Impacts on fisheries/aquaculture	1
*Impacts to commercial	0

*Additional vulnerabilities were added where applicable across the three lists

Figure A6. Economic analysis theme ranking and grouping results.



GEOGRAPHY MAPPING – 25 mins

Purpose:

This session determined partners' prioritization of geographic locations for use throughout the duration of the project. These areas did not exclusively decide the locations for coastal analysis, but were instead used as expert opinion in concert with previous research in the region and the findings from each assessment. (The team hoped to explore how the identified geographies compare and contrast with those identified through other analyses.)

Actions:

Partners were given colored dots that align with each office (Table A7), and were asked to place dots on their top three geographies within the study region (L.A. County) using the enlarged map provided. Participants were prefaced with: Think about geographies for analysis and without limiting your selections to specific vulnerabilities or risks (i.e., place dots for any risk, vulnerability, or combination). Along with placing their dots, partners were asked to complete the accompanying ranking sheet, which asked for their three locations and reasoning for choosing each. Discussion ensued. Ranking sheets were collected and map was photographed (Figures A7 and A8) and retrieved.

Results:

Table A7. Participating organizations and corresponding dot color.

Organization	Dot Color/Design
University of Southern California Sea Grant	Red
NOAA's Office for Coastal Management – West Coast	Blue
City of Los Angeles, Mayor's Office	Yellow
University of California Los Angeles	Green
National Centers for Coastal Ocean Science	Green Square

Table A8. Mapping prioritization results.

Location	Affiliation	Color	Reason
Harbor Area (ports, Wilmington)	Sea Grant	Red	Goods movement, social vulnerability
Marina del Rey/ Venice/ Santa Monica	Sea Grant	Red	Ballona, ecosystem values, flooding, cultural values
Long Beach	Sea Grant	Red	Housing, wetlands, industry, river, social vulnerability
Port/Wilmington	City of LA	Yellow	Coastal, SLR, economic, flooding, oil infrastructure, EJ (trucking pollution), older residential buildings, social vulnerability
River	City of LA	Yellow	Watershed/water quality, ecosystem, flooding, financial investment, revitalization planning, gentrification, access to open space
South LA/East (Boyle Heights)	City of LA	Yellow	EJ, water availability/quality, social vulnerability, gentrification, lack of green/open space
Port of LA/Long Beach	NOAA OCM	Blue	Flooding/SLR impacts to ports (goods movement)
Marina Del Rey/ Venice	NOAA OCM	Blue	Flooding/SLR impacts to residential/marina
Malibu	NCCOS	Green	Cliff erosion – residential/commercial properties
Port Complex (Long Beach)	NCCOS	Green	Business/transportation supply chains
San Gabriel Forest	NCCOS	Green	Fire, ecological values/corridors

Appendix A photo gallery:

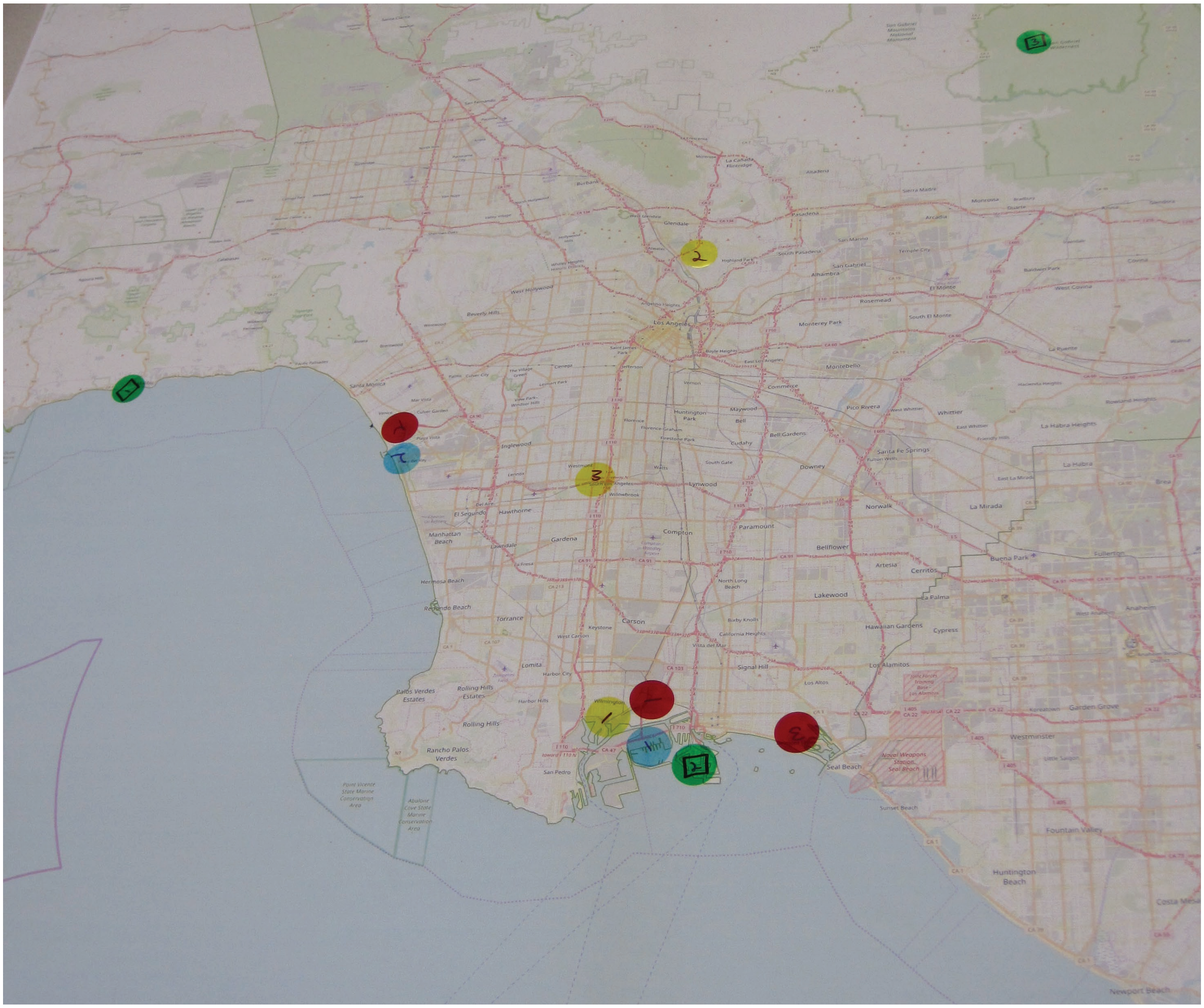


Figure A7. Visualization of mapping prioritization exercise.

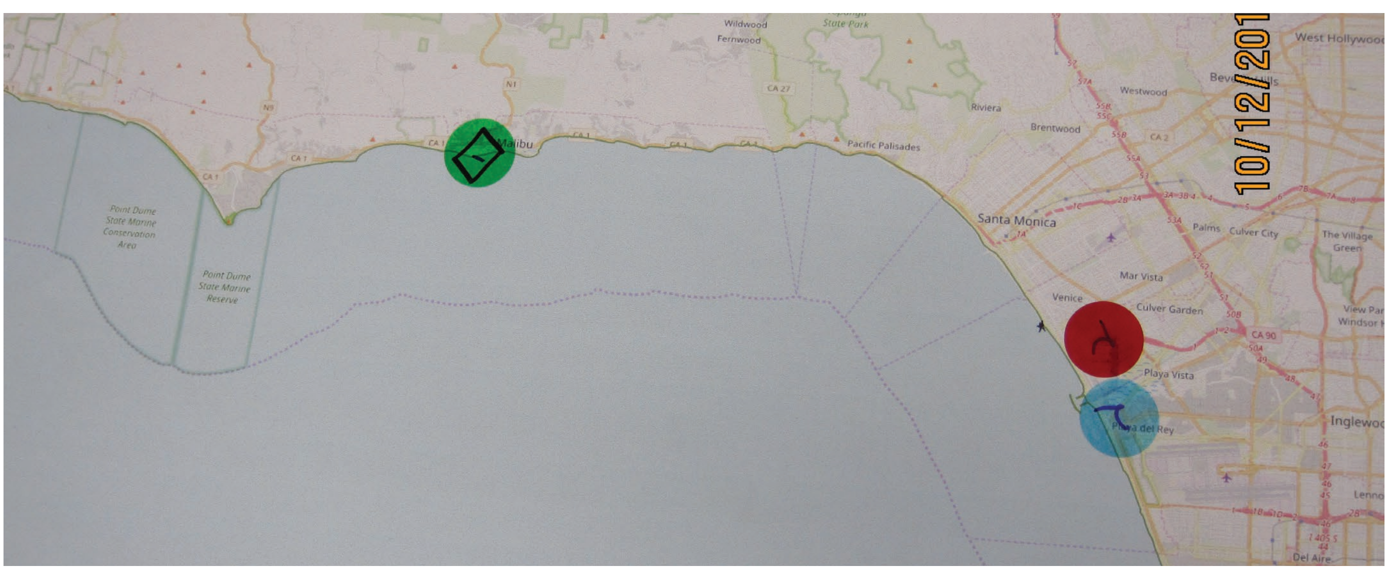


Figure A8a. Additional close-up photos from mapping prioritization exercise.

Figure A8b. Additional close-up photos from mapping prioritization exercise.

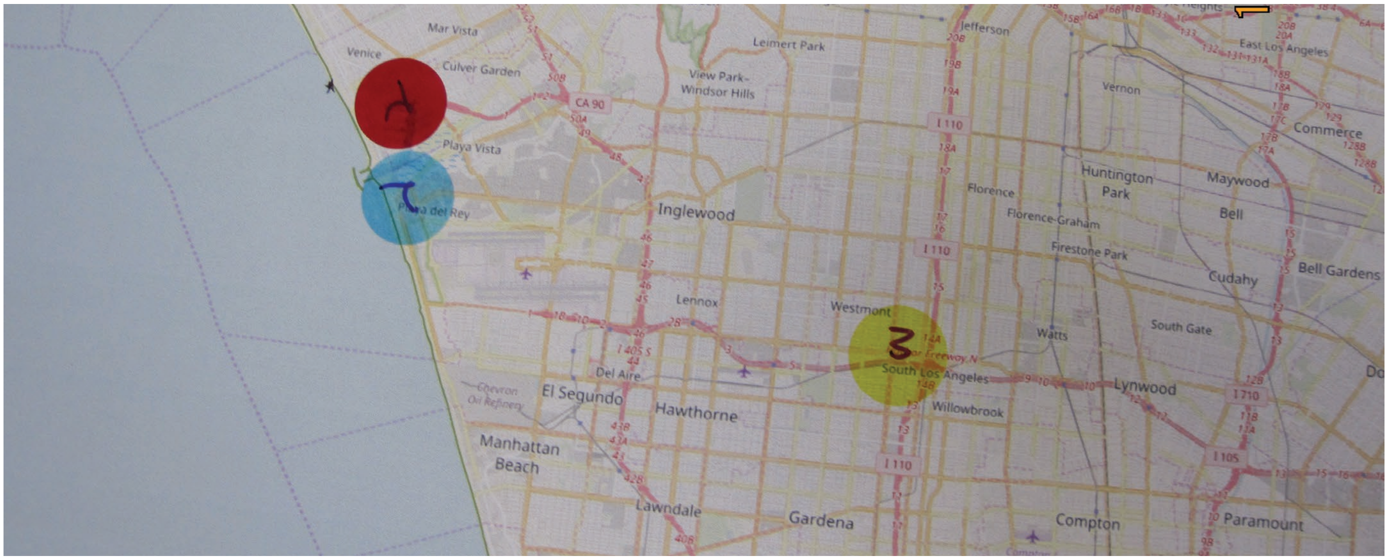


Figure A8c. Additional close-up photos from mapping prioritization exercise.

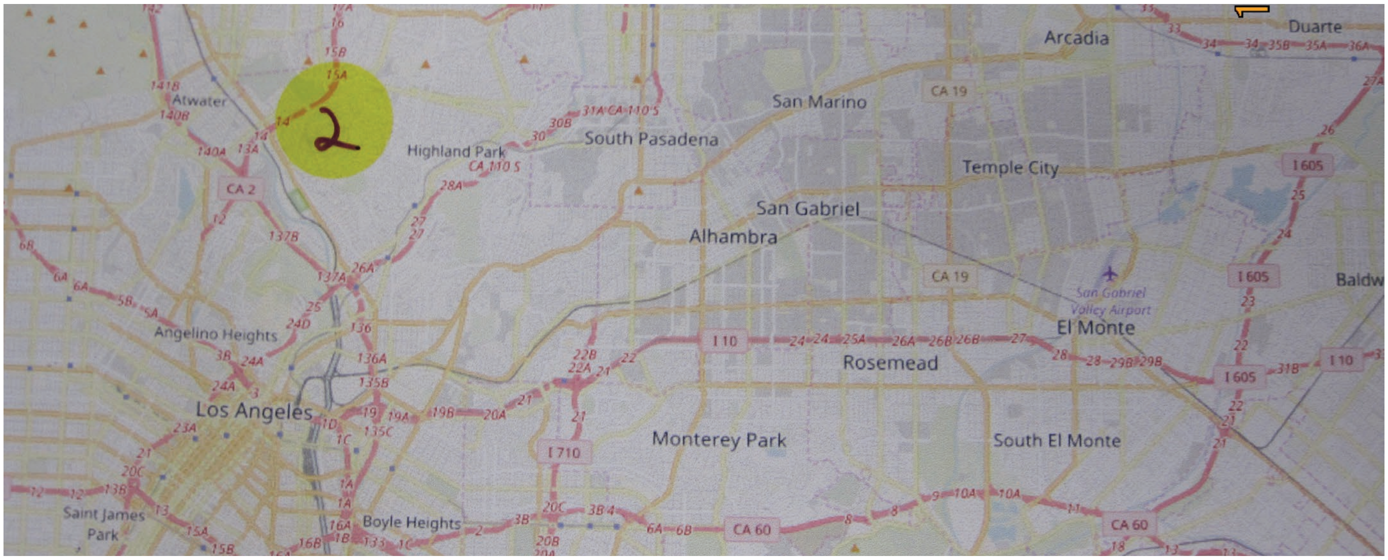


Figure A8d. Additional close-up photos from mapping prioritization exercise.

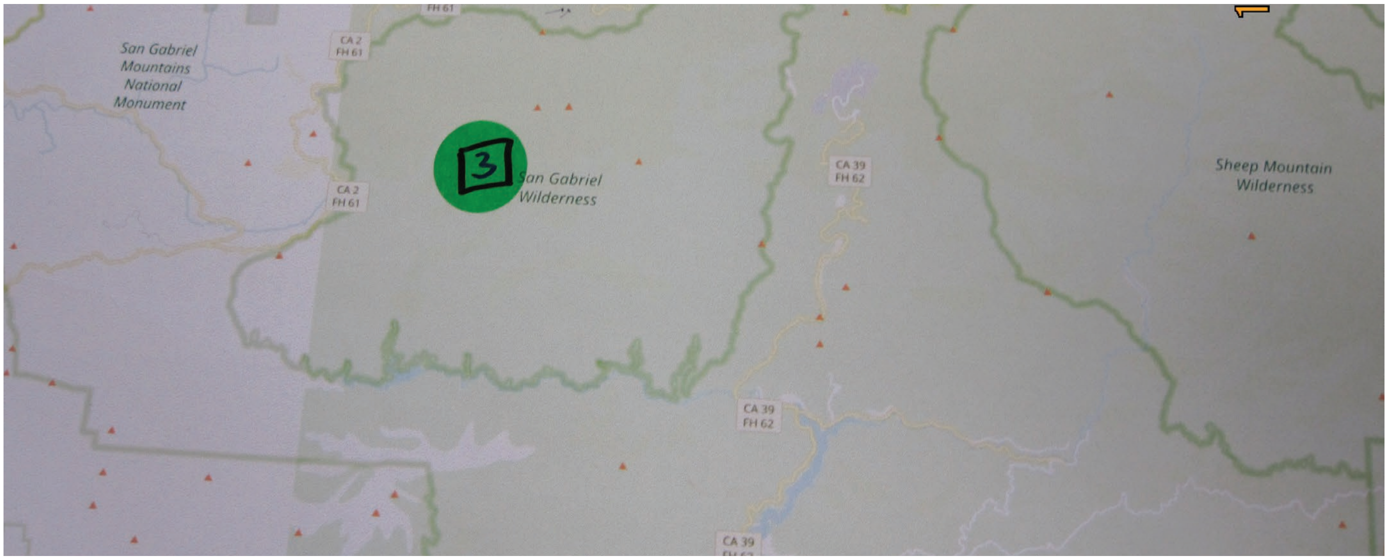


Figure A8e. Additional close-up photos from mapping prioritization exercise.

Prioritization consideration. Credit: Theresa Goedeke, NOAA

Prioritizing coastal risks. Credit: Theresa Goedeke, NOAA

Prioritizing geographic areas of concern. Credit: Theresa Goedeke, NOAA

Considering natural resource vulnerability themes.
Credit: Theresa Goedeke, NOAA

Considering geographies with coastal flooding.
Credit: Theresa Goedeke, NOAA

Developing a coastal hazard conceptual model.
Credit: Theresa Goedeke, NOAA

Ranking natural resource vulnerability themes. Credit: Theresa Goedeke, NOAA

Leading prioritization and ranking discussions. Credit: Theresa Goedeke, NOAA

House along Venice Canals. Credit: Amy Freitag, NOAA

Appendix B: Report-Out Meeting Mapping and SNAP Exercises

Los Angeles Vulnerability project in-person results workshop on 06/06/19

GEOGRAPHY MAPPING – 60 mins

Purpose:

This exercise reassessed partner and stakeholder driven geographic areas of interest or concern within the study area. This effort confirmed previously identified priority areas and expanded into new areas before being incorporated into final products.

Actions:

Partners were divided into groups and given colored dots that aligned with each office (Table B1), and were asked to place dots on their top three geographies within the study region (L.A. County) using the enlarged map provided. Participants were prefaced with: Think about geographies for analysis and without limiting your selections to specific vulnerabilities or risks (i.e., place dots for any risk, vulnerability, or combination). Along with placing their dots, partners were asked to complete the accompanying ranking sheet, which asked for their three locations and reasoning for choosing each (Table B2). Discussion ensued. Ranking sheets were collected and map was photographed (Figure B1) and retrieved.

Table B1. Participating organizations and corresponding color.

Group	Participants	Color
Group 1	City of Malibu, City of L.A., City of Manhattan Beach, Santa Monica, South Bay Cities Council of Governments	Purple
Group 2	The Nature Conservancy, The Bay Foundation	Green
Group 3	USGS, USC Sea Grant, OCM	Yellow
Group 4	California Coastal Commission	Red

Results:

Table B2. Geography mapping results

Location	Group	Reason
San Pedro port area	1	Social vulnerability
Venice	1	Venice has a tide gage systems that controls the water that comes in and out of the canal area; Many properties at risk of coastal flooding; Venice is low lying and has unique infrastructure
Manhattan Beach	1	Peninsula is not highest in social vulnerability, but at risk of erosion; Finite amount of evacuation options and an elderly population; Manhattan Beach Pier at risk of sea level rise; Already seeing vulnerability underneath the peer; Hoping to do some confluence modelling using CoSMoS and stormwater flooding analyses
L.A. River	2	Current project; Flood risk is high; Aiming to do projects that show multiple benefits addressing flood risk and helping to build resilience
Point Dume/Lagoon Area	2	Beaches and adaptation project; Identifying some of these beaches that have over 5 million visitors every year; Identifying beaches with flood risk, but also structural vulnerability
Port of L.A.	2	Highly developed infrastructure, with little access to nature or the ocean; Coastal/stormwater flooding risk among other elements that pose issues
San Pedro	3	Structural vulnerability and flooding
Malibu (Broad Beach)	3	Coastal erosion and flooding; Limited sediment input in that area; Is an area that serves many social functions, but added risks of wildfires, etc; Many people who work in this area directly impacted
Venice	3	Coastal flooding and social vulnerability (thinking about the homeless population)
Port of L.A. and Long Beach	4	Lots of storage and transportation of hazardous materials; Lowest priority, because they have more adaptation capacity
Venice	4	Flooding risk (bathtub)
Long Beach	4	Waves already overtopping coastal properties; Marina area with low lying seawalls; Wetlands that will be “squeezed” by coastal and inland flooding

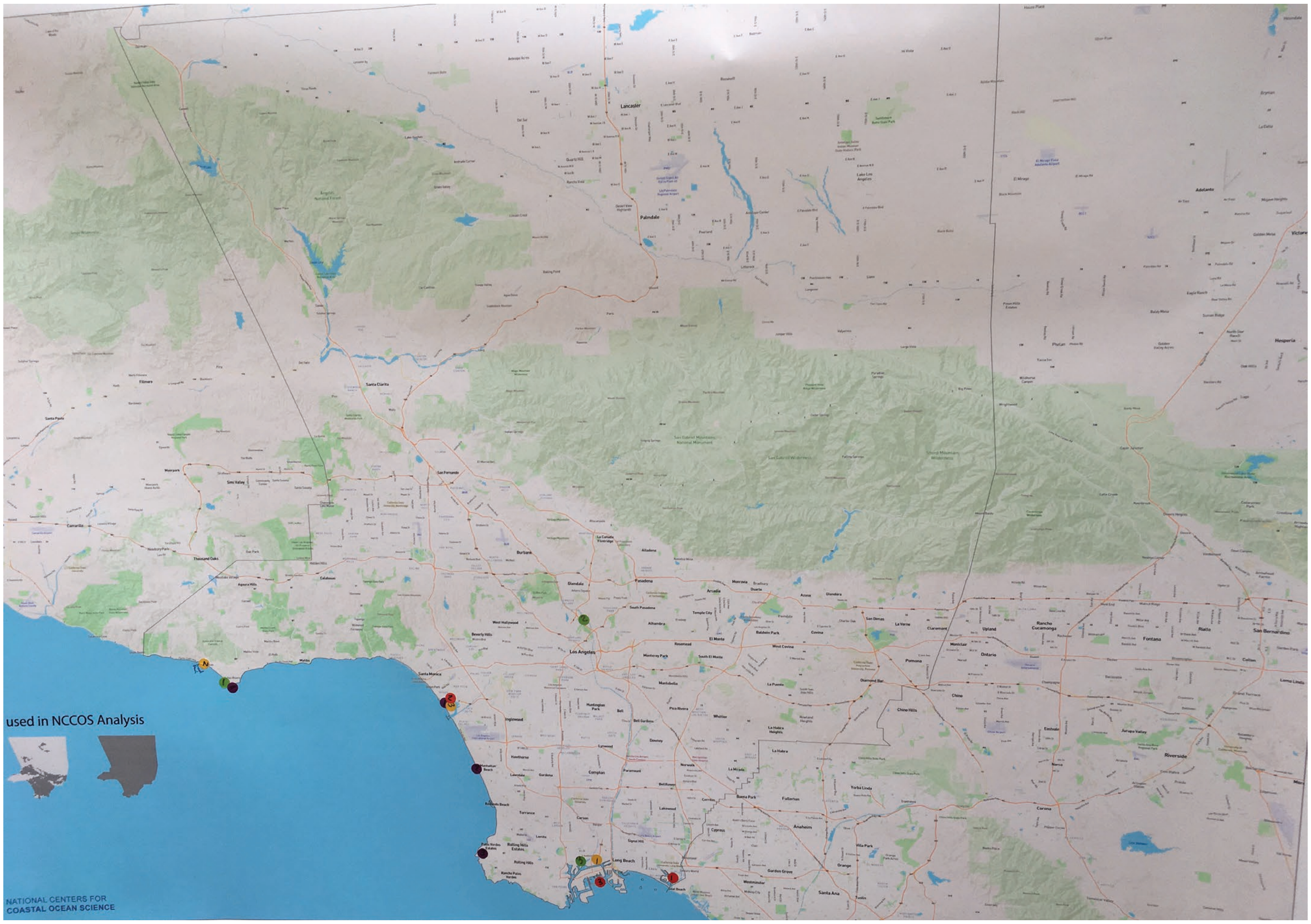


Figure B1. Final geography prioritization map.

SNAP EXERCISE – 30 mins

Purpose:

This exercise helped to prioritize assessment and analysis results. Given the large quantity of geographies, vulnerabilities, and risks, this step was necessary when developing final project deliverables. The SNAP exercise was conducted in two steps.

STEP ONE

Purpose:

This step determined stakeholders' prioritization of vulnerability and risk combinations, and aided the research team in organizing and prioritizing assessment results.

Actions:

Stakeholders were asked to write their top two risks of most concern on individual sticky notes, and were then asked to consider the categories of social, natural, or structural vulnerability. Participants placed sticky notes one at a time under the category they felt most interacted with their chosen risks. As each sticky note was placed, other participants were asked to consider if either of their chosen risks also fit most appropriately in the chosen category. If they agreed, they would attach their sticky note to the original to give a visual of the most important interactions.

Results:

Two large clusters formed: wildfire risk on natural resources vulnerability and coastal flooding/erosion on structural vulnerability.

STEP TWO

Purpose:

This step determined additional thematic areas for analysis by asking stakeholders to consider the potential drivers of their prioritized vulnerability and risk combinations.

Actions:

Step two instructed participants to consider the potential drivers of their most prioritized vulnerability and risk combinations. Prompts included: For example, what are the strongest contributing factors to the relationship between wildfire risk and natural resource vulnerability? Since each risk and vulnerability is a composite indicator, participants were asked to think about the contributing factors that might be driving the relationship for each composite. This question led to more discussion between stakeholders as they attempted to cluster their ideas by theme.

Results:

Results are shown in Figure B2. The cluster of six in the lower right represents a concern that blufftop and other marginal development spaces are especially prone to erosion and coastal flooding. The cluster of 5 in the lower left represents a concern that critical infrastructure – most notably evacuation and other transportation routes – are in areas at risk to coastal flooding and erosion. The cluster of four in the middle-right represents concerns about access to open space and natural habitat, which has implications for all three types of vulnerability.

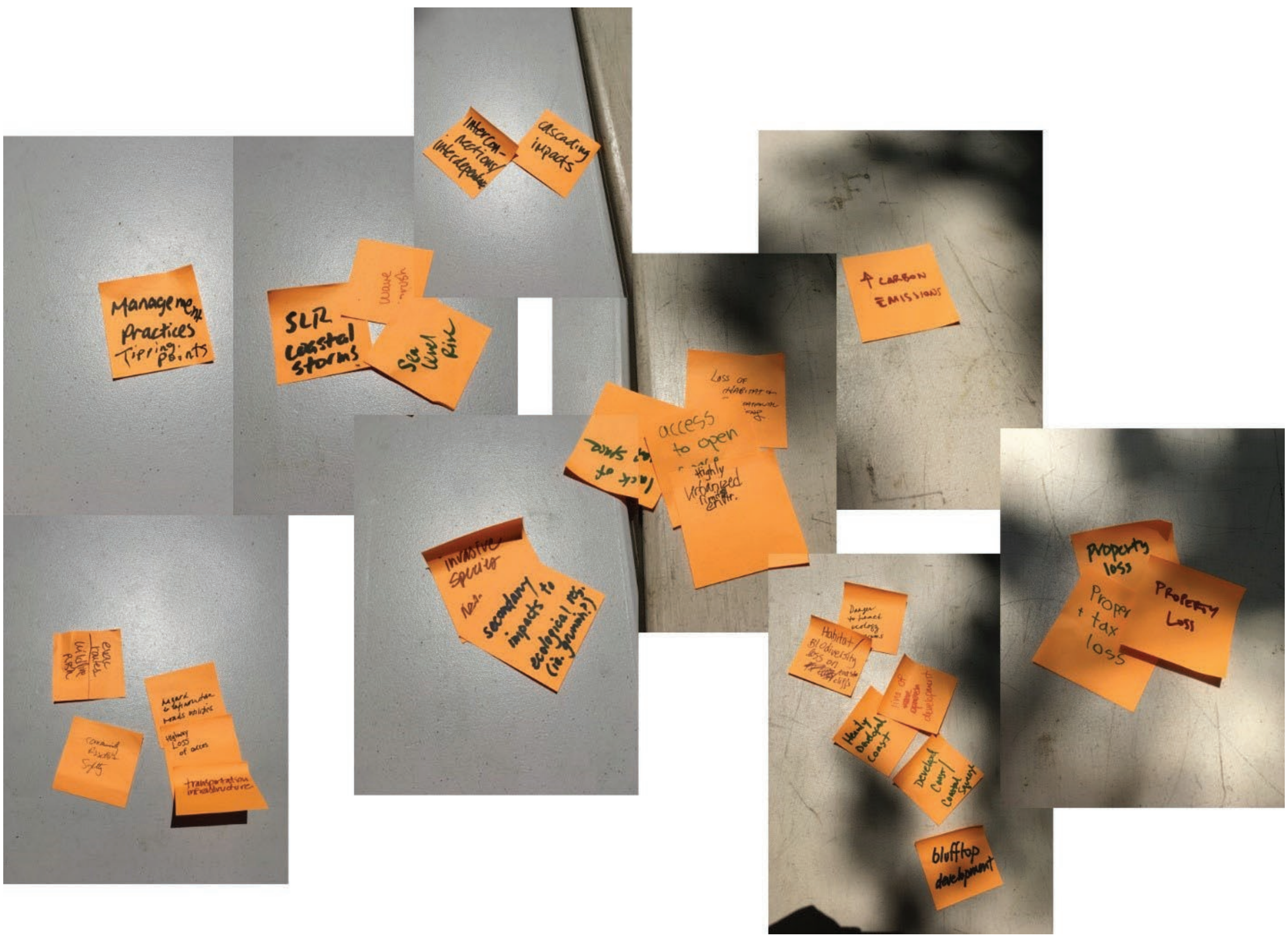
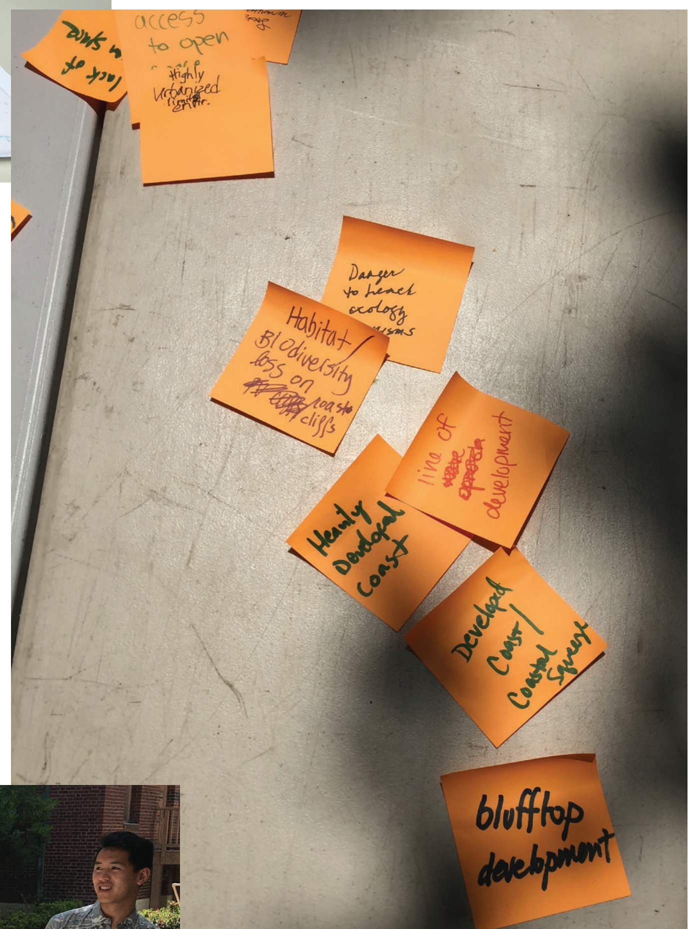


Figure B2. SNAP exercise results.

Appendix B photo gallery:

Placing points during mapping exercise.
Credit: Heidi Burkart, NOAA-CSS



SNAP exercise sticky notes.
Credit: Seann Regan, NOAA-CSS

Participating in SNAP exercise. Credit: Heidi Burkart, NOAA-CSS

Participating in mapping exercise. Credit: Heidi Burkart, NOAA-CSS

Break out discussions. Credit: Heidi Burkart, NOAA-CSS

Leading prioritization mapping exercise. Credit: Heidi Burkart, NOAA-CSS

Wealth in Los Angeles. Credit: Chloe Fleming, NOAA-CSS

Appendix C: Data Sources

Table C1. Sources for data used in vulnerability metrics.

	Variable	Resolution	Year	Source	Notes
Social Vulnerability	All	Polygon (Census block group)	2012-2016	US Census Bureau, American Community Survey	
Structural Vulnerability	Parcel Age	Polygon (parcel)	2016	Los Angeles County Geoportal	Percentage of parcels within the block group with an effective build date before 1978
	Disaster Routes	Line	2015	Disaster Route Layer from Los Angeles County Geoportal	Mileage of disaster routes (freeway, highway, or arterial) in a block group normalized to the land area of the block group
	Improvement Value	Polygon (structure)	2014	Los Angeles Region Imagery Acquisition Consortium (version 4) data from Los Angeles County Geoportal	Sum of improvement values for each building in the block group (from the County Tax Assessor's Office)
	Critical Infrastructure	Point	2015	Points of Interest layer from Los Angeles County Geoportal	Location count per block group of facilities considered critical to the functioning of a city: power plants, wastewater treatment, dams, reservoirs, police and fire, emergency services, educational, hospitals
	Historic Places	Point	updated 2017	National Register of Historic Places	Location count per block group of places registered with the National Register of Historic Places
Natural Resource Vulnerability	Greenness	30m Raster	2018	Normalized Difference Vegetation Index by US Geological Survey from ESRI Online (retrieved 4/5/18)	Percentage of pixels per block group with an Normalized Difference Vegetation Index value greater than 0.2 (non-desert vegetative growth)
	Tree Canopy Cover	30m Raster	2011	National Land Cover Database by US Forest Service	Percentage of each pixel covered with tree canopy
	Habitat Fragmentation	Polygon	2011	National Land Cover Database	Aggregation level of land cover types that can serve as habitat for mobile species in the region, utilizing the clumpiness index (Wang et al. 2014), calculated per block group using FRAGSTATS (McGarigal et al. 2012)
	Wetland Cover	Polygon	2017	National Wetlands Inventory	Percent areal cover per block group designated as wetland
	Predicted Species Richness	30m Raster	2017	Global Biodiversity Information Facility/ Coastal Change Analysis Program	Prediction of the number of species found in each pixel; Modelled using MaxEnt software; 980 species
	Significant Ecological Areas	Polygon	2015	Los Angeles County Department of Regional Planning	Areas of irreplaceable biological resources

Table C2. Sources for data used in risk metrics.

	Variable	Resolution	Year	Source	Notes
Coastal Flooding	Inundation	2m Raster	2017	Coastal Storm Modeling System	Short term-low risk with an annual storm event; mid term-medium risk with a 20 year storm event; long term-high risk with a 100 year storm event
Stormwater Flooding	Flow Accumulation	10m Raster	2016	US Geological Survey Digital Elevation Model	Derived from elevation data from the US Geological Survey's 10-meter National Elevation Dataset Resampled to 30m for analysis
	Rainfall Intensity	400m Raster	2006	Los Angeles Department of Public Works	50-yr frequency rainfall for 24-hour duration; Resampled to 30m for analysis
	Hydrologic Soil Groups	Polygon	2002-2017	US Department of Agriculture Natural Resources Conservation Service Soil Survey Geographic Database	Individual soil surveys merged and clipped to Los Angeles County; Reclassified according to hydrogroup; Converted to 30m raster for analysis
	Land Cover	30m Raster	2010	Coastal Change Analysis Program 2010	Reclassified according to land cover type propensity to inundation
	Slope	10m Raster	2016	US Geological Survey Digital Elevation Model	Derived from elevation data from the US Geological Survey's 10-meter National Elevation Dataset Resampled to 30m for analysis
	Elevation	10m Raster	2016	US Geological Survey Digital Elevation Model	Derived from elevation data from the US Geological Survey's 10-meter National Elevation Dataset Resampled to 30m for analysis
	Density of Drainage Network	Polyline	2018	National Hydrography Dataset Flowline	Line density calculated for Southern California region and then clipped to Los Angeles County; 30m raster product used in analysis
Erosion	Soil Wind Erodibility	Polygon	2002-2017	US Department of Agriculture Natural Resources Conservation Service Soil Survey Geographic Database	Individual soil surveys merged and clipped to Los Angeles County
	Water Erosion Hazard	Polygon	2002-2017	US Department of Agriculture Natural Resources Conservation Service Soil Survey Geographic Database	Individual soil surveys merged and clipped to Los Angeles County
Drought	Drought Severity and Coverage Index	Polygon	2017	US Drought Monitor	Weekly polygons converted to 30m raster and combined in calculation of Accumulated Drought Severity and Coverage Index
Heat	Temperature Normals	Point	1981-2010	National Oceanic and Atmospheric Administration National Centers for Environmental Information	Rasterized from point data to all of Los Angeles County
Wildfire	Wildfire Threat	30m Raster	2004	California Department of Forestry and Fire Protection	Raster dataset

Los Angeles River. Credit: Chloe Fleming, NOAA-CSS

Appendix D: Map Book

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Mapbook Appendix

This appendix provides full resolution maps of all assessment vulnerability and risk profiles and underlying indices, where appropriate. All bivariate choropleth maps discussed in Chapter 4 as well as all coastal analysis maps shown in Chapter 5 are also included.

Corresponding figure numbers have been assigned to each map in this appendix.

- Pages 121-130 introduce and display the vulnerability and risk index map collection.

Pages x-x display vulnerability and risk profiles and indices.
- Pages 131-141 introduce and display the vulnerability and risk final profile map collection.

Pages x-x display drought themed bivariate choropleth maps.
- Pages 142-145 introduce the bivariate choropleth map collection, and display maps related to drought risk.

Pages x-x display heat themed bivariate choropleth maps.
- Pages 146-147 display bivariate choropleth maps related to heat risk.

Pages x-x display erosion themed bivariate choropleth maps.
- Pages 148-152 display bivariate choropleth maps related to wildfire risk.

Pages x-x display wildfire themed bivariate choropleth maps.
- Pages 153-155 display bivariate choropleth maps related to erosion risk.

Pages x-x display flooding themed bivariate choropleth maps.
- Pages 156-161 display bivariate choropleth maps related to flooding risk.

Pages x-x display all coastal analysis maps.
- Pages 162-167 introduce the coastal analysis map collection, and display coastal analysis maps related to NFIP claims.

- Pages 168-172 display the remainder of the coastal analysis map collection.

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Vulnerability and Risk Indices

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Figure D1. (Figure 2.2. in Chapter 2)

Index Components: Social Vulnerability

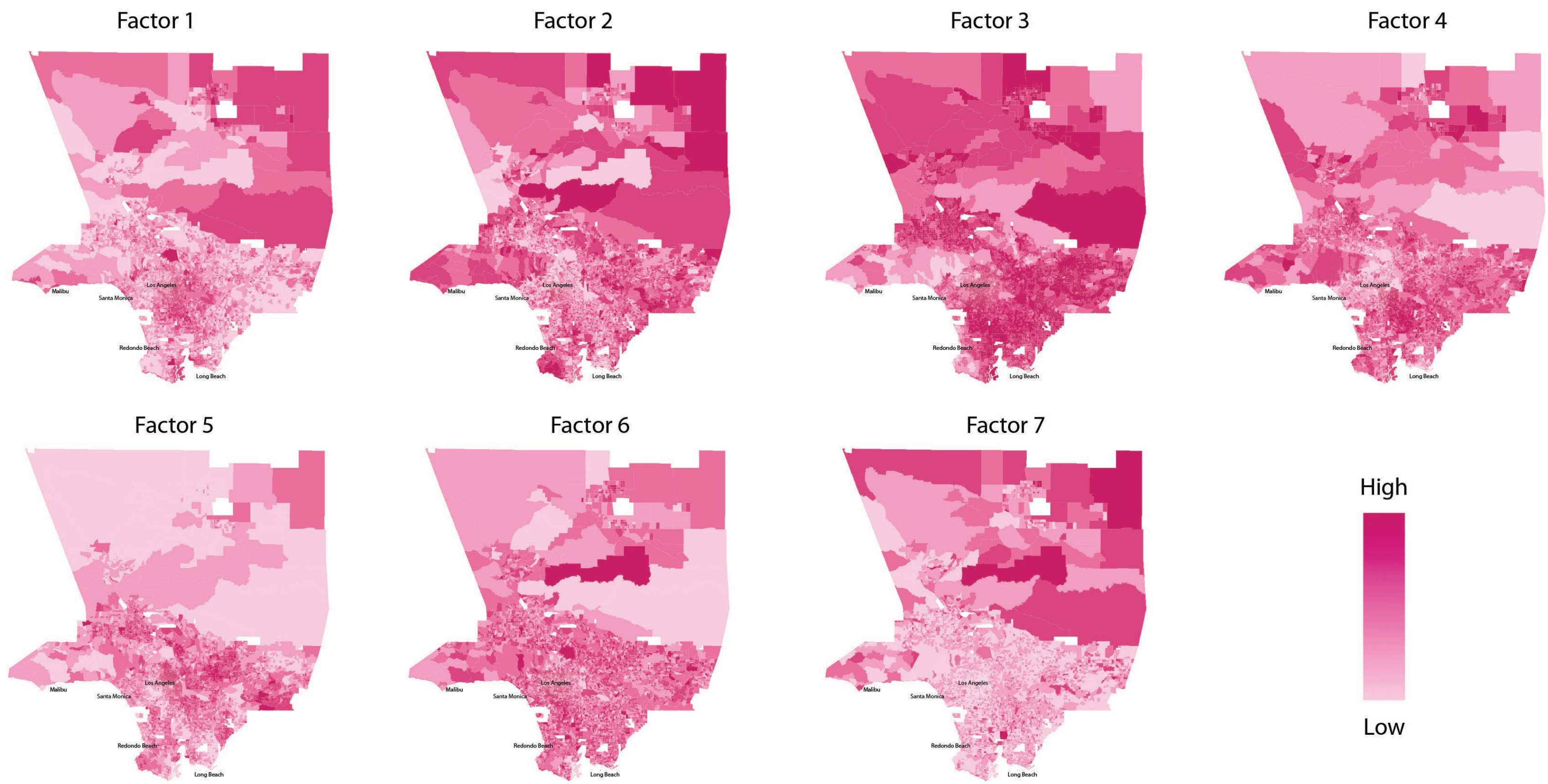

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Figure D2. (Figure 2.3. in Chapter 2)

Index Components: Structural Vulnerability

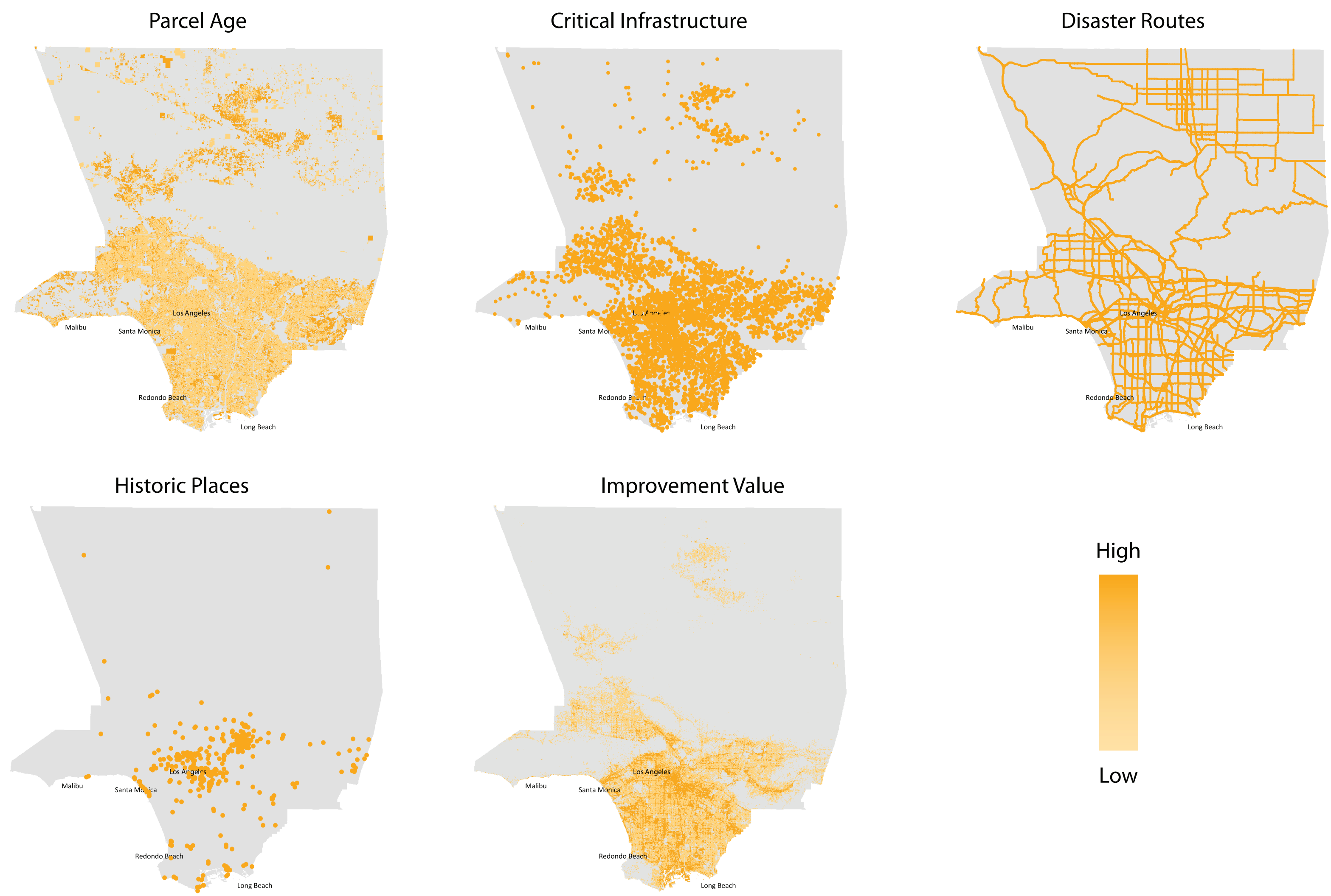

Figure D3. *(Figure 2.4. in Chapter 2)*

Index Components: Natural Resource Vulnerability

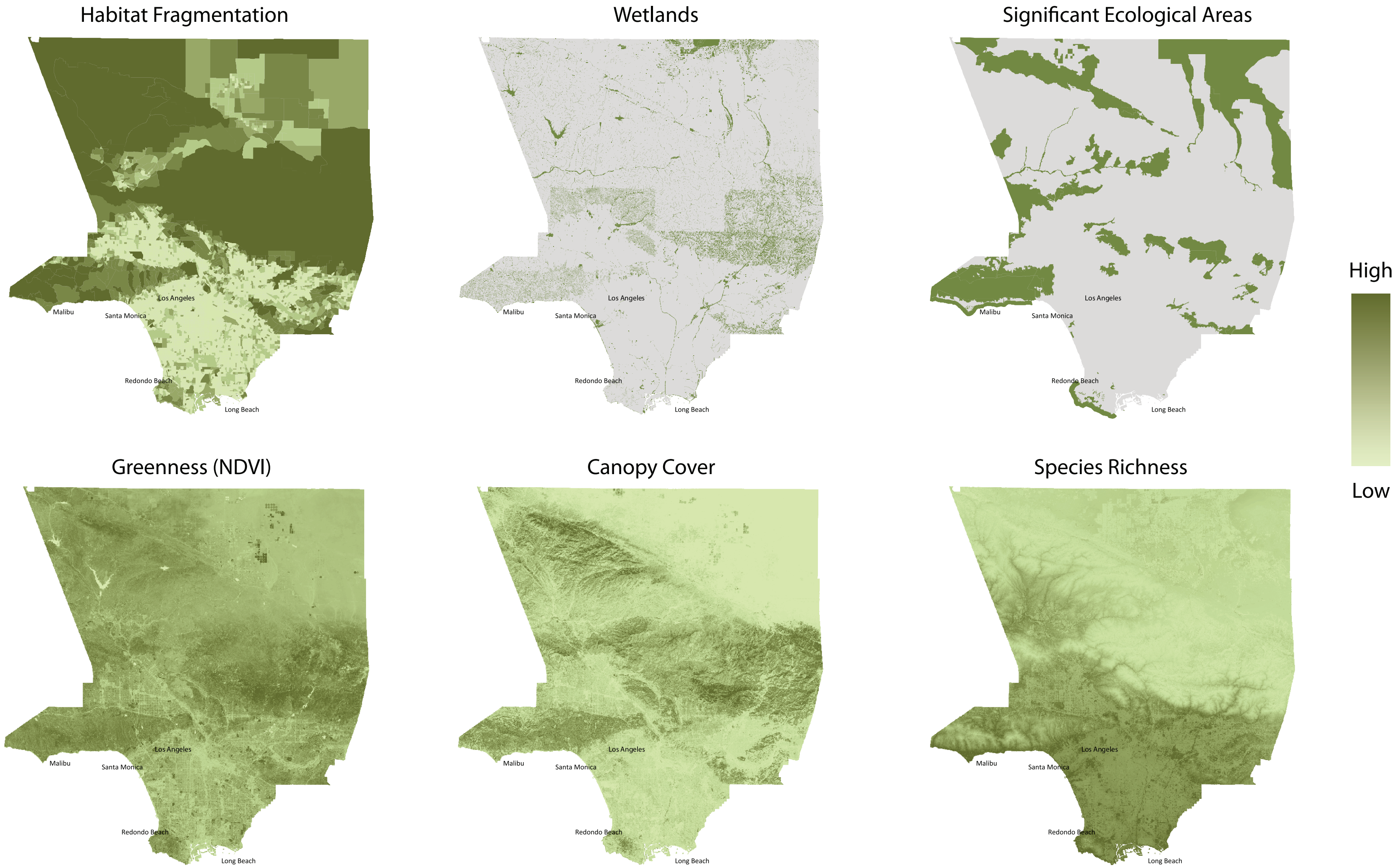

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Fig 12

Figure D4. (Figure 2.5. in Chapter 2)

Index Components: Coastal Flooding

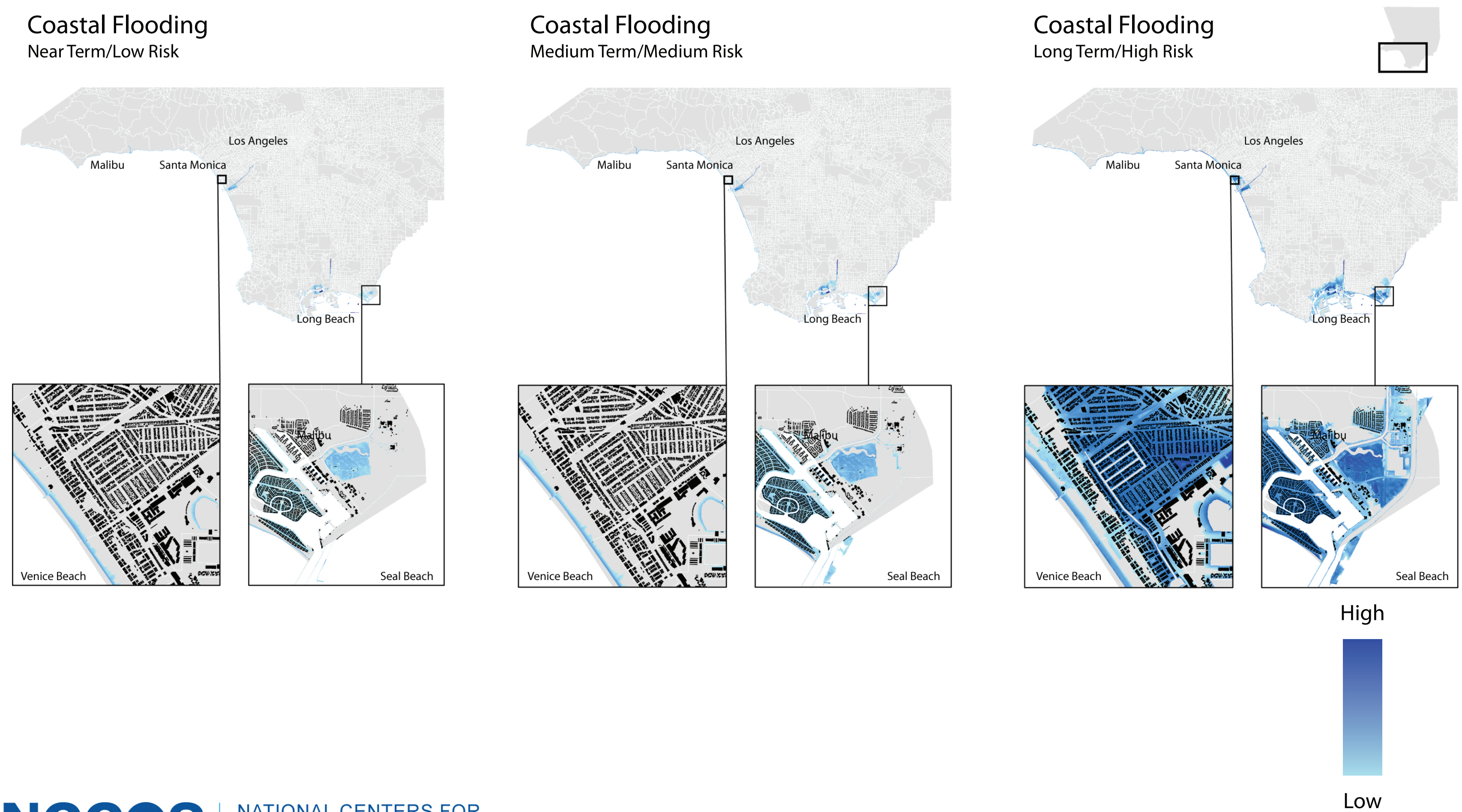

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Fig 13

Figure D5. (Figure 2.6. in Chapter 2)

Index Components: Stormwater Flooding

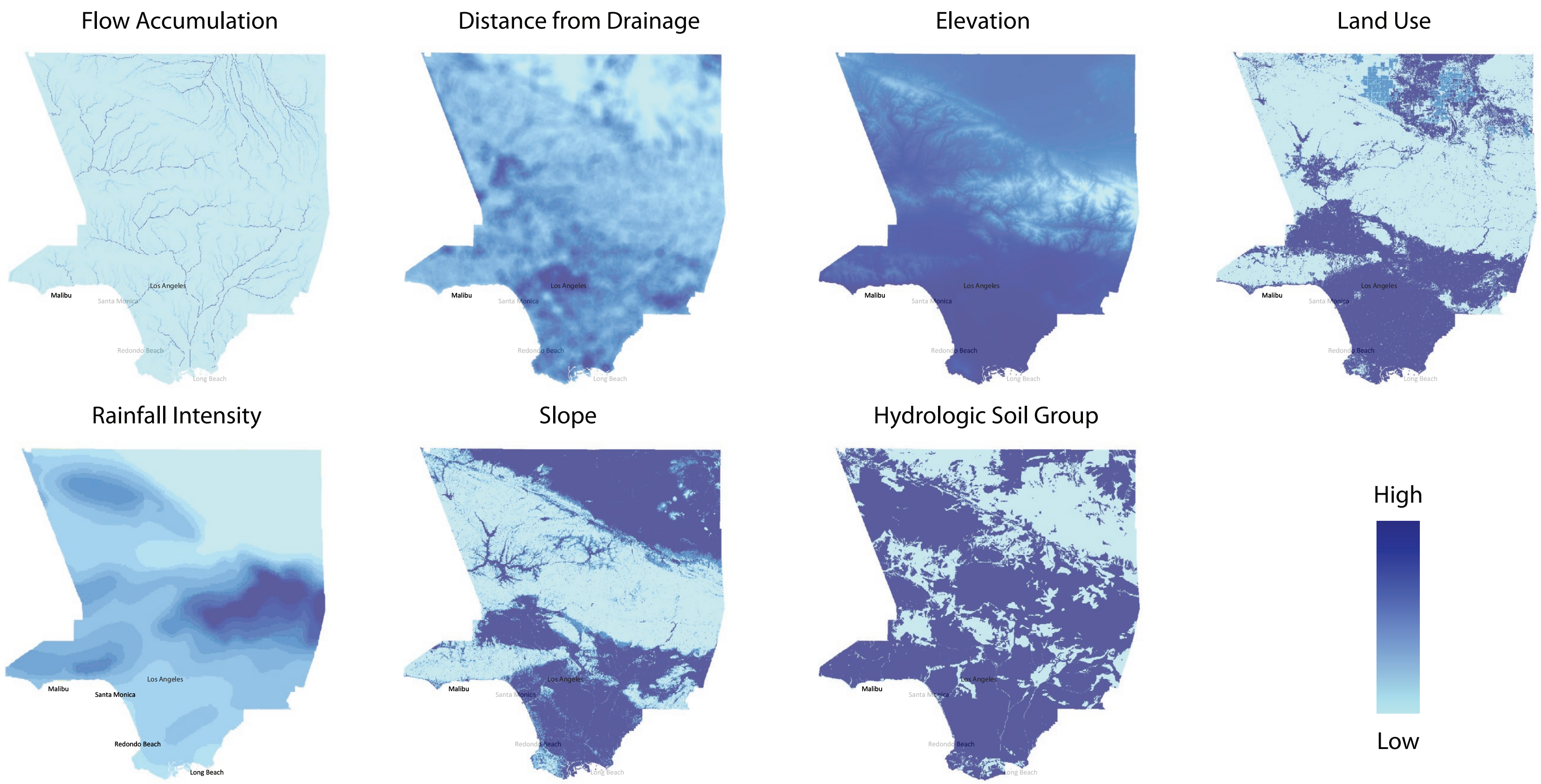

Figure D6. (Figure 2.7. in Chapter 2)

Index Components: Erosion

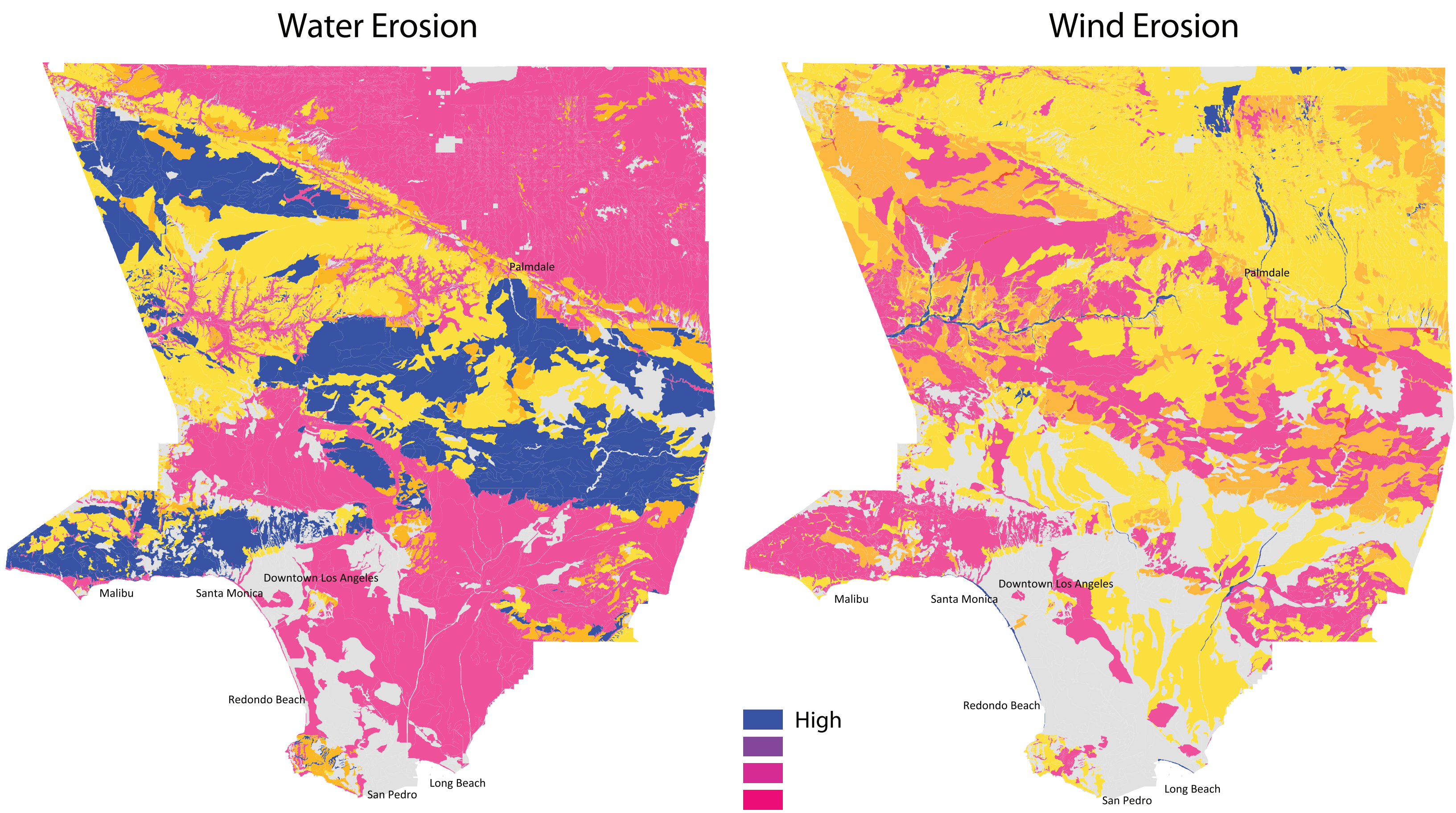

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Figure D7. (Figure 2.8. in Chapter 2)

Index Components: Drought

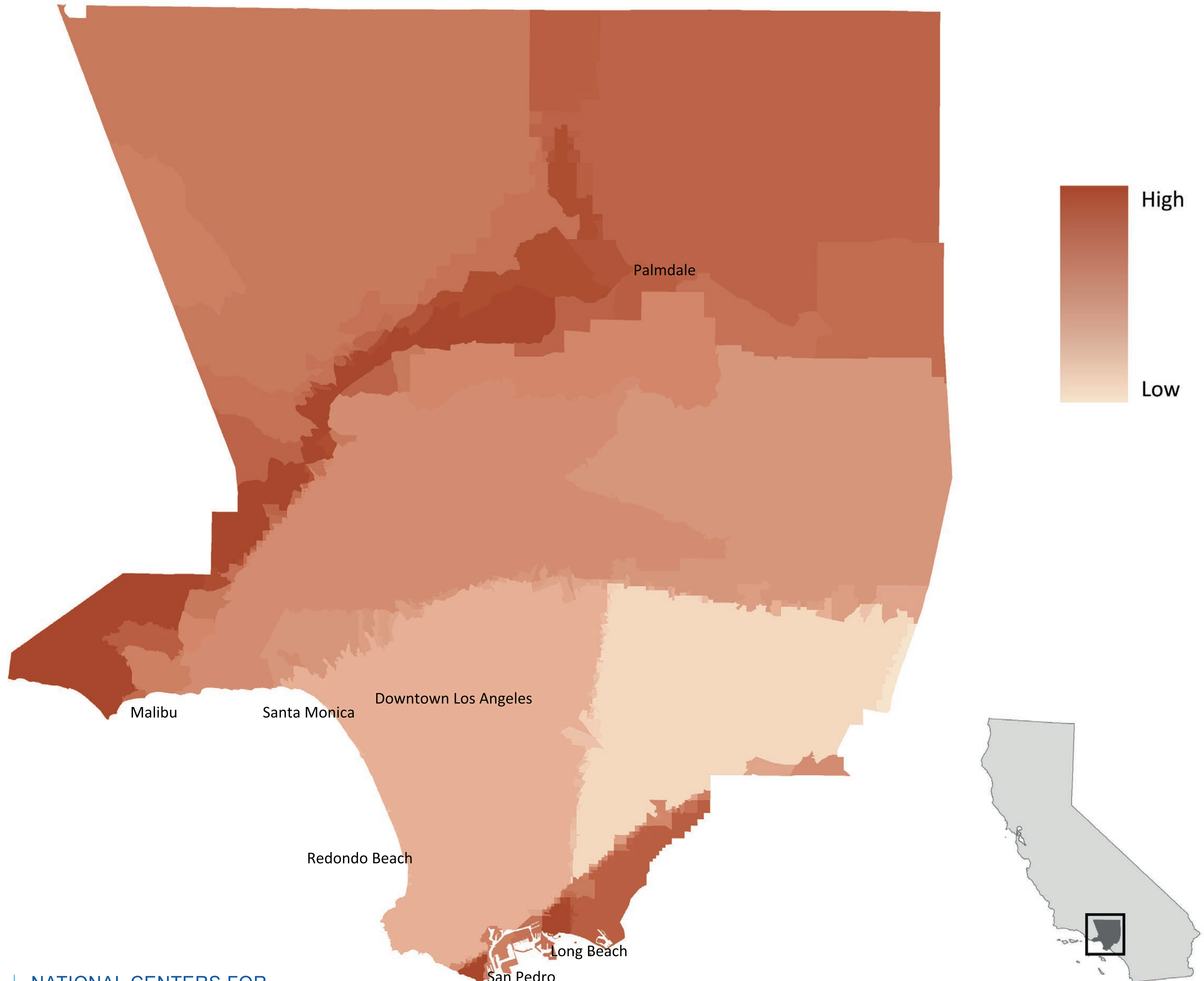

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Fig 16

Figure D8. (Figure 2.9. in Chapter 2)

Index Components: Heat

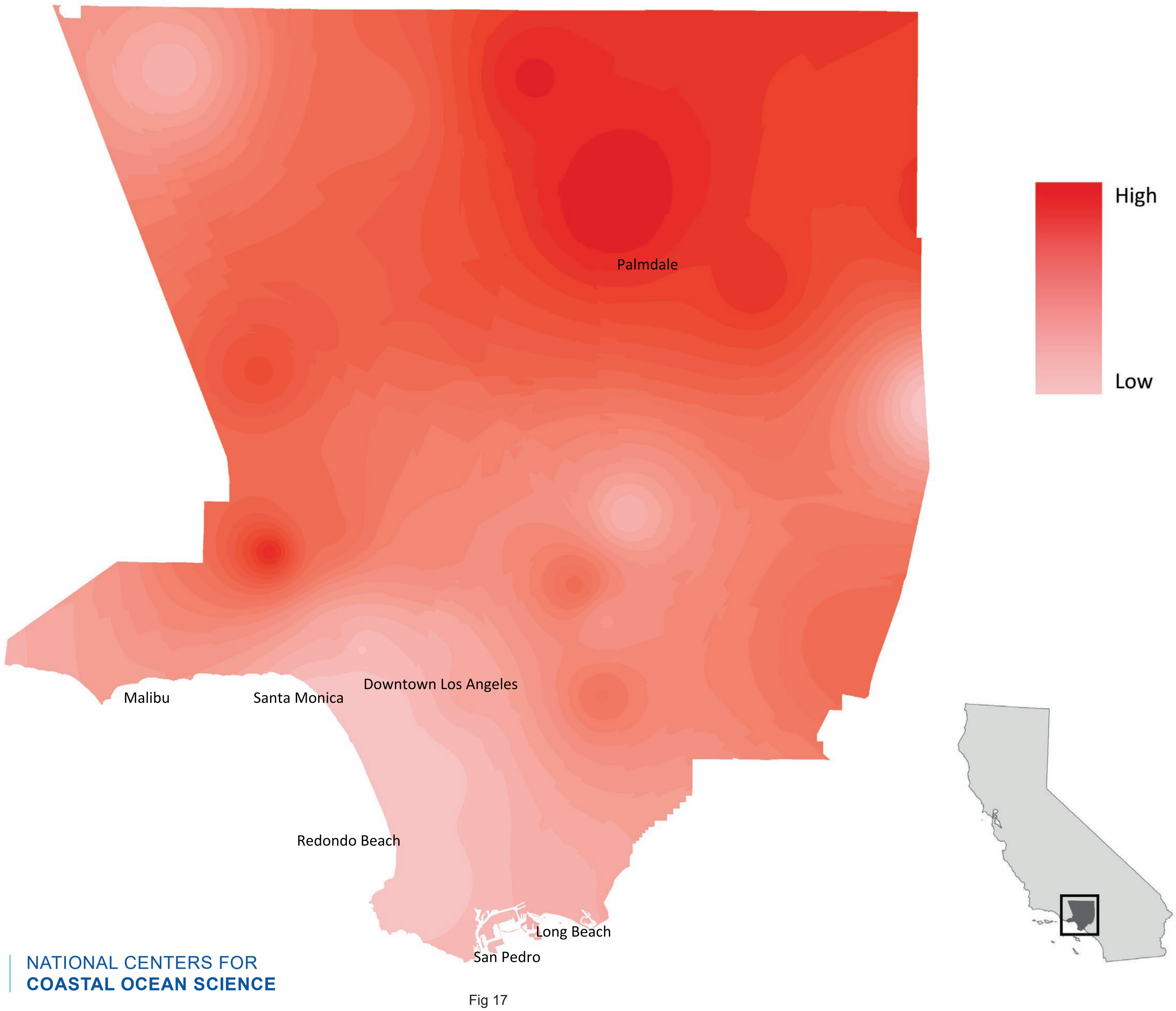

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Figure D9. (Figure 2.10. in Chapter 2)

Index Components: Wildfire

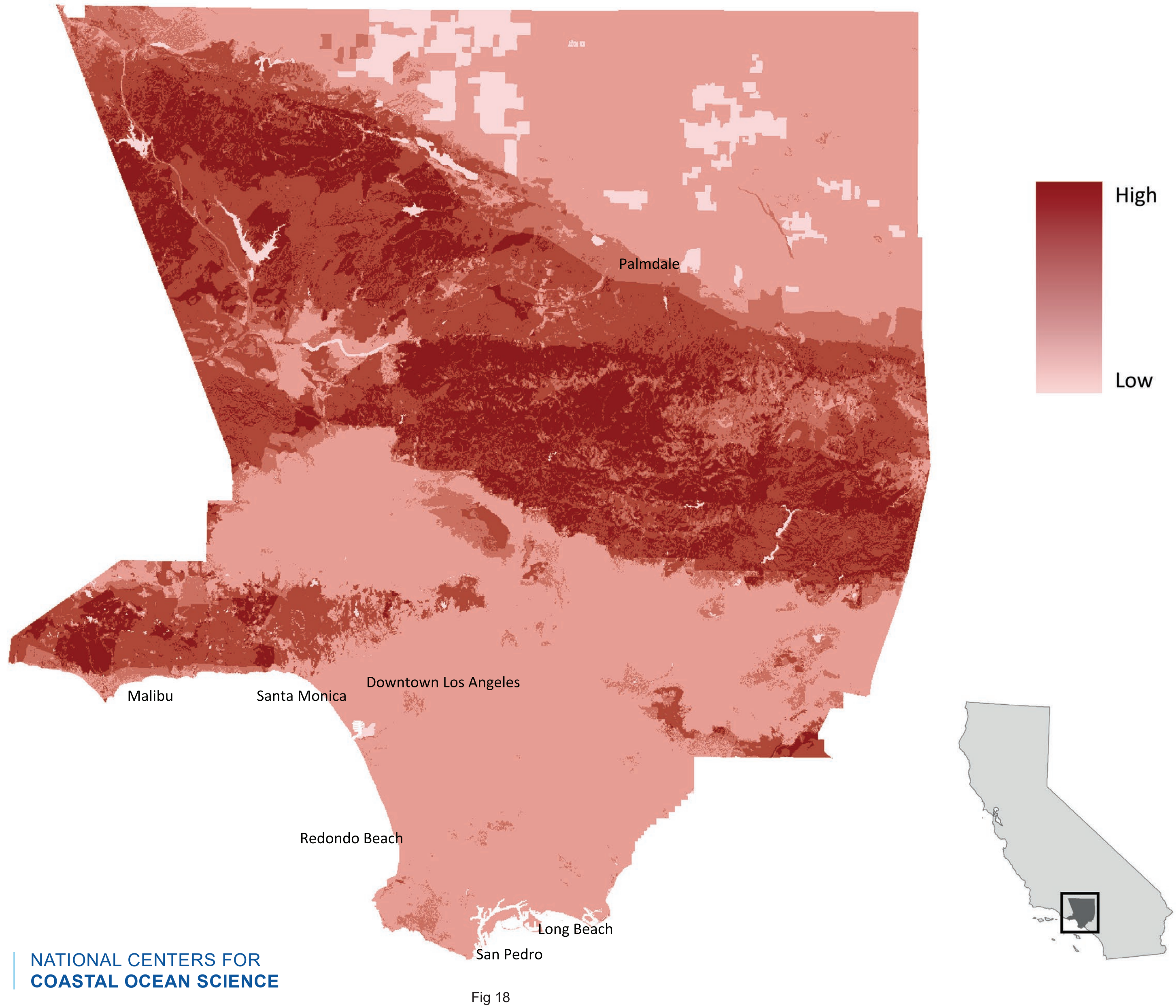

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Figure D10. (Figure 4.1. in Chapter 4)

Social Vulnerability in Los Angeles County

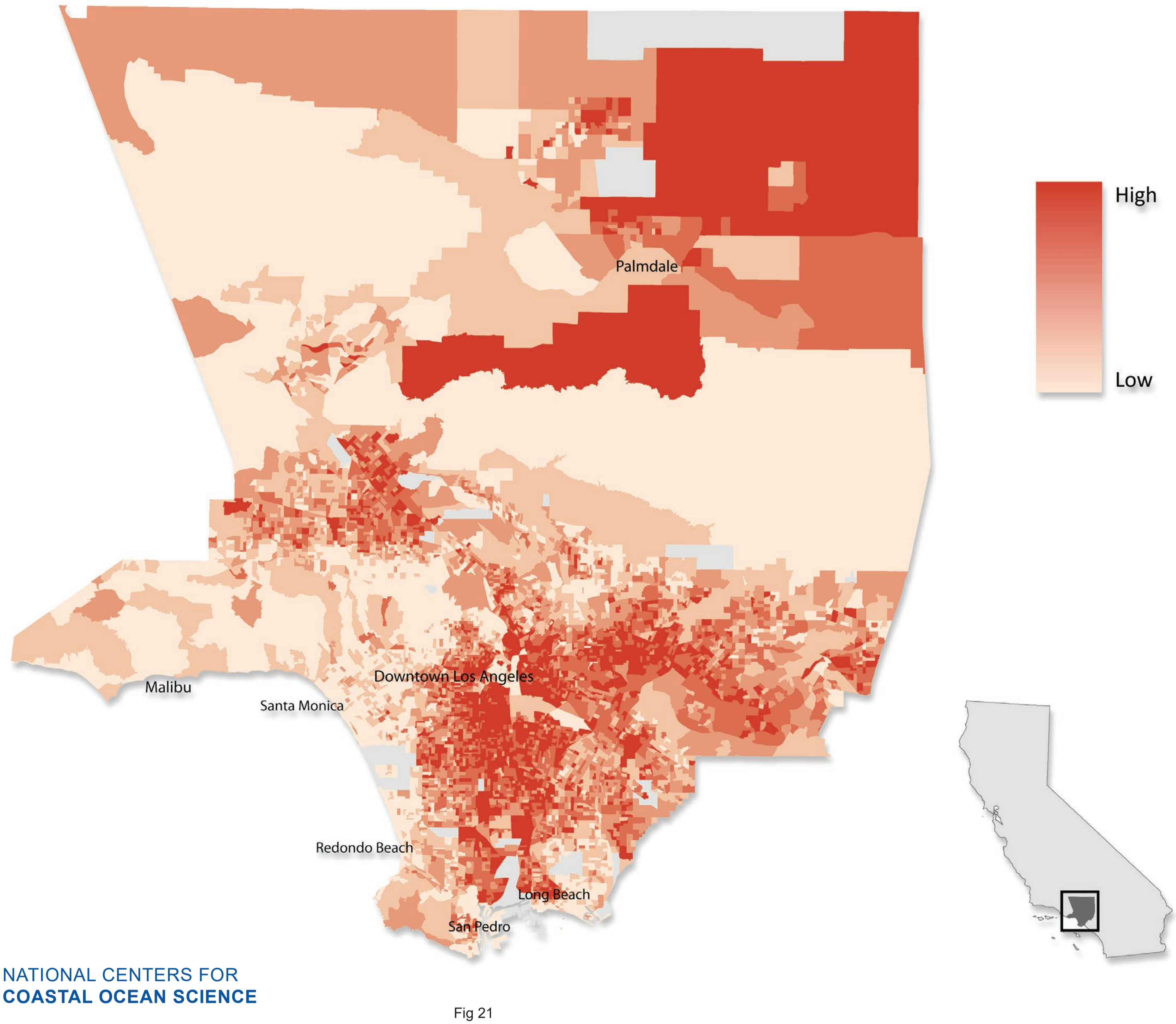

Fig 21

Figure D11. (Figure 4.2. in Chapter 4)

Structural Vulnerability in Los Angeles County

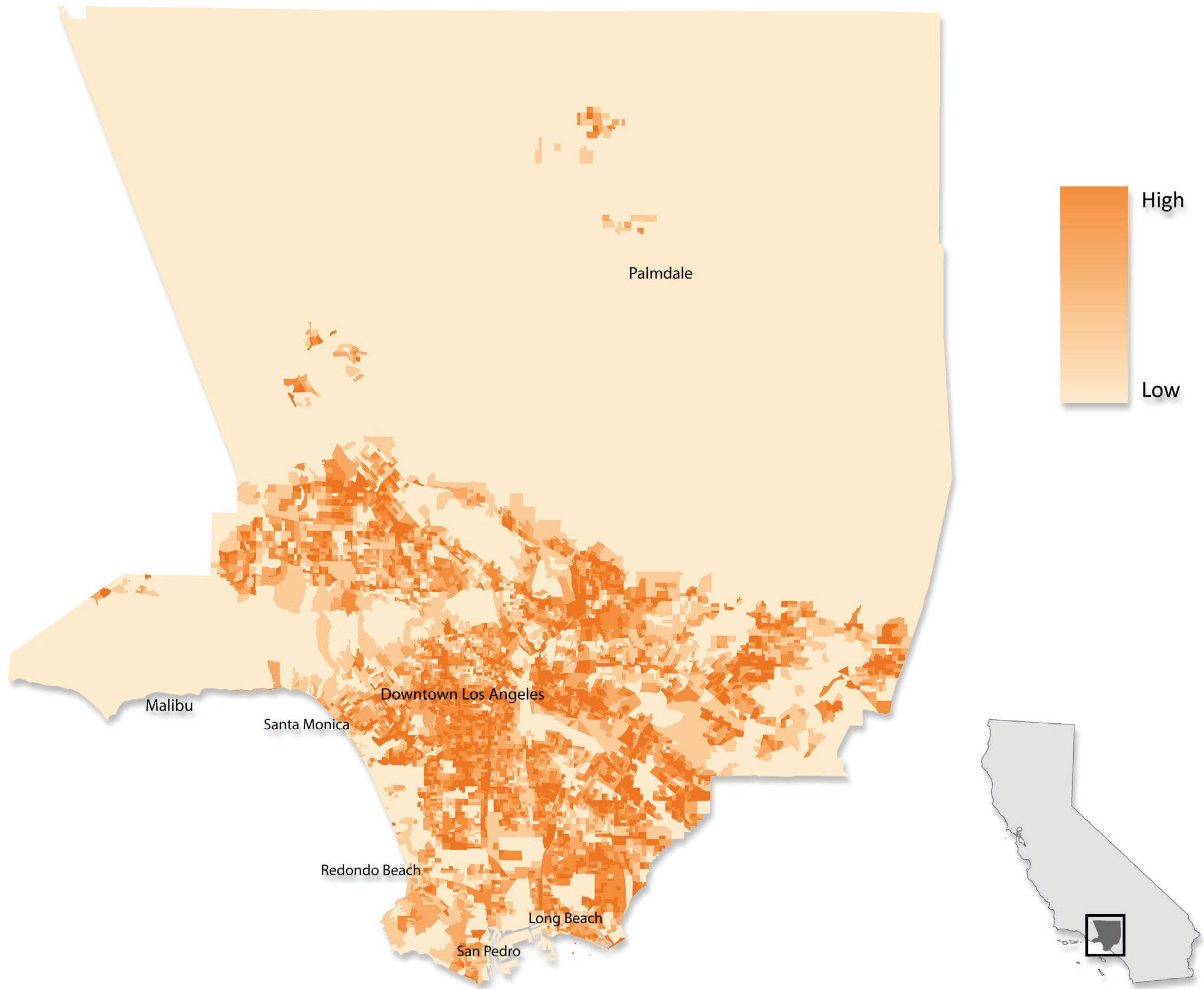

Fig 23

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Figure D12. (Figure 4.3. in Chapter 4)

Natural Resource Vulnerability in Los Angeles County

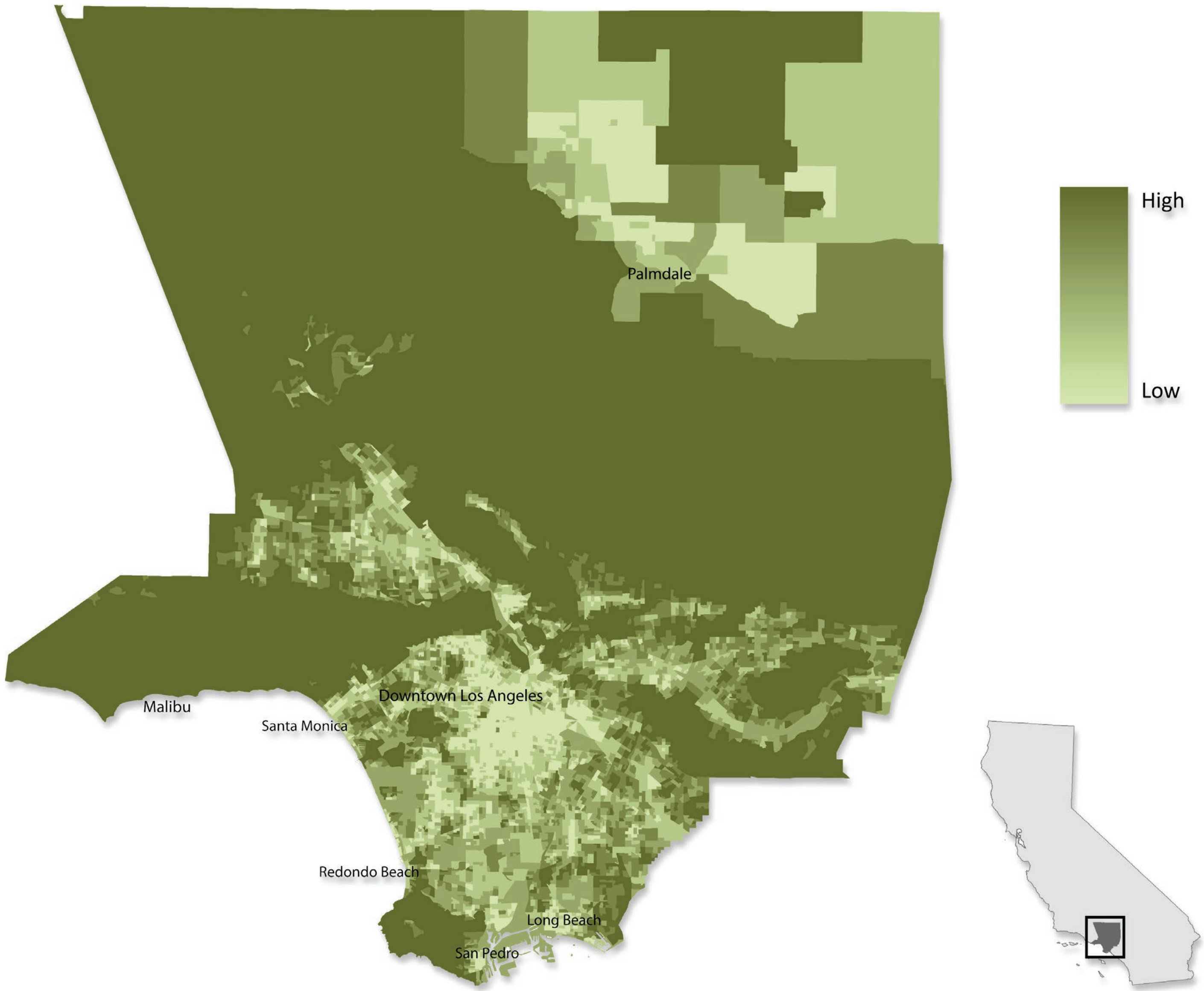

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Fig 24

Figure D13. (Figure 4.4.(left) in Chapter 4)

Coastal Flooding Risk in Los Angeles County

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Fig 25

Figure D14. (Figure 4.4.(right) in Chapter 4)

Stormwater Flooding Risk in Los Angeles County

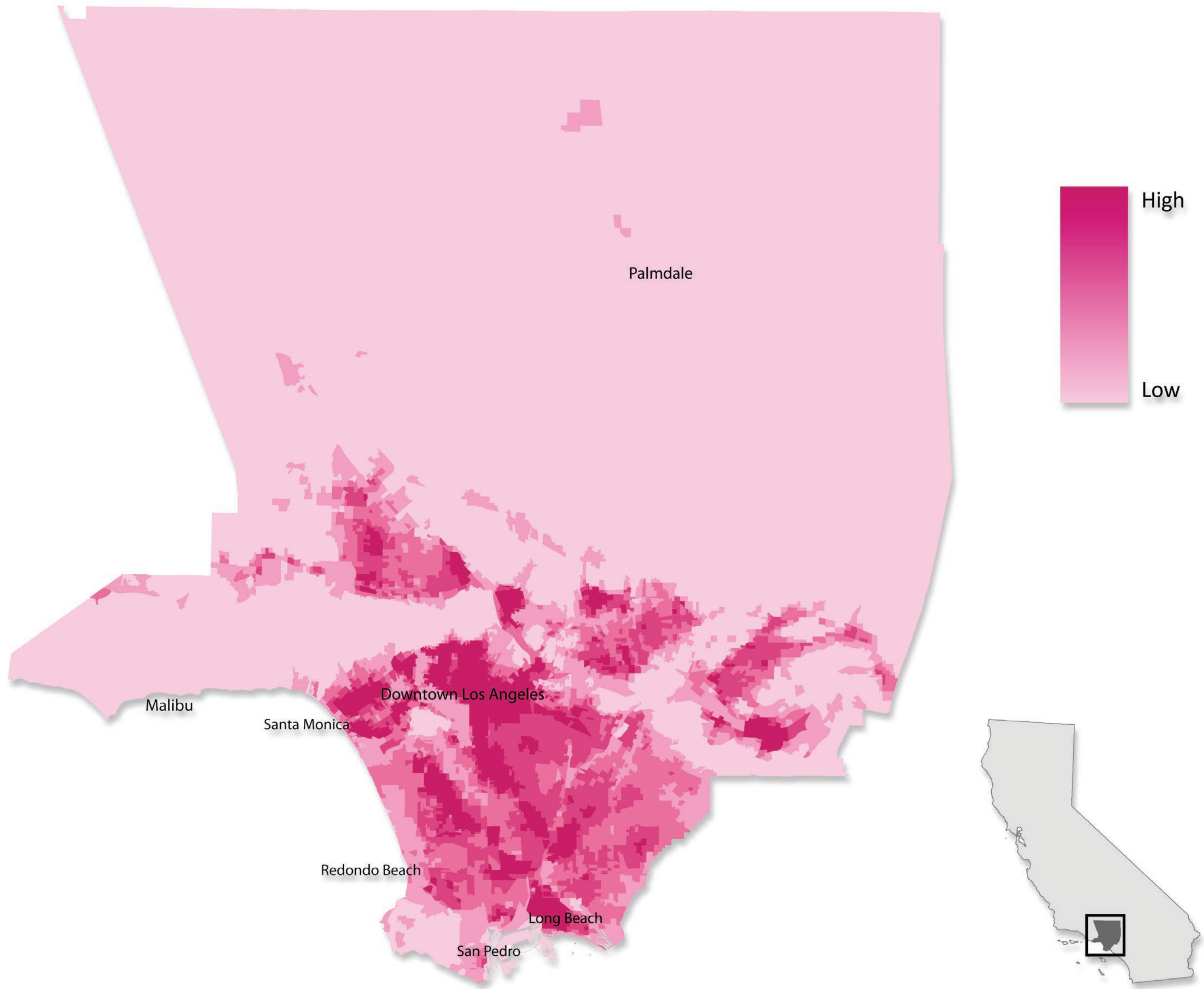

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Fig 25 right

Figure D15. (Figure 4.5. in Chapter 4)

Combined Flooding Risk in Los Angeles County

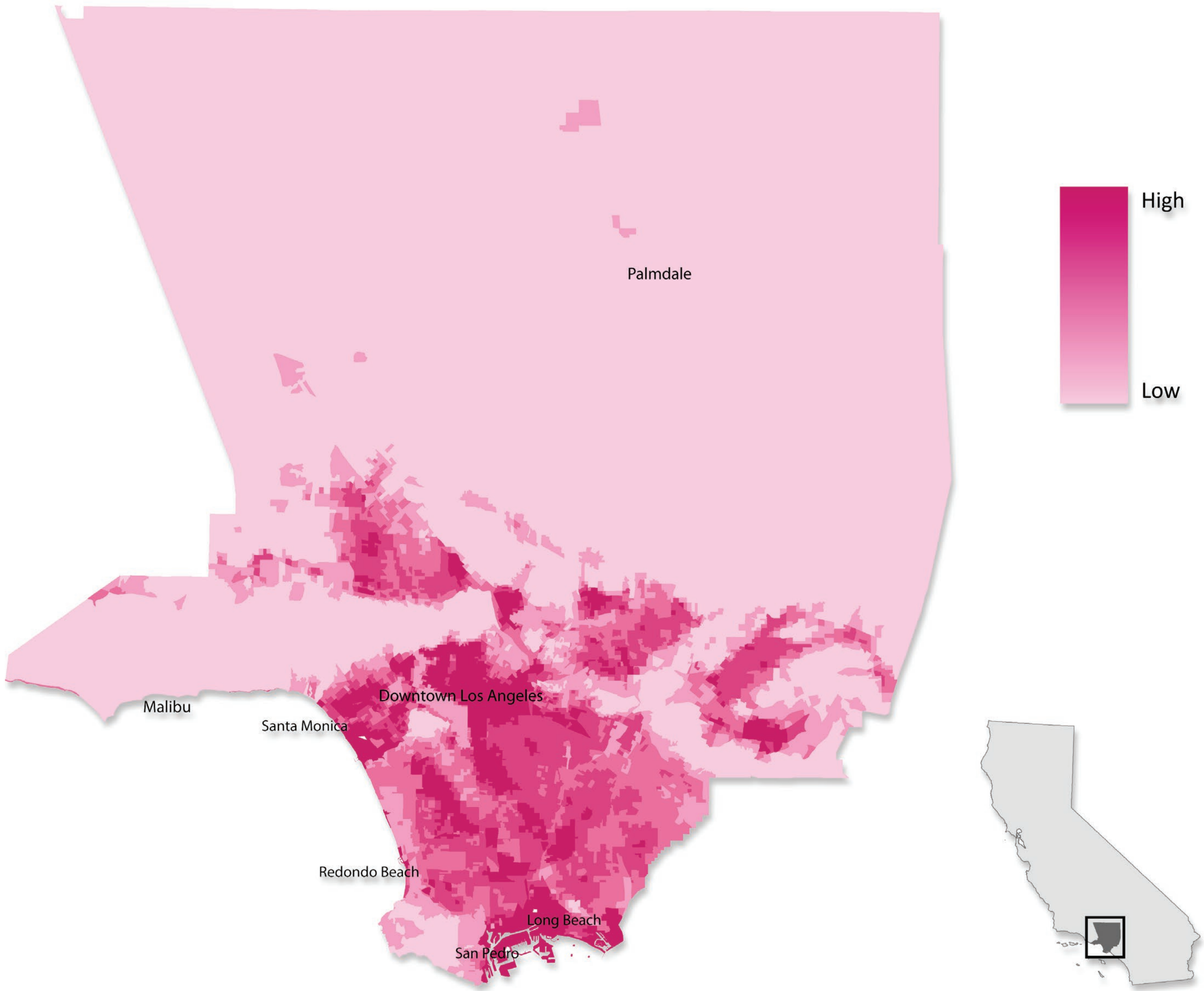

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Fig 25 left

Figure D16. (Figure 4.6. in Chapter 4)

Erosion Risk in Los Angeles County

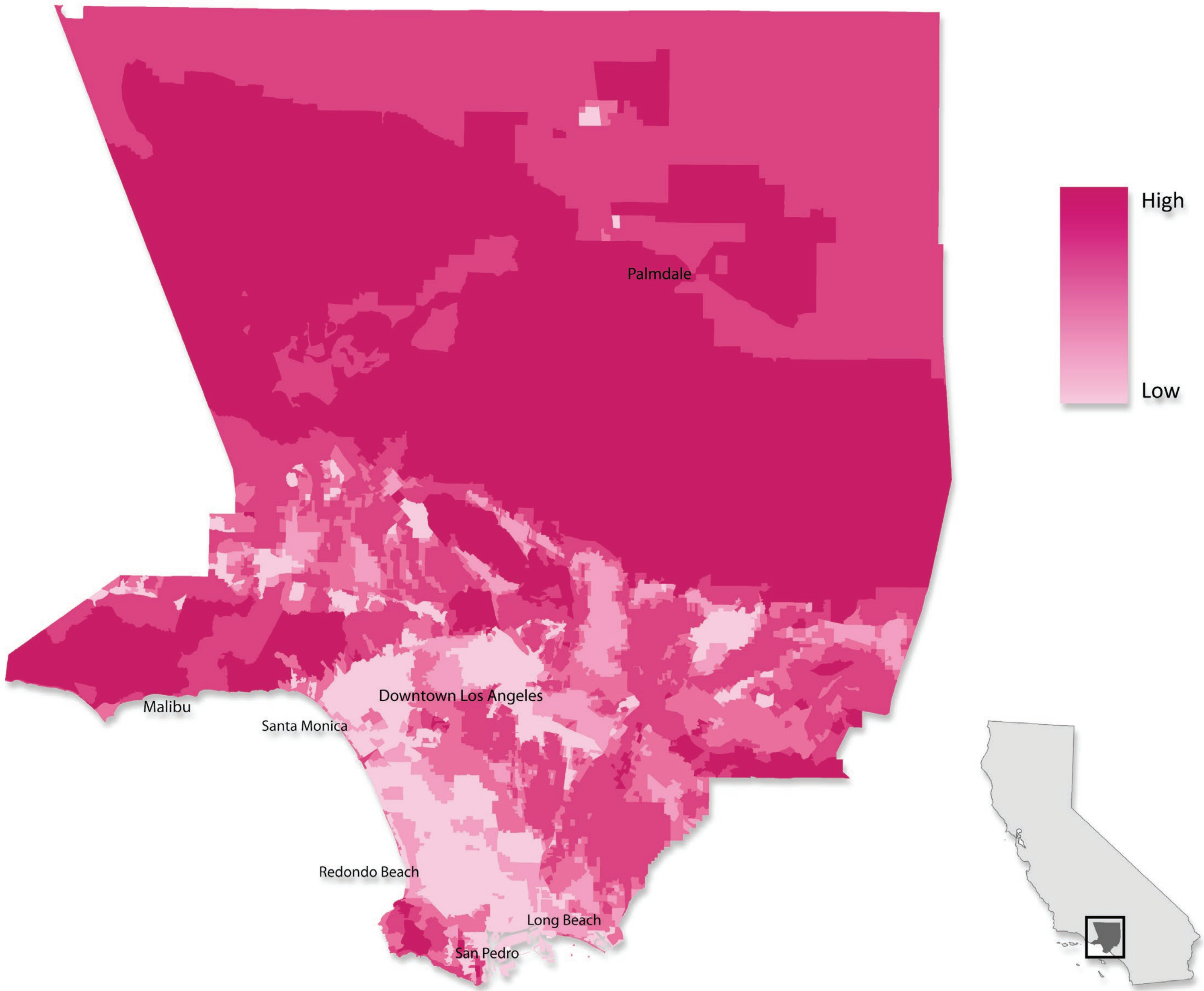

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Fig 27

Figure D17. (Figure 4.7. (left) in Chapter 4)

Heat Risk in Los Angeles County

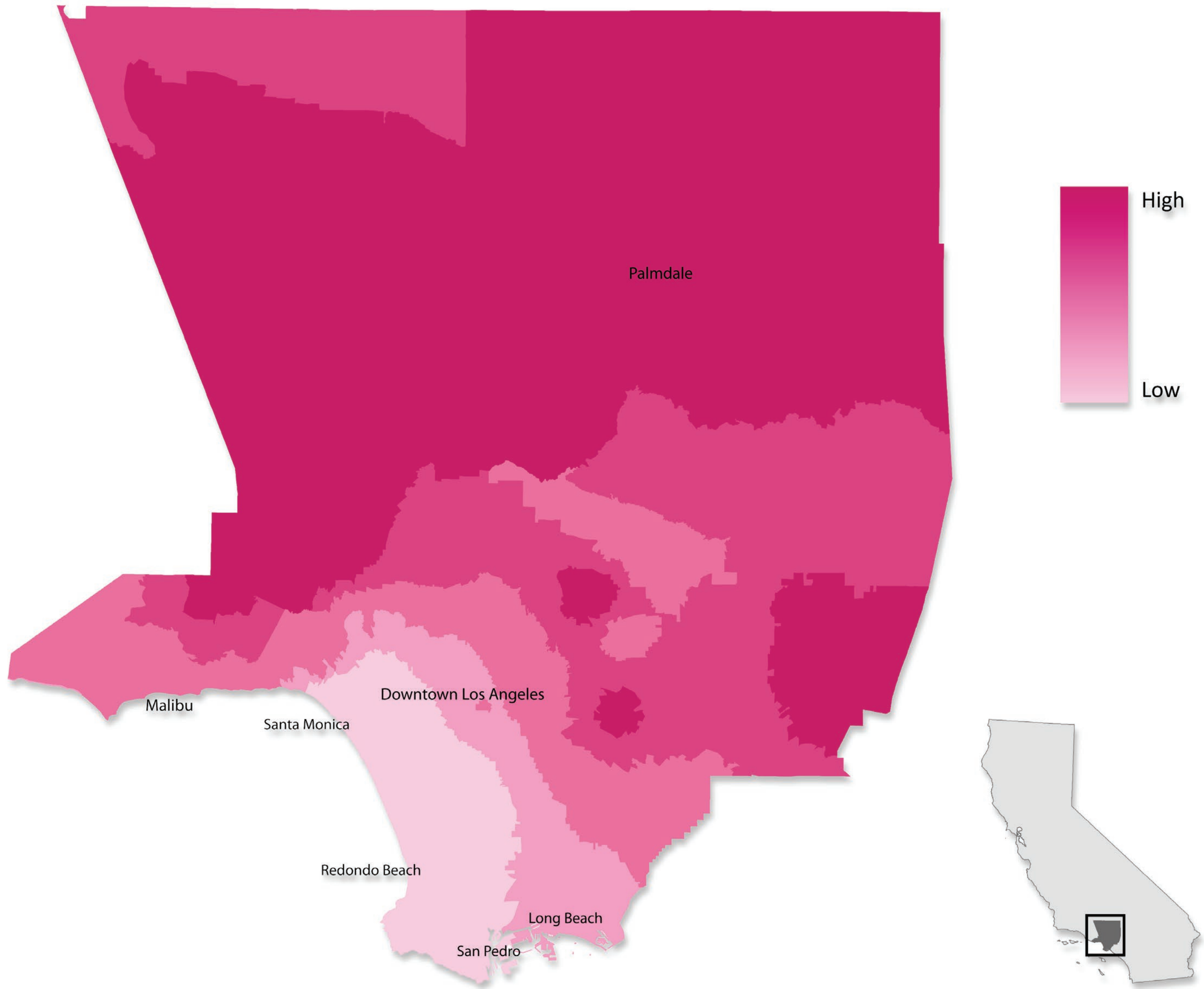

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Fig 28 left

Figure D18. (Figure 4.7. (right) in Chapter 4)

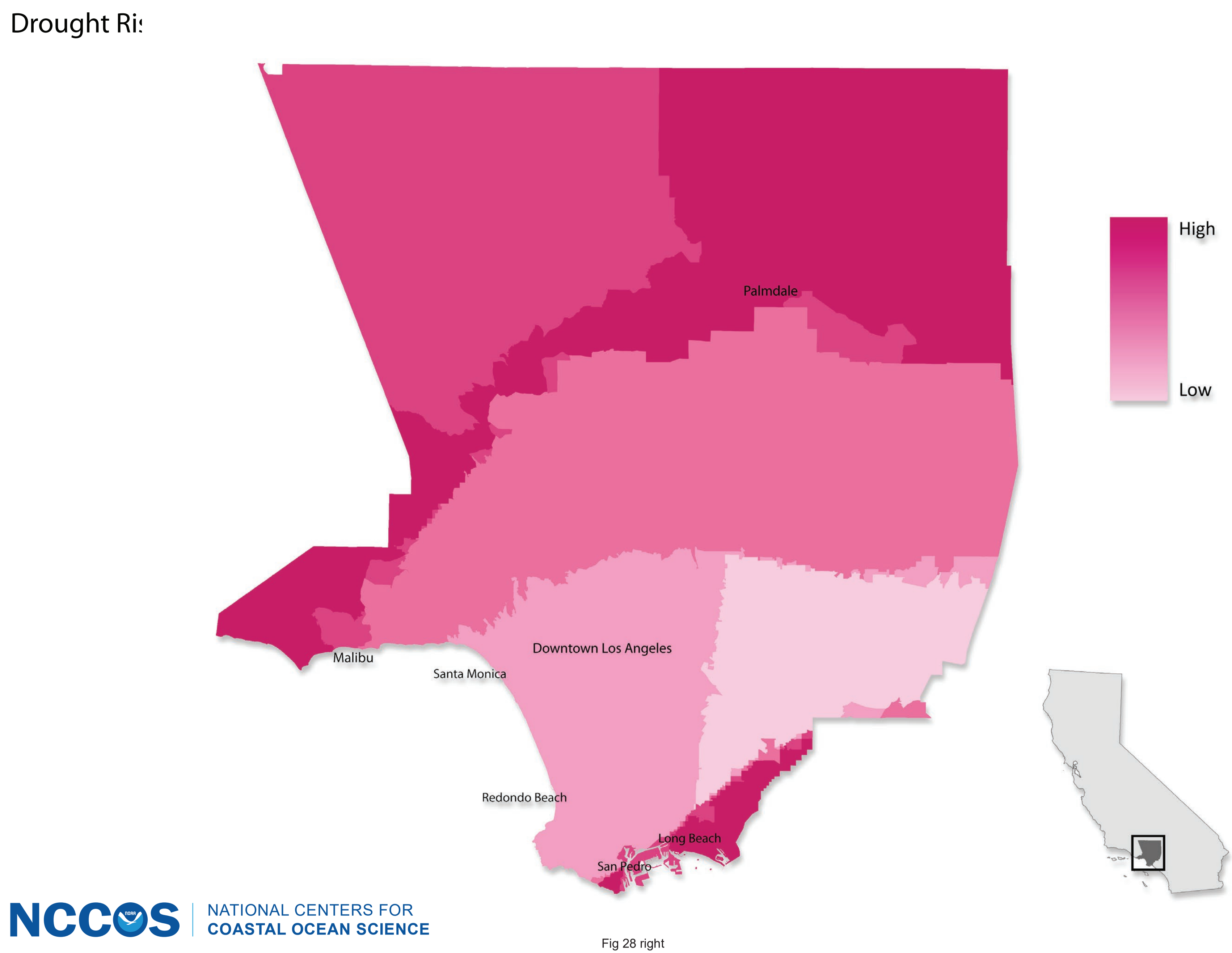

Fig 28 right

Figure D19. (Figure 4.8. in Chapter 4)

Wildfire Risk in Los Angeles County

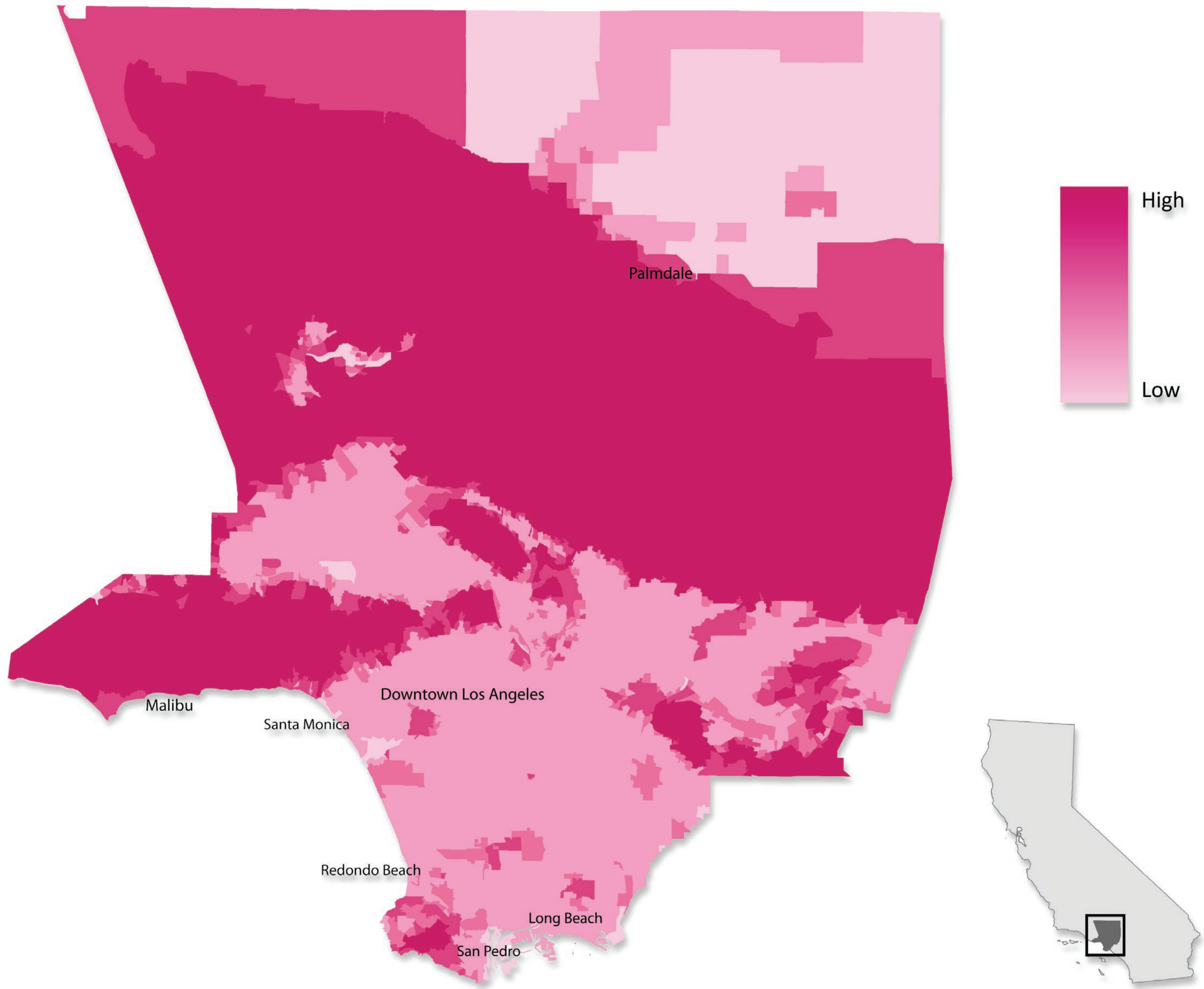

Fig 29

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Vulnerability and Risk Bivariate Maps

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Figure D20. Bivariate choropleth map legend. (Figure 4.9. in Chapter 4)

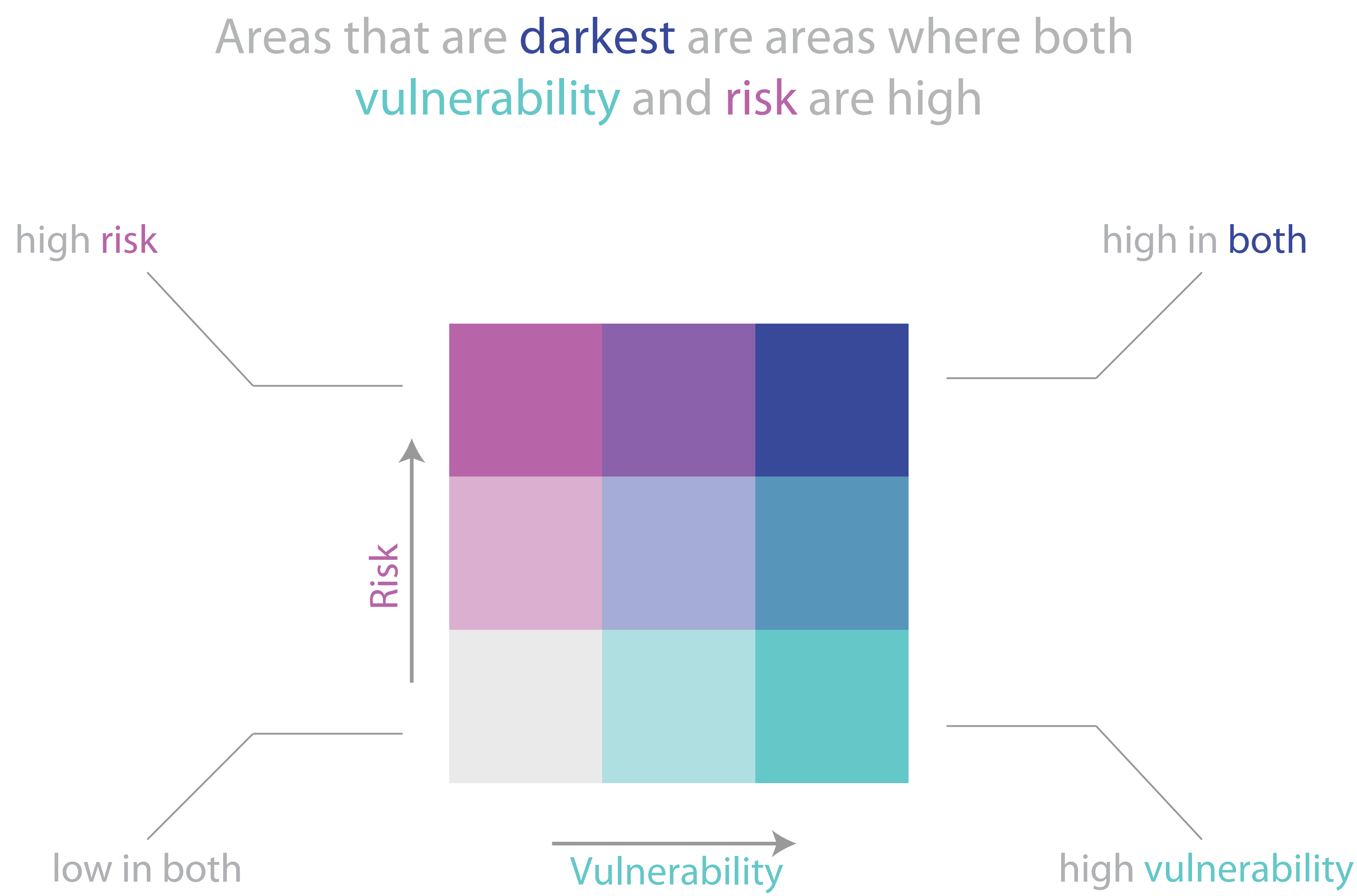

Figure D21. (Figure 4.10. (left) in Chapter 4)

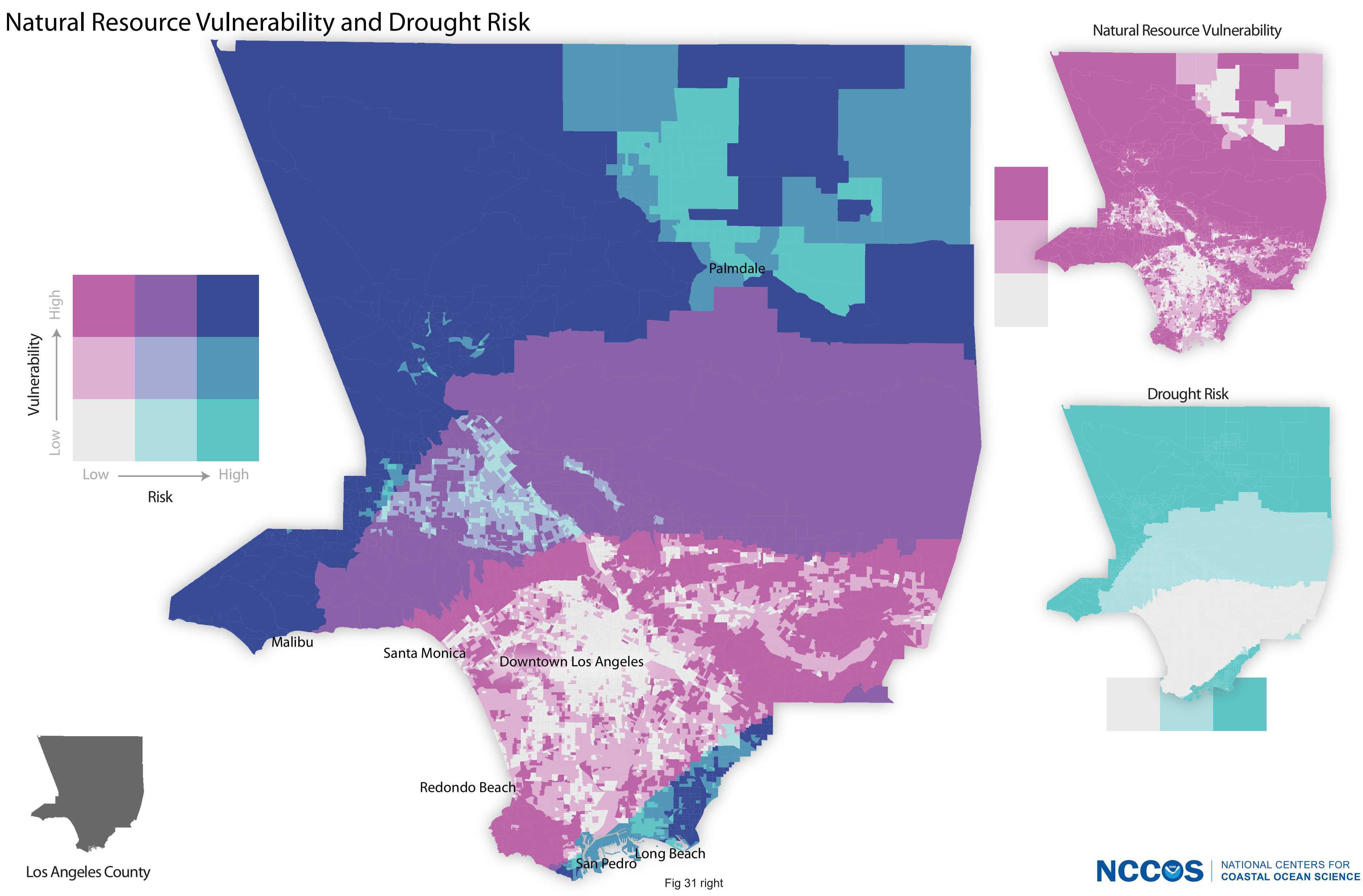

Figure D22. (Figure 4.10. (right) in Chapter 4)

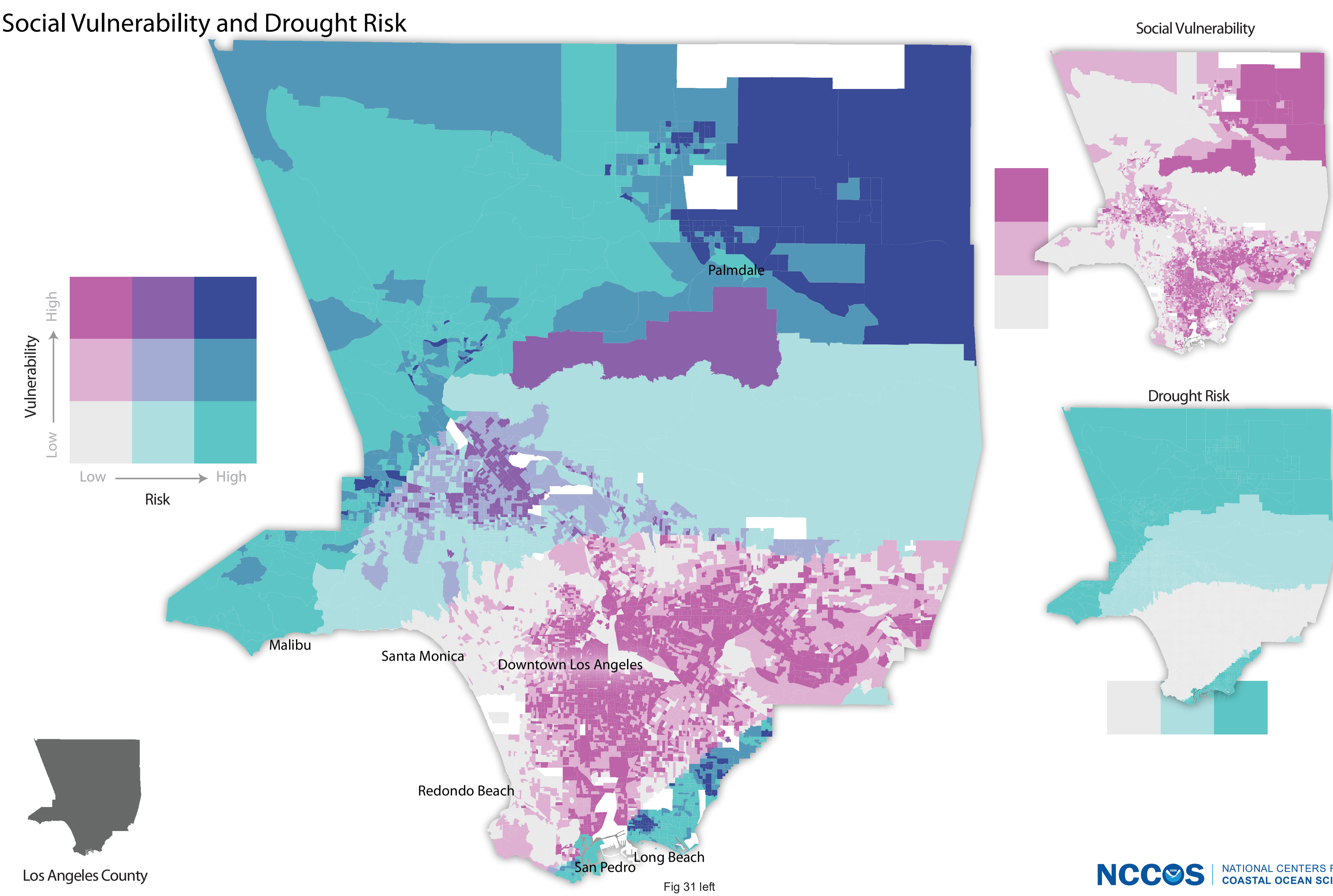

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Figure D23. (Figure 4.11. (left) in Chapter 4)

Natural Resource Vulnerability and Heat Risk

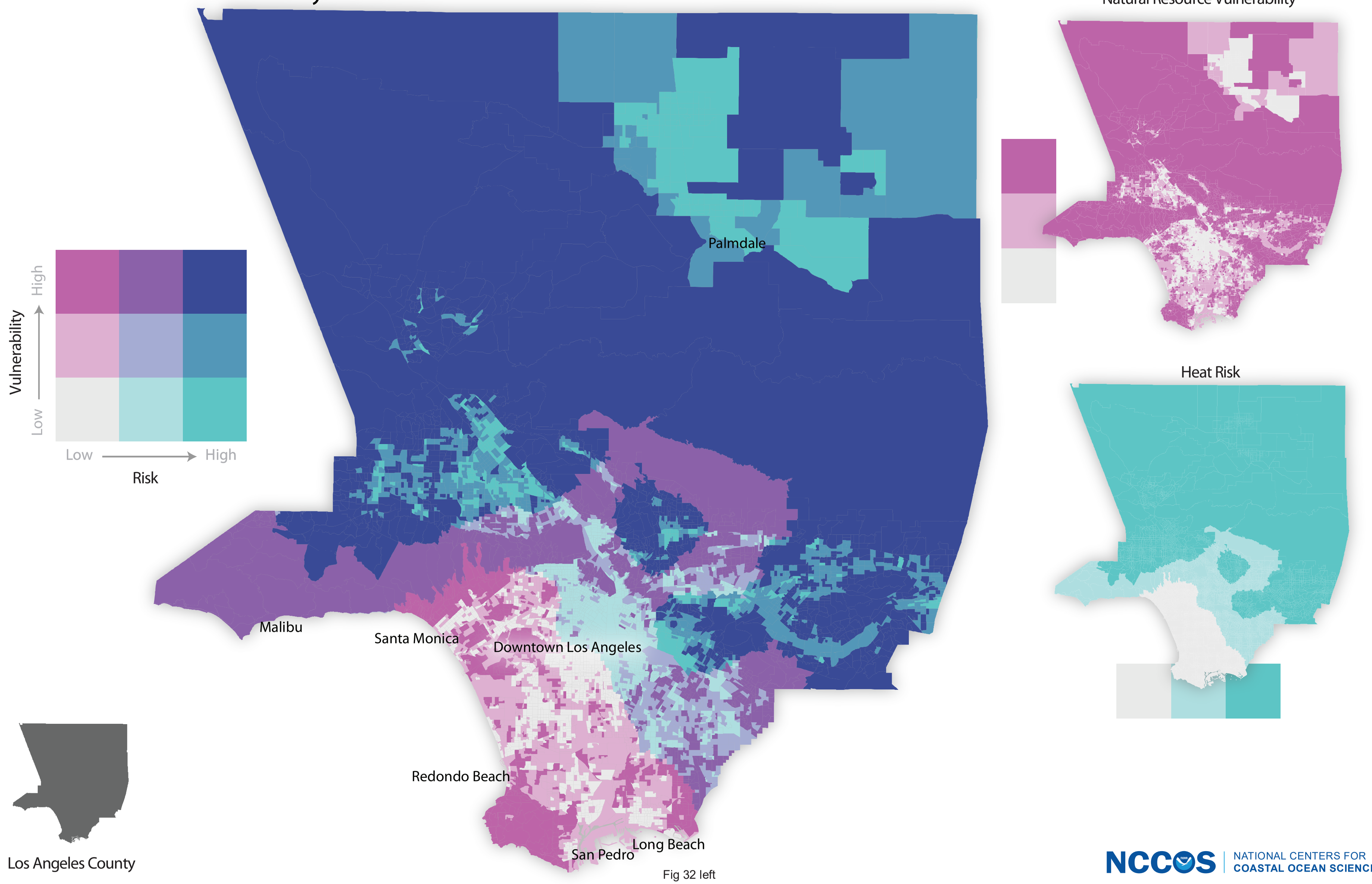
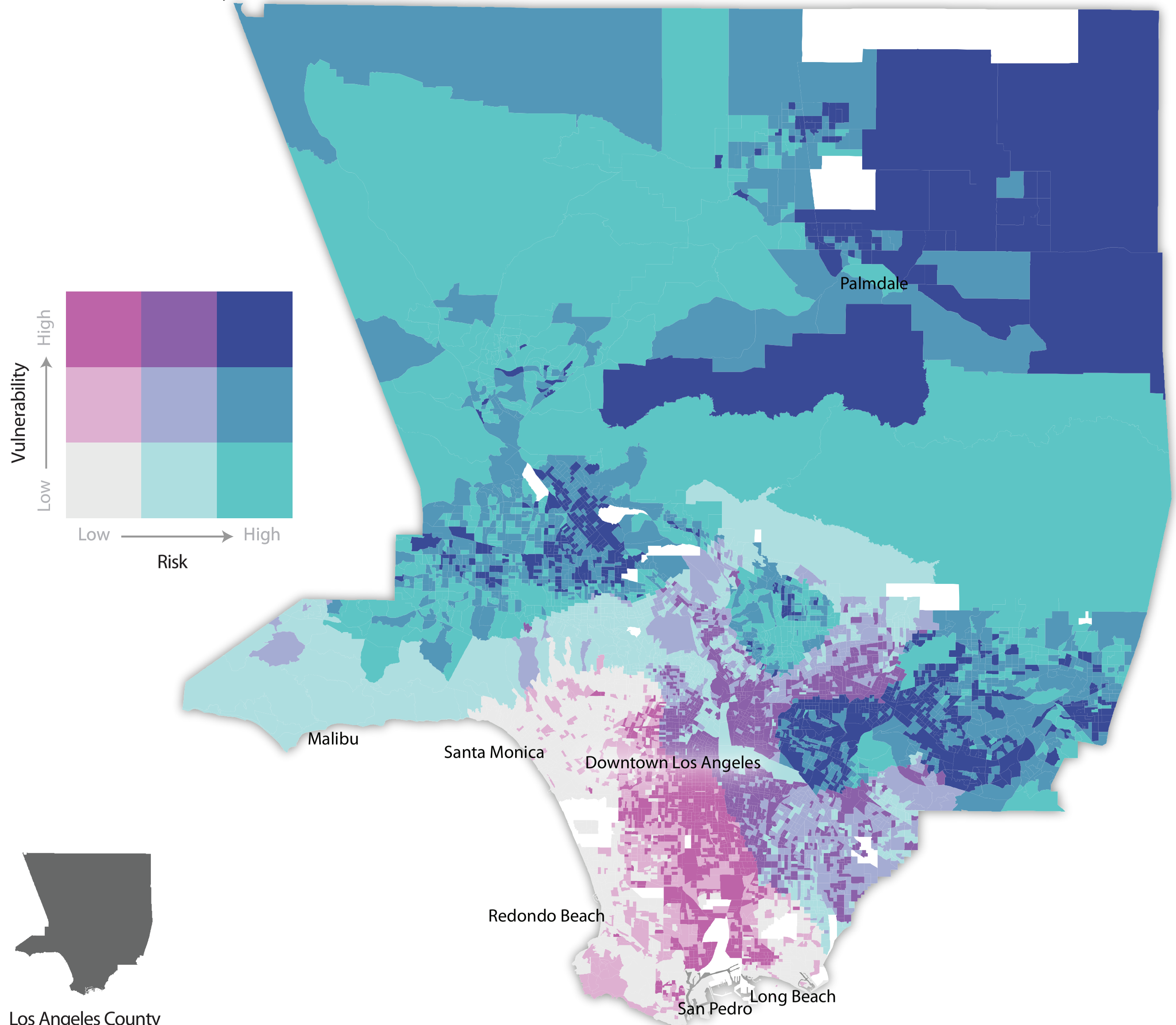
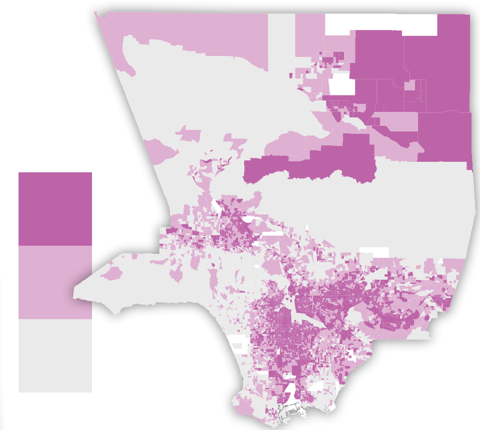


Figure D24. (Figure 4.11. (right) in Chapter 4)

Social Vulnerability and Heat Risk





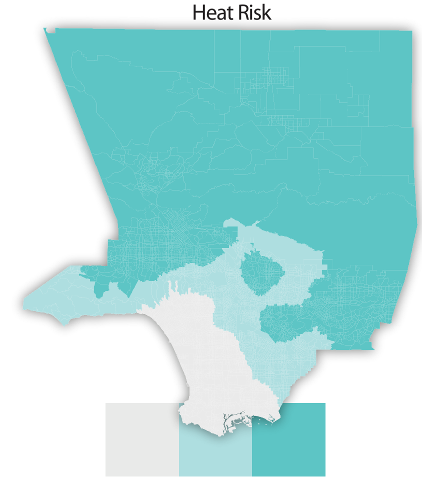


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Figure D25. (Figure 4.13. (left) in Chapter 4)

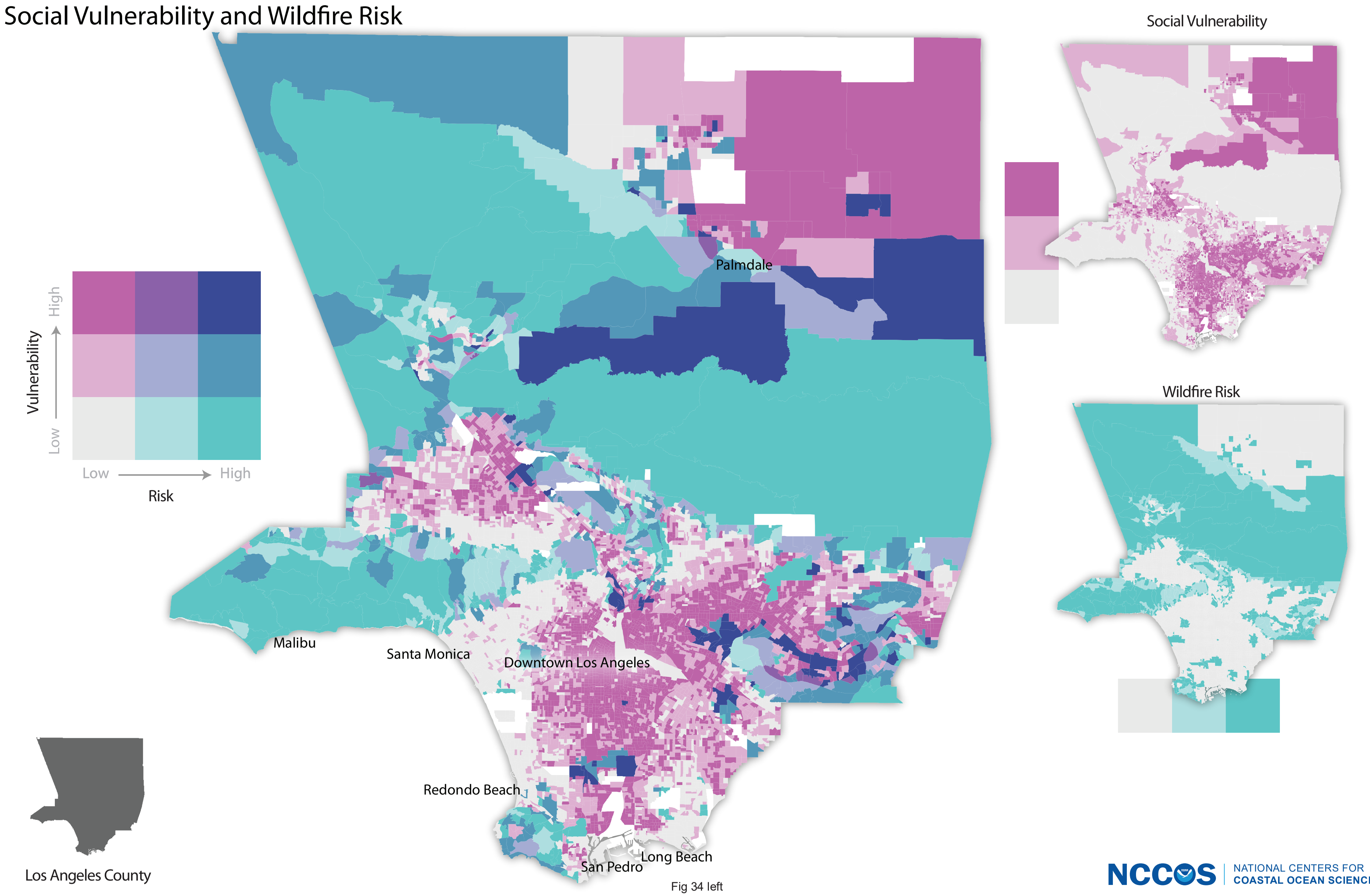

Figure D26. (Figure 4.13. (right) in Chapter 4)

Social Vulnerability and Wildfire Risk

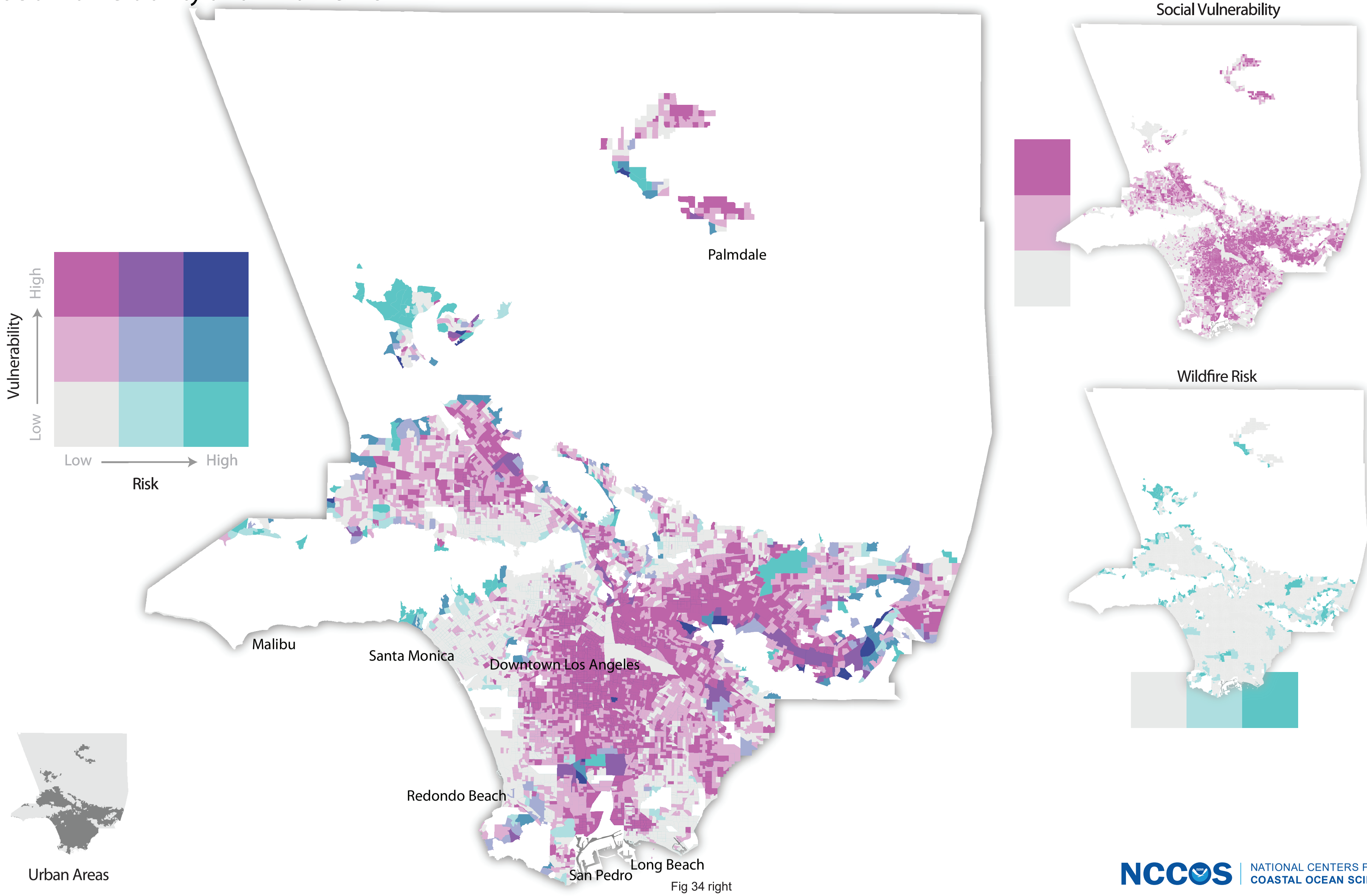

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Figure D27. (Figure 4.14. (left) in Chapter 4)

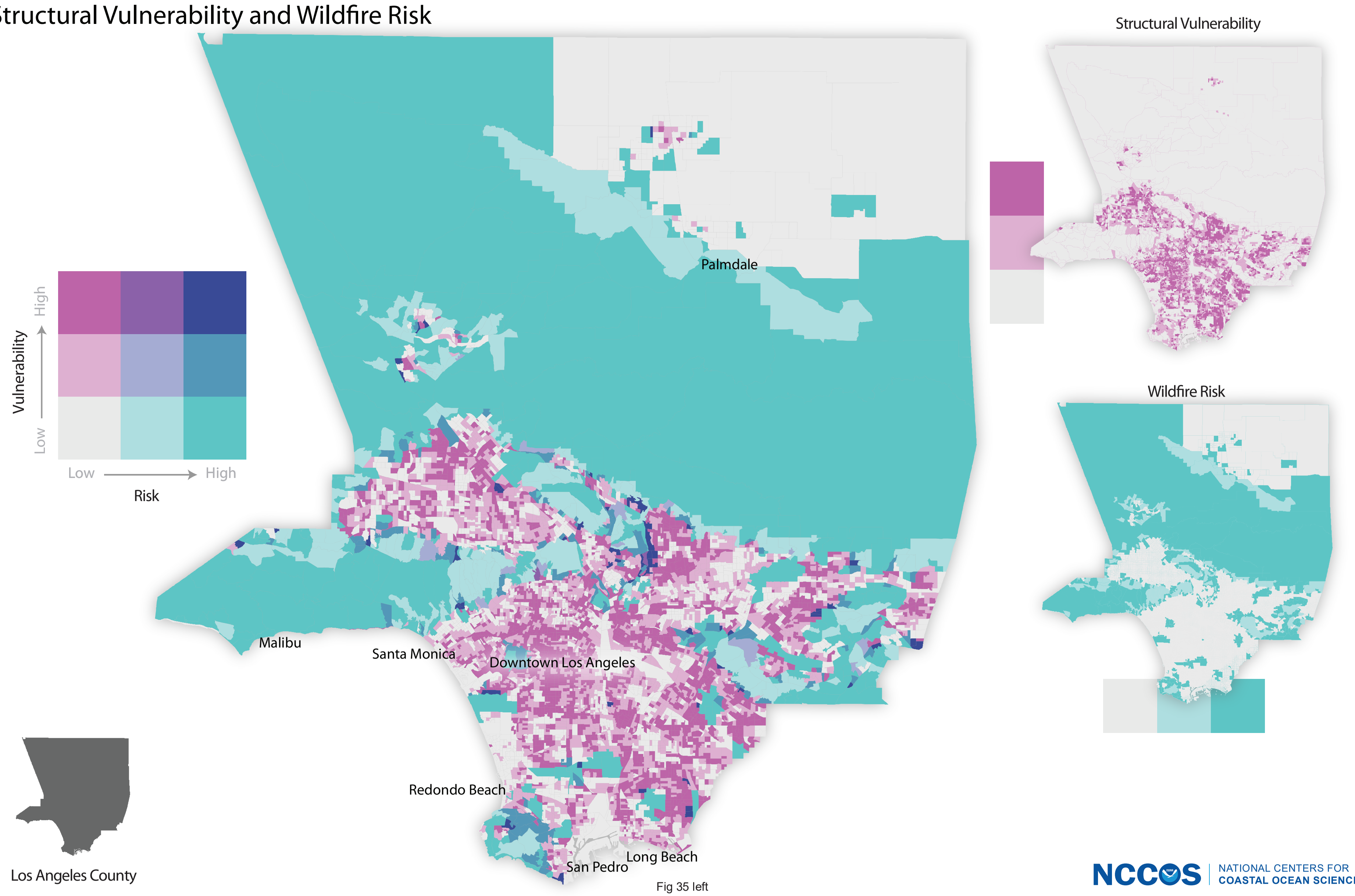

Figure D28. (Figure 4.14. (right) in Chapter 4)

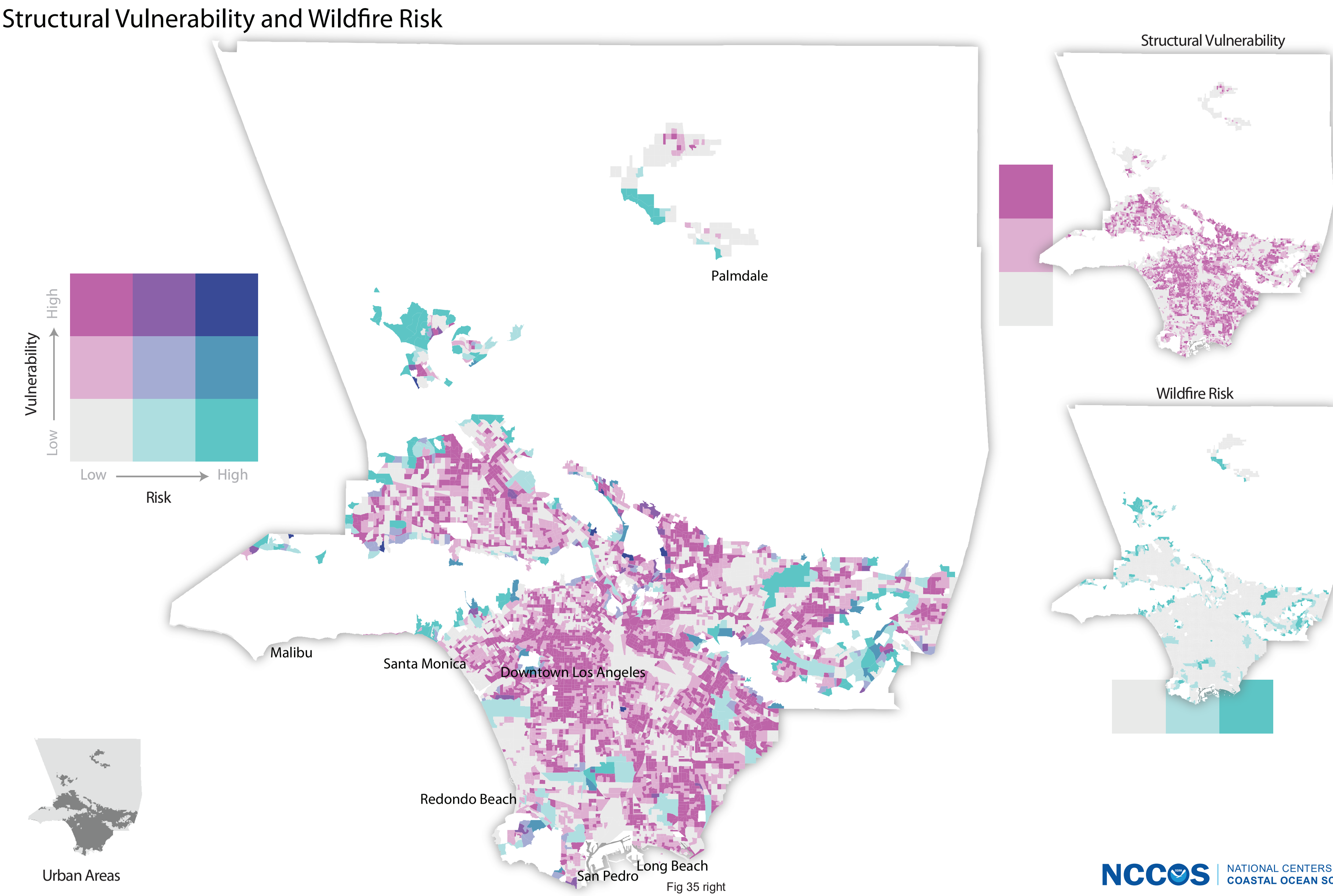

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Figure D29. (Figure 4.15. in Chapter 4)

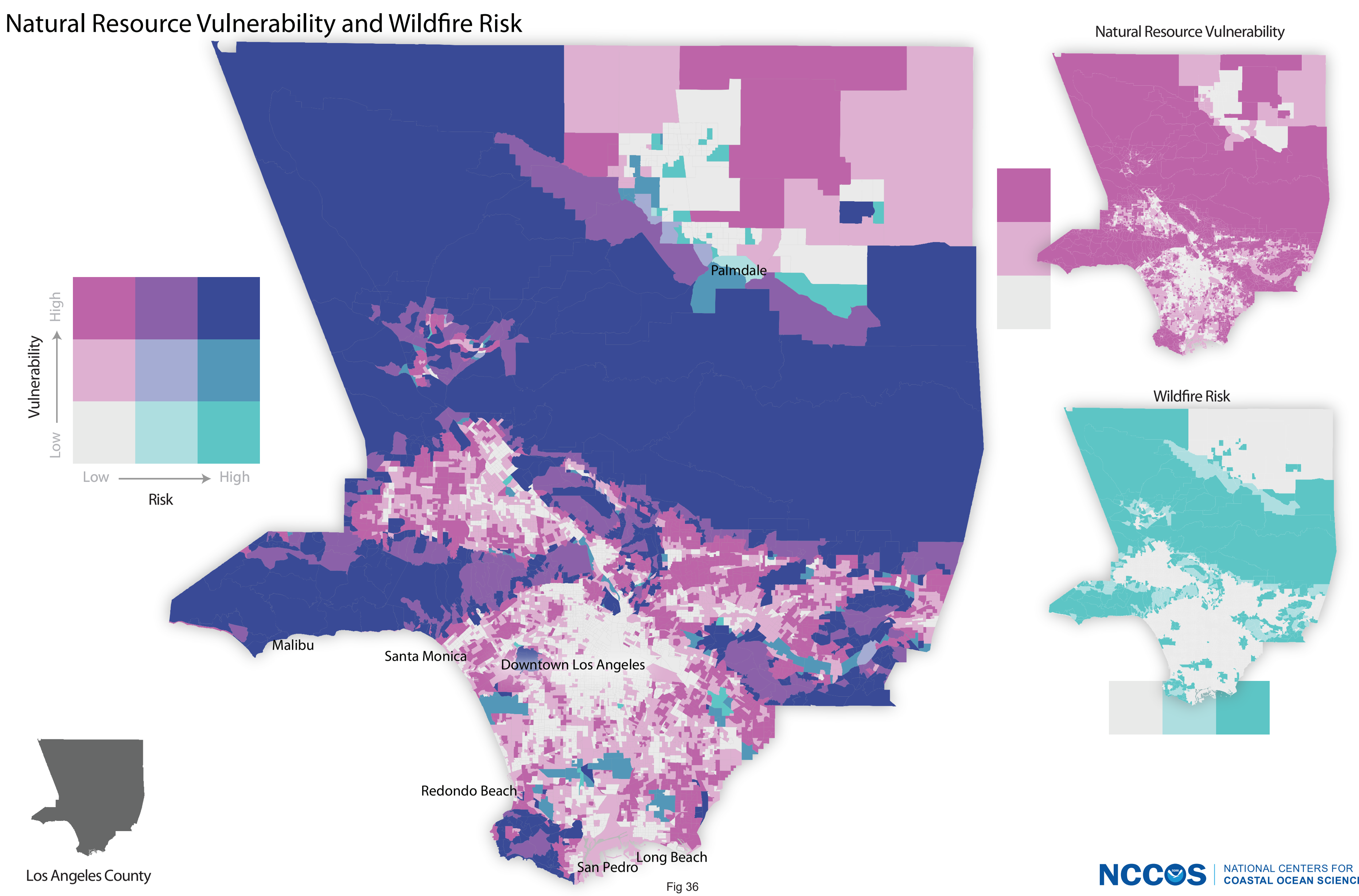

Figure D30. (Figure 4.16. (left) in Chapter 4)

Social Vulnerability and Erosion Risk

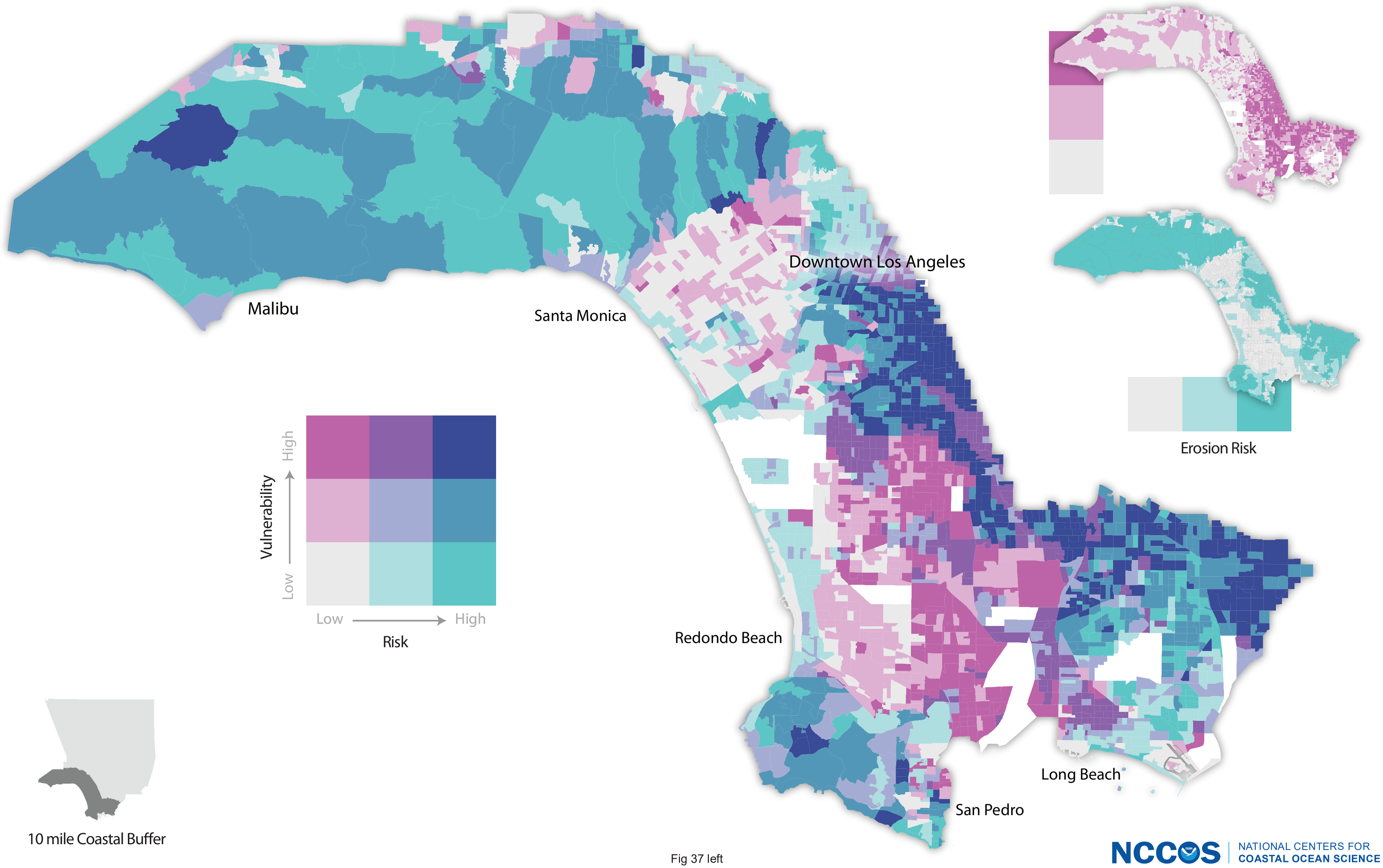

Figure D31. (Figure 4.16. (right) in Chapter 4)

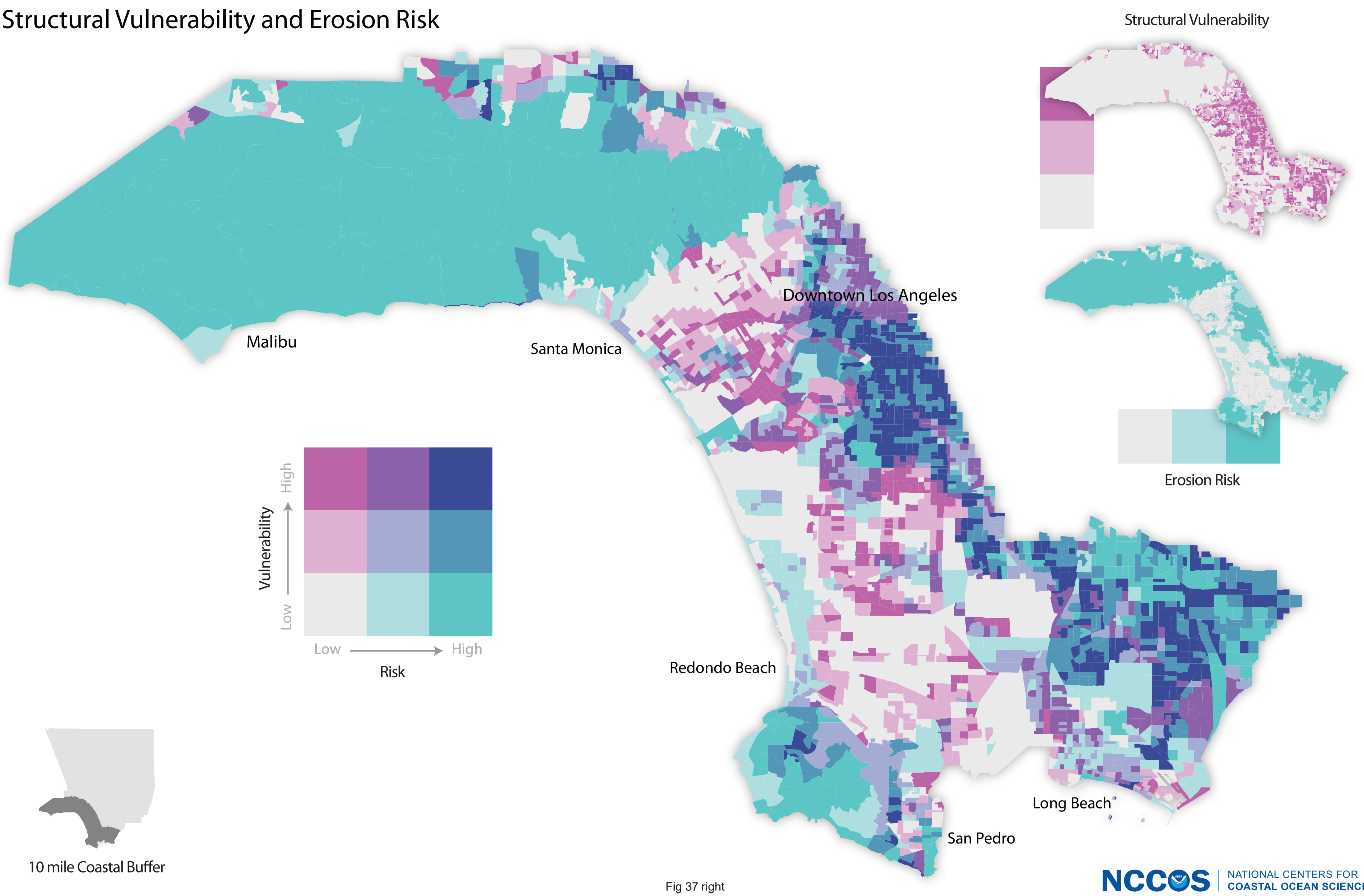

Figure D32. (Figure 4.17. (left) in Chapter 4)

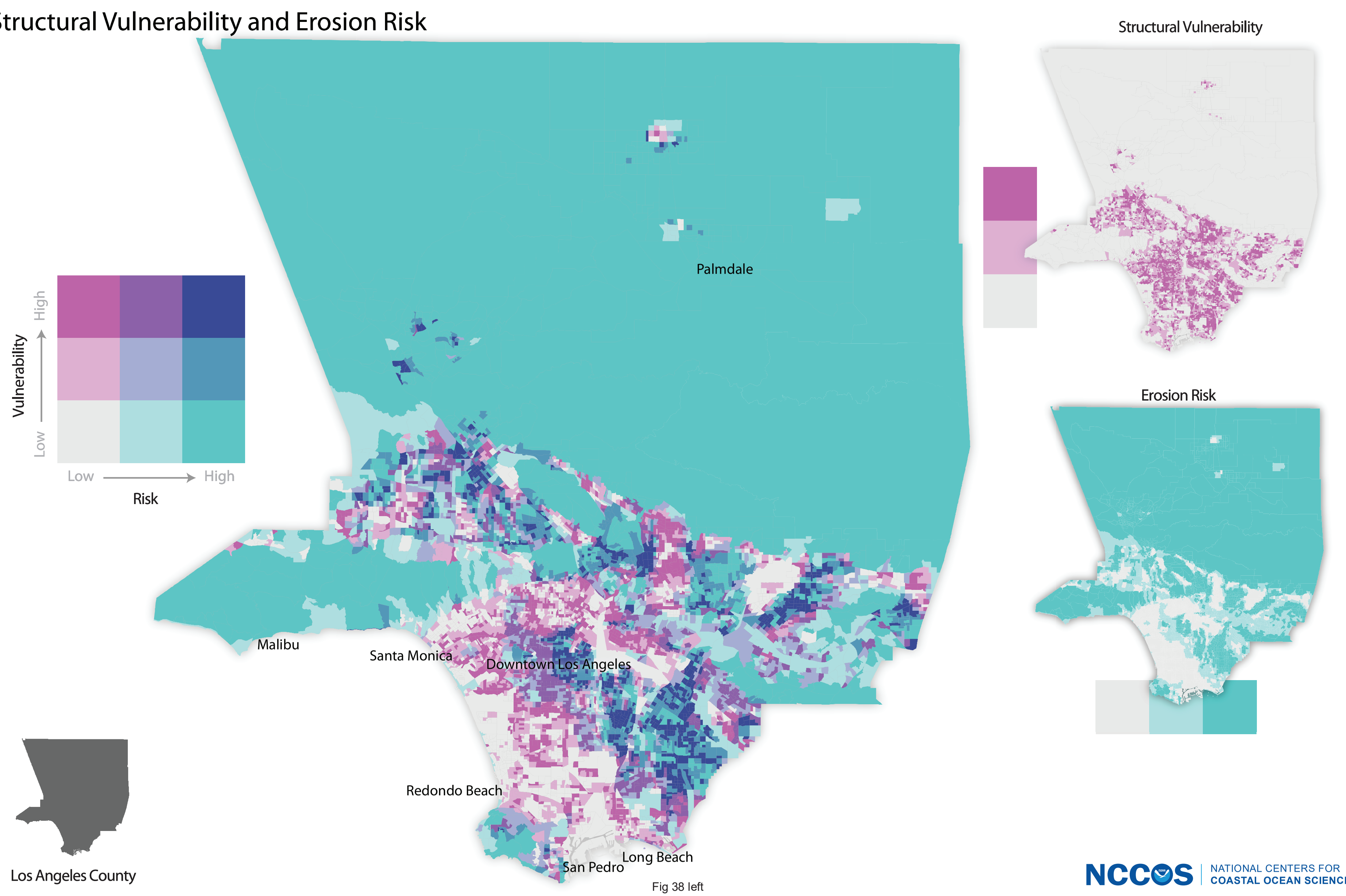

Figure D33. (Figure 4.17. (right) in Chapter 4)

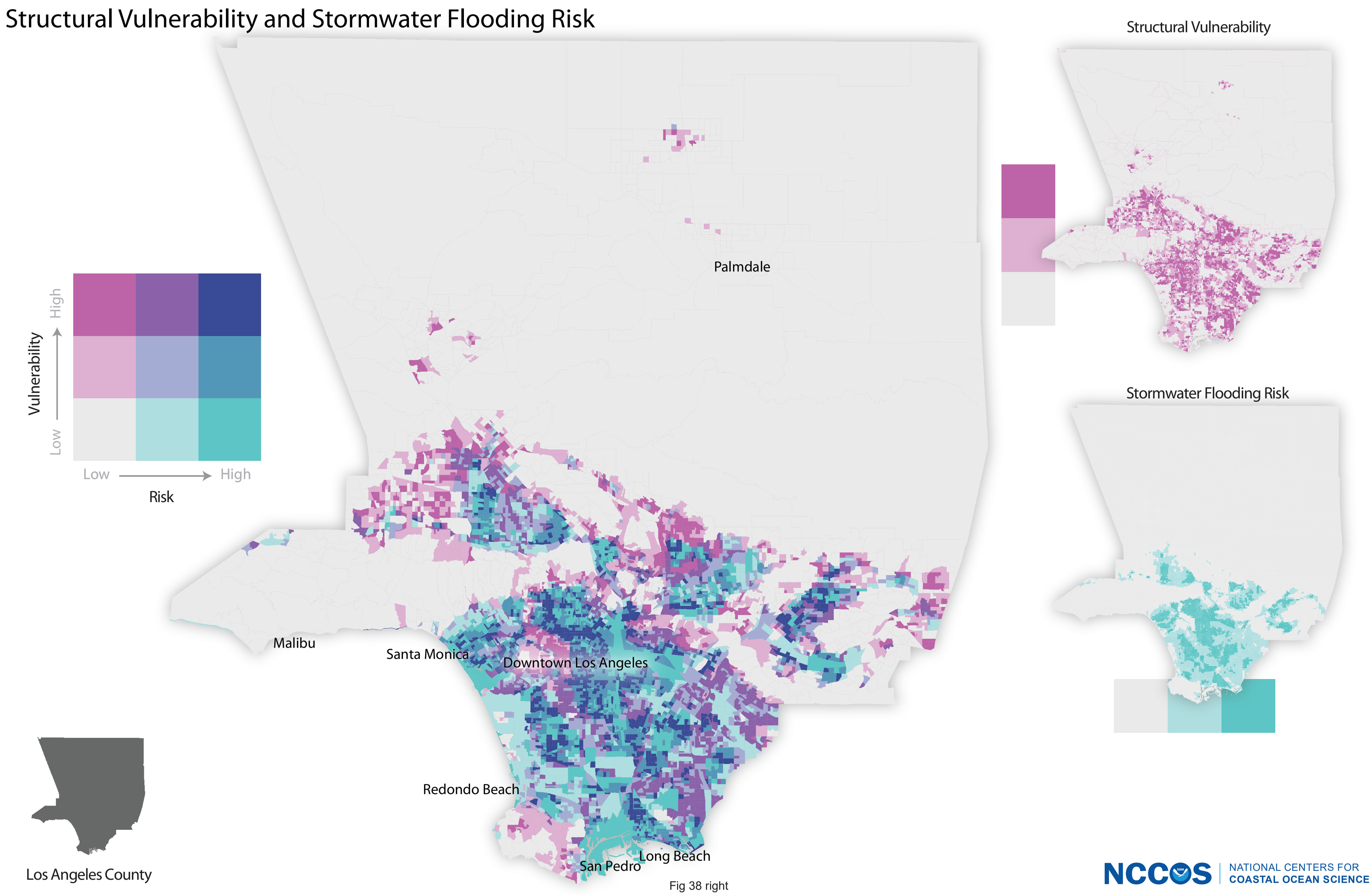

Figure D34. (Figure 4.18. (left) in Chapter 4)

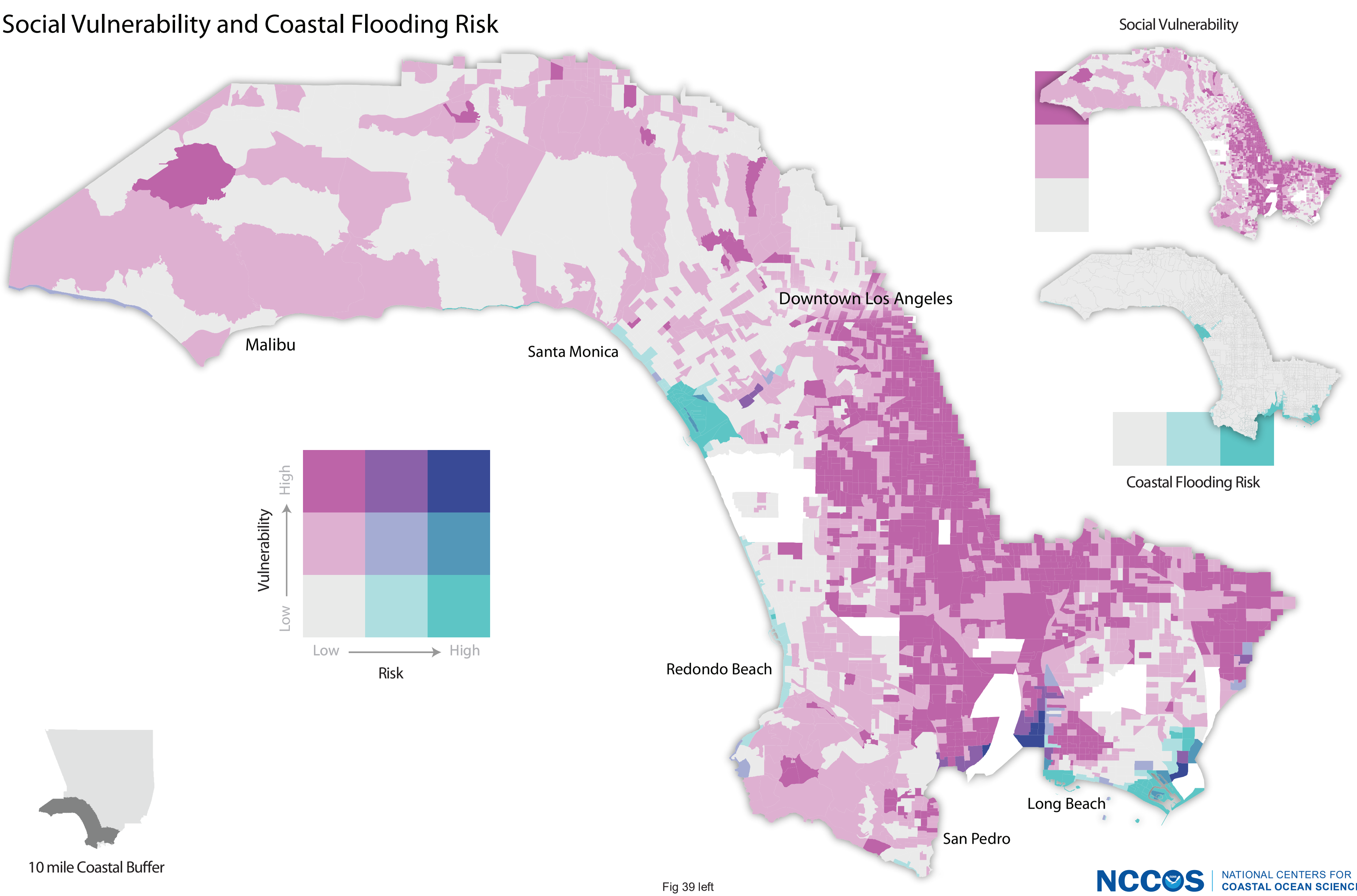

Figure D35. (Figure 4.18. (right) in Chapter 4)

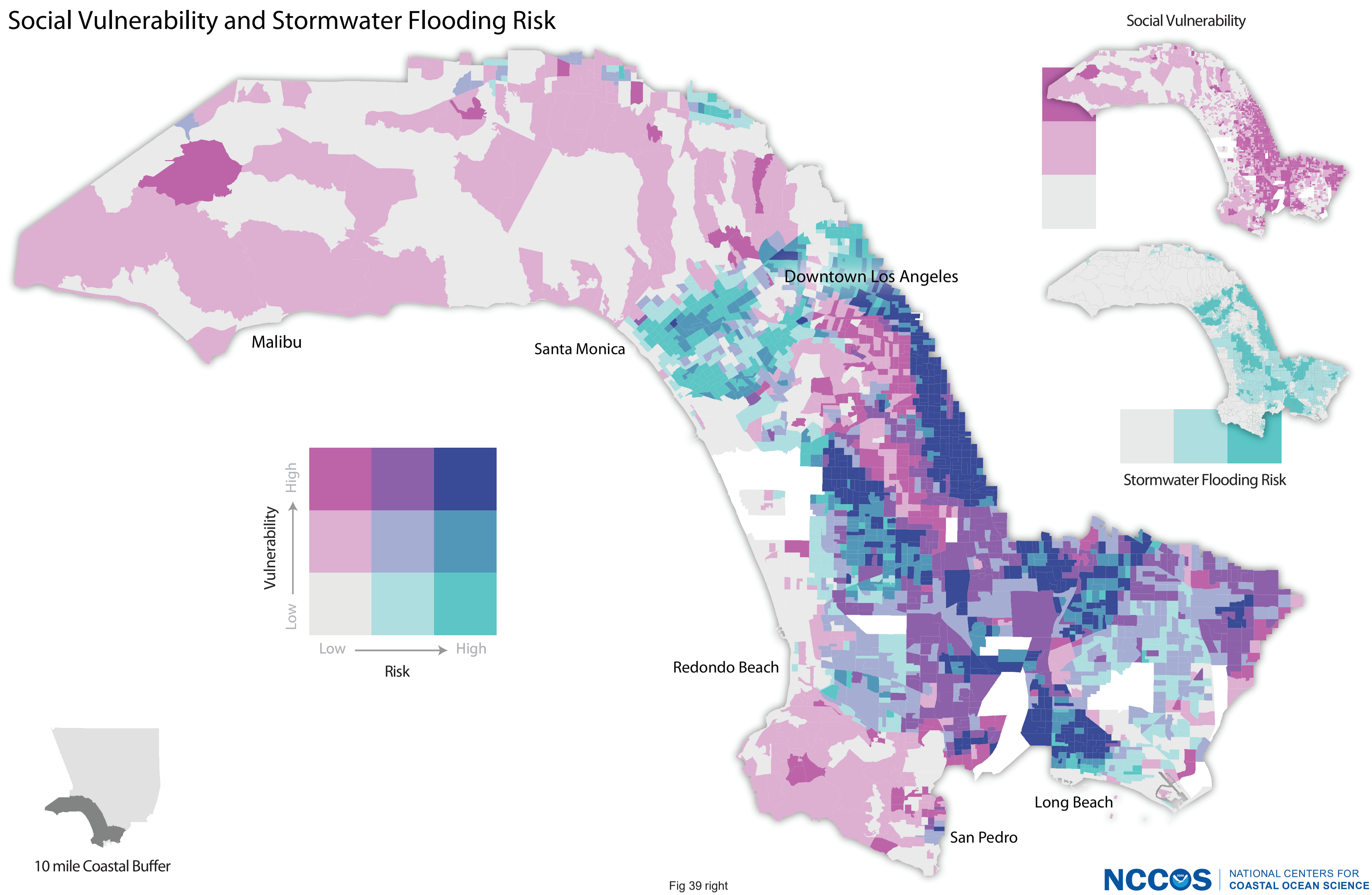

Figure D36. (Figure 4.19. in Chapter 4)

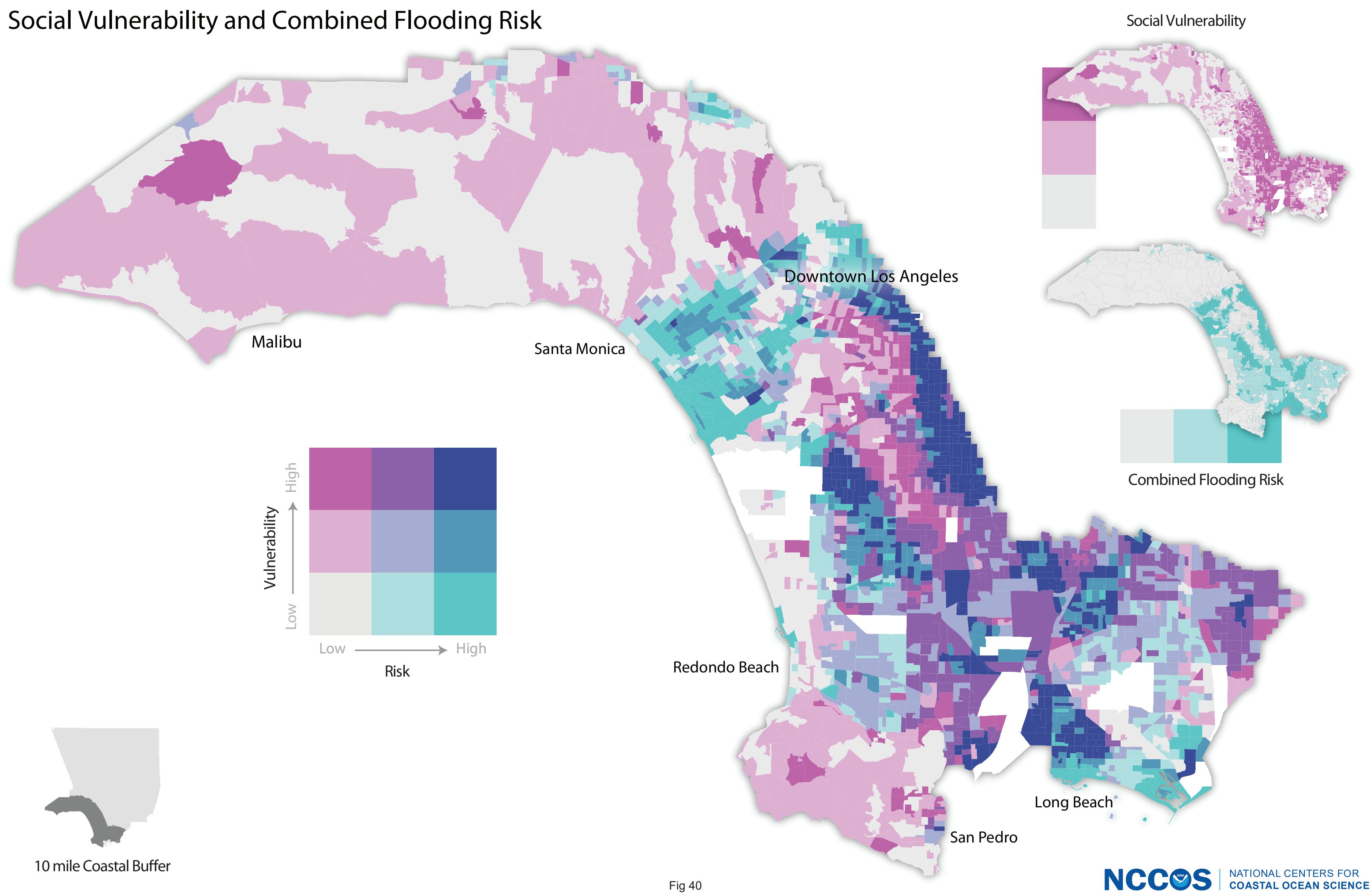

Figure D37. (Figure 4.21. in Chapter 4)

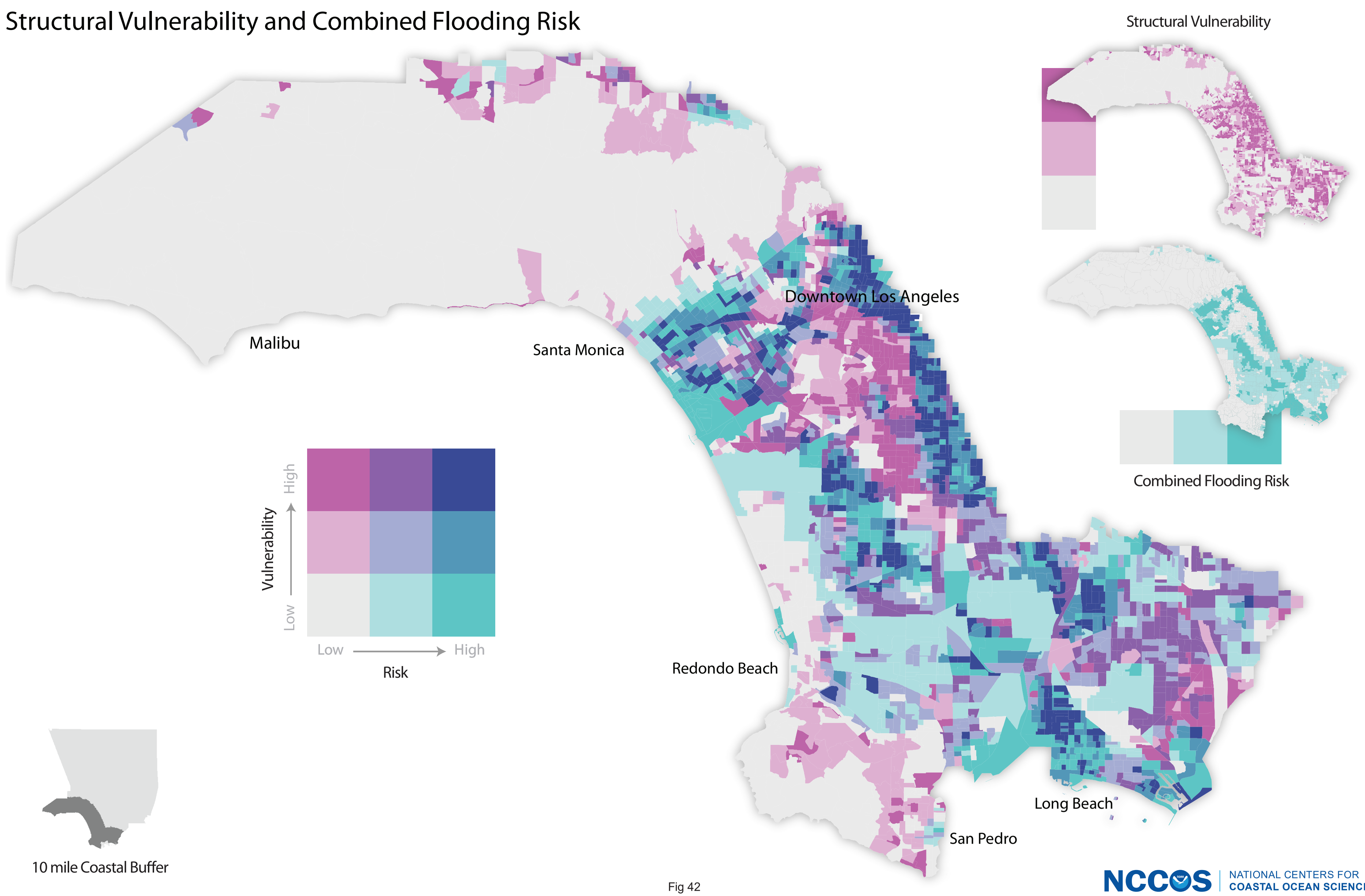

Figure D38. (Figure 4.22. in Chapter 4)

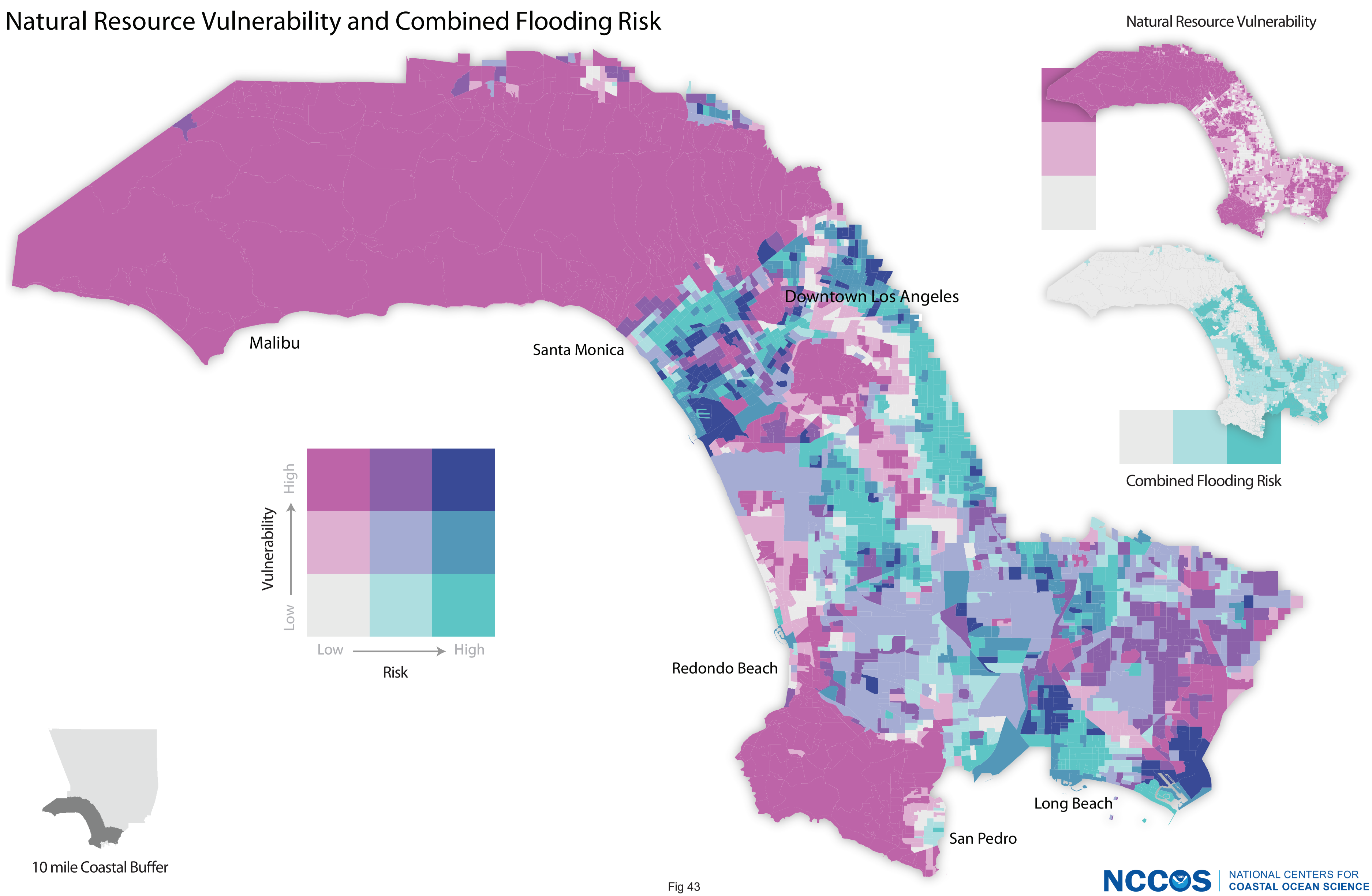

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Figure D39. (Figure 5.1. in Chapter 5)

NFIP Claims Paid Out

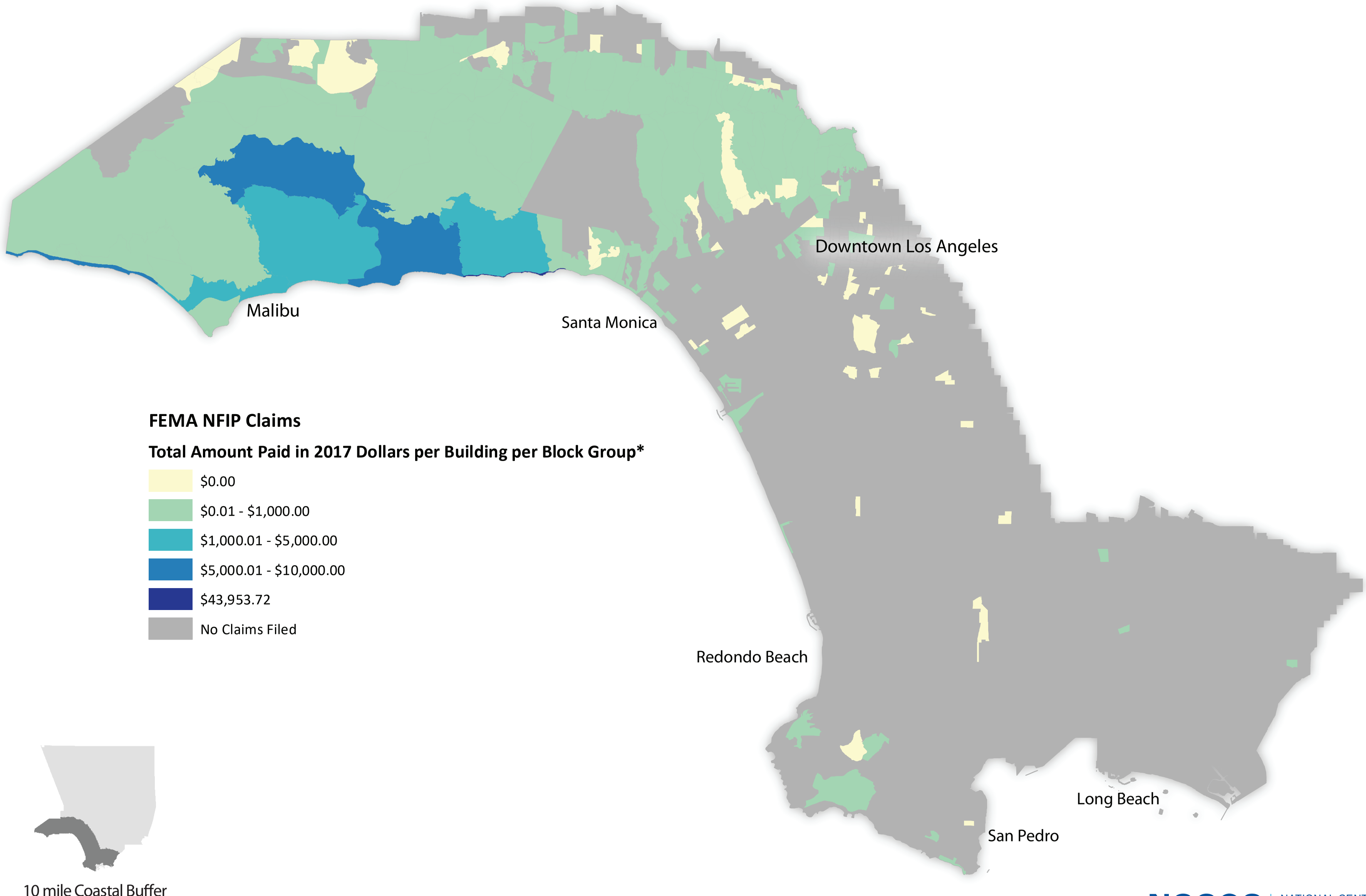

Fig 44

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Figure D40. (Figure 5.2. in Chapter 5)

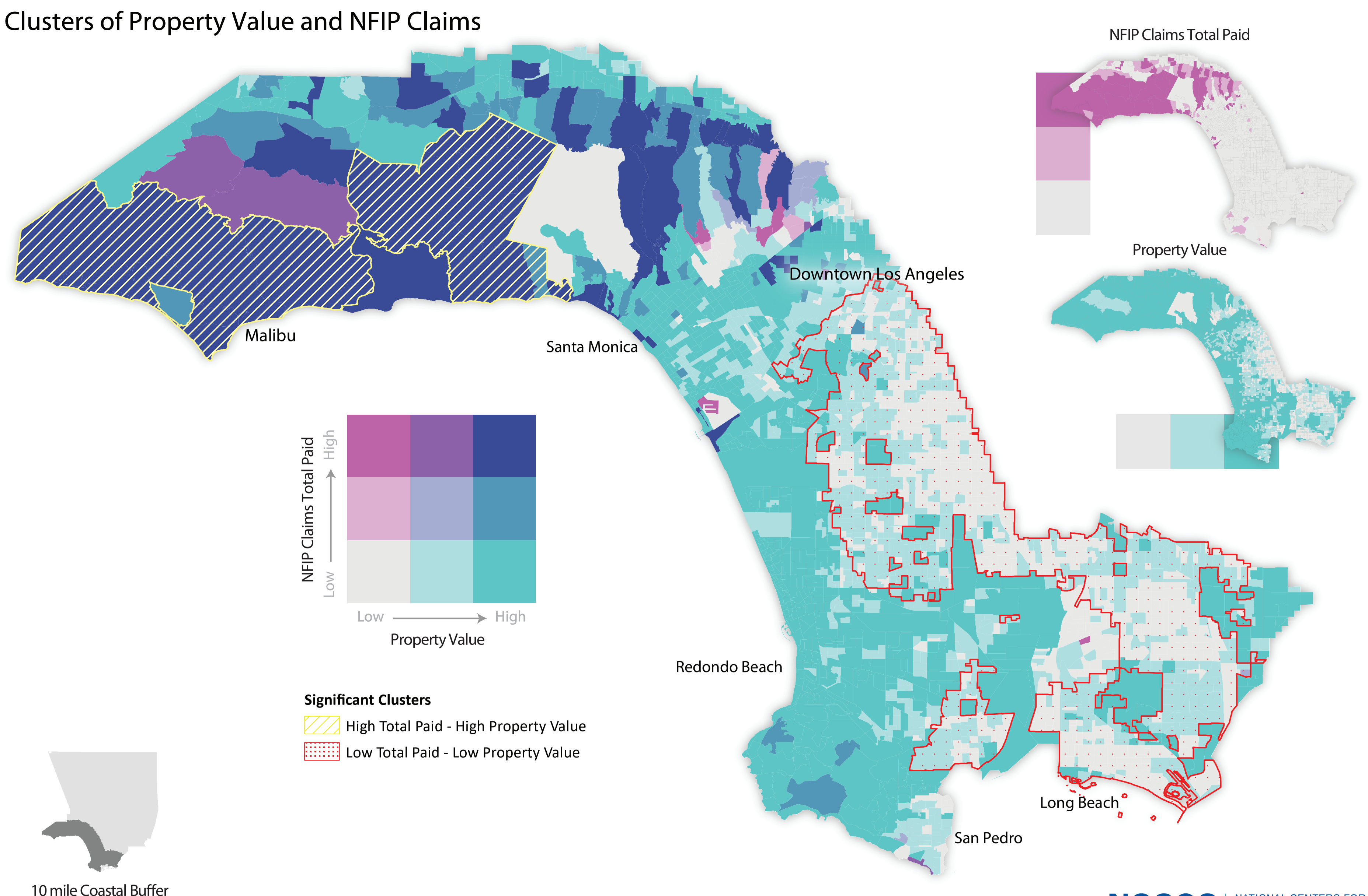

Fig 45

Figure D41. (Figure 5.3. in Chapter 5)

Clusters of Erosion Risk and NFIP Claims

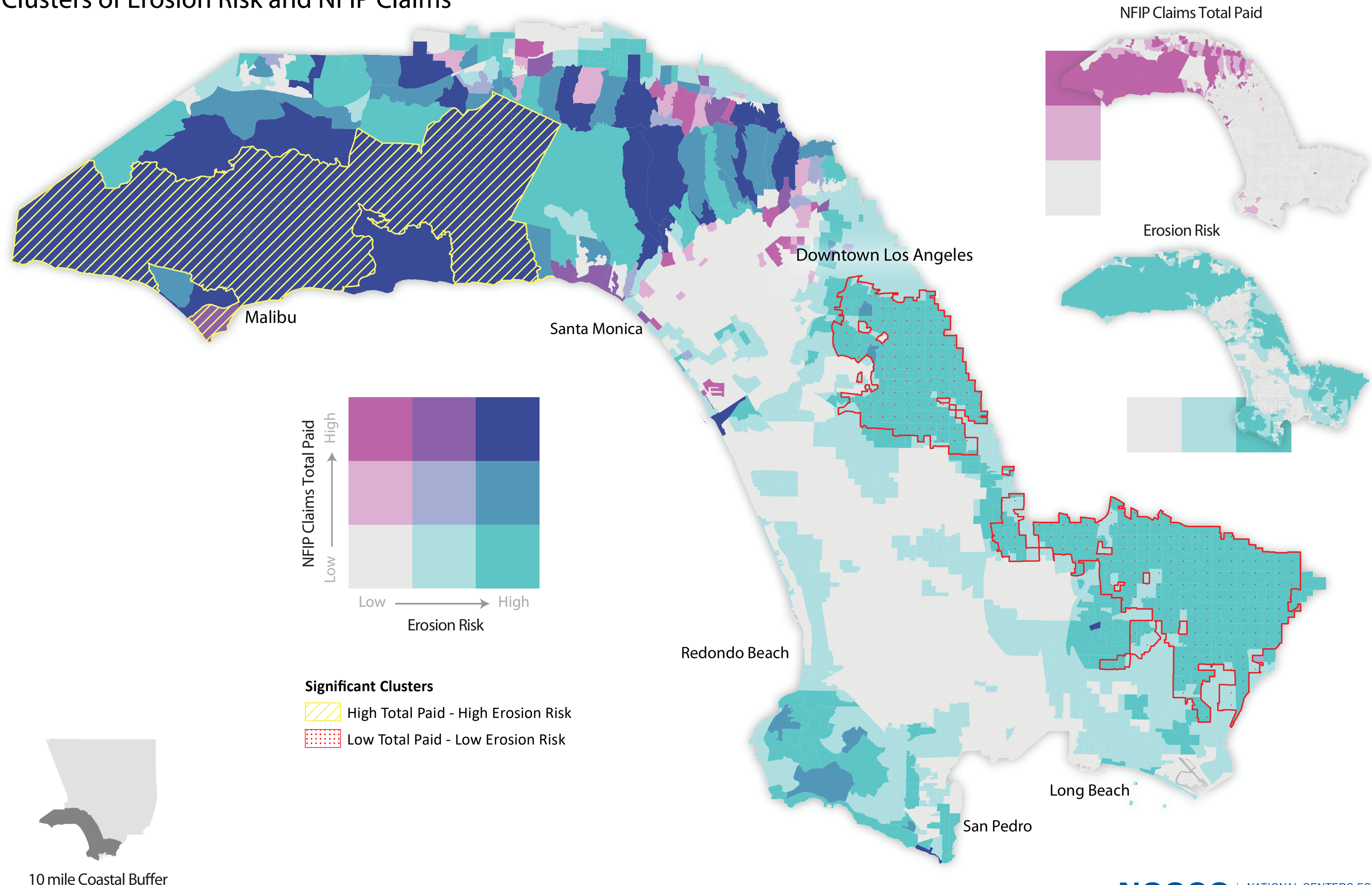

Fig 46

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Figure D42. (Figure 5.4. in Chapter 5)

Clusters of Combined Flooding Risk and NFIP Claims

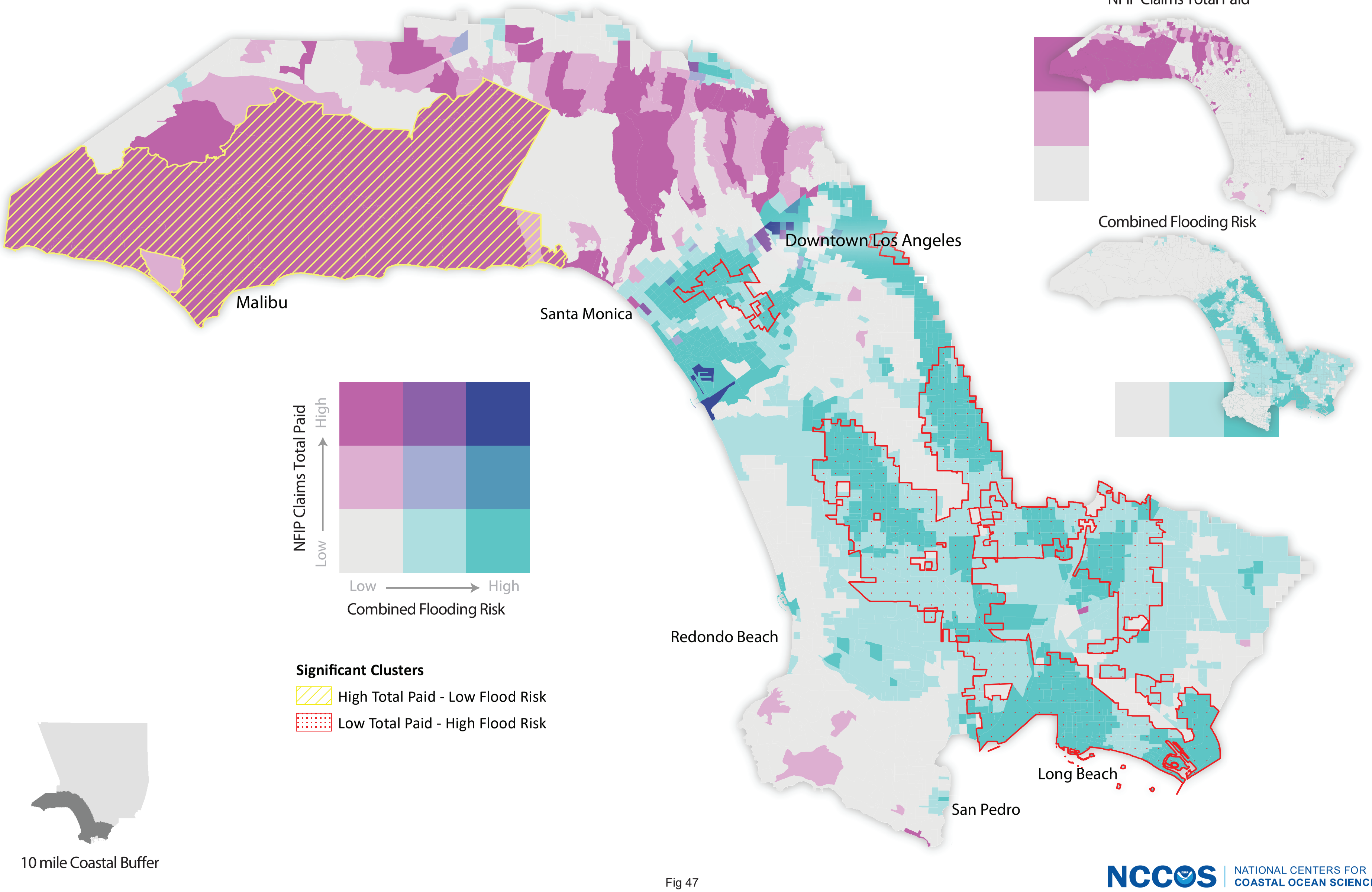

Fig 47

Figure D43. (Figure 5.5. in Chapter 5)

Clusters of Social Vulnerability and NFIP Claims

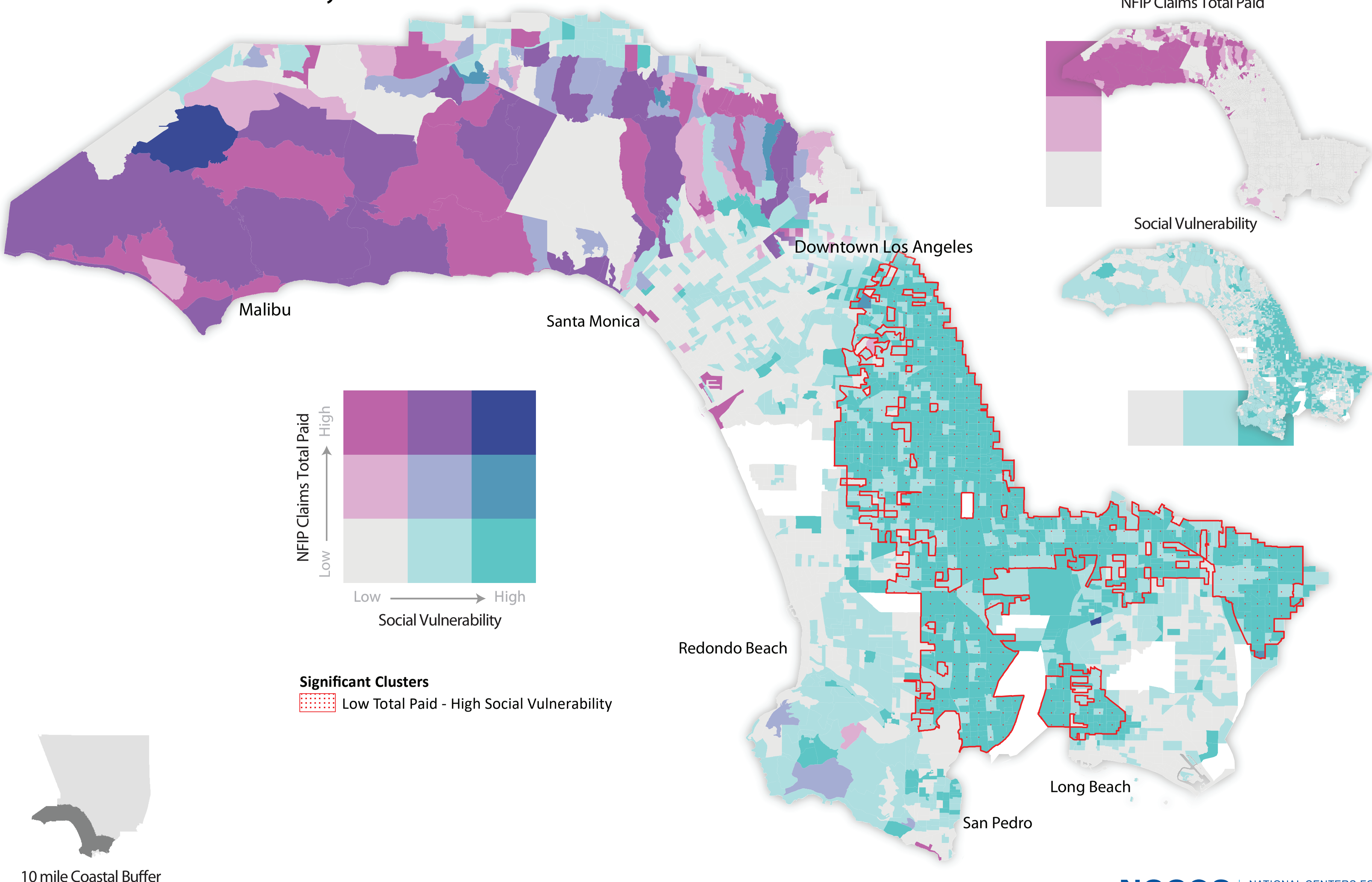

Fig 48

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Figure D44. (Figure 5.6. in Chapter 5)

Areas of Low Greenness and High Social Vulnerability with Combined FLooding Risk

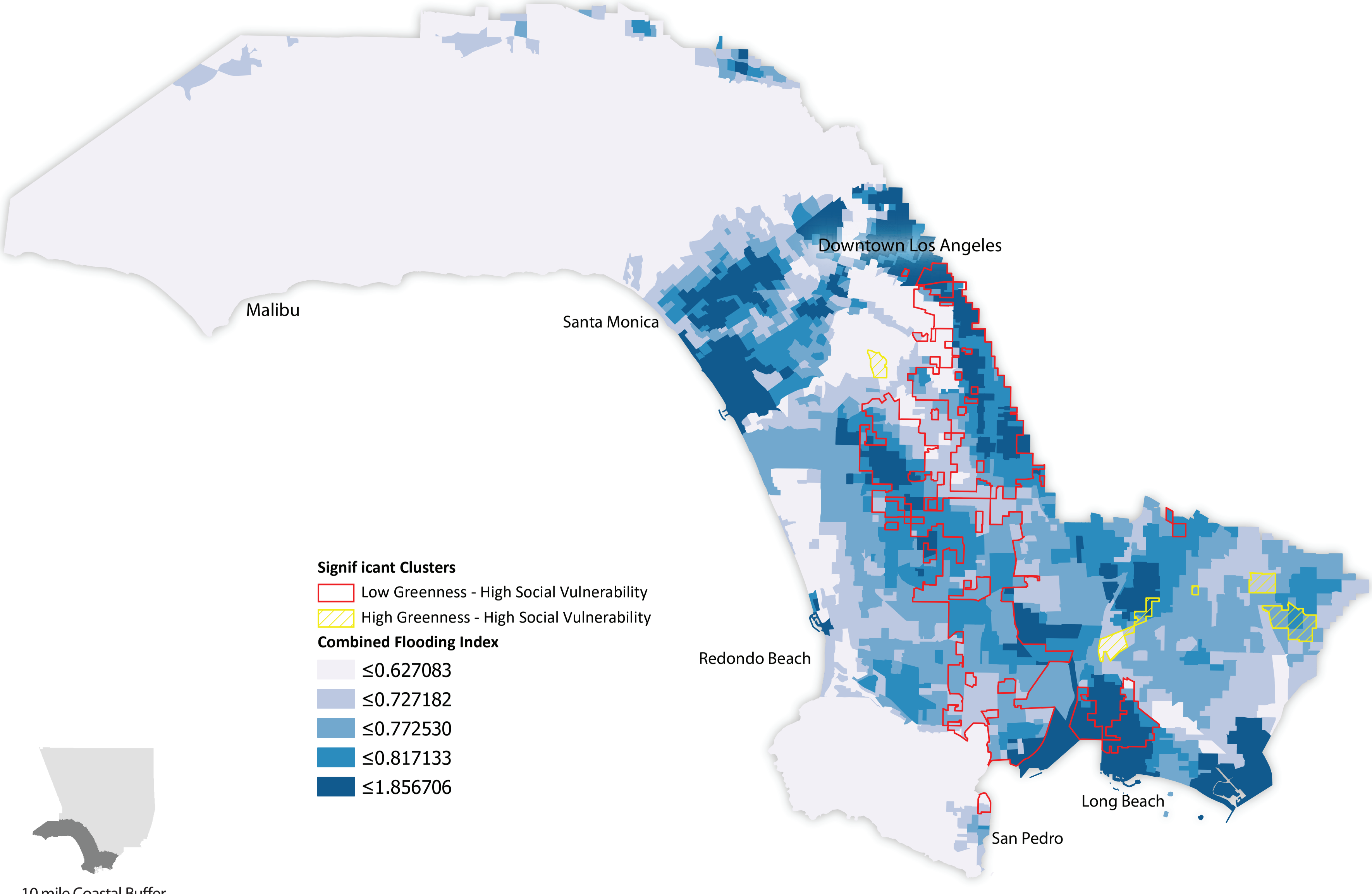

Fig 49

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Figure D45. (Figure 5.7. in Chapter 5)

Cultural Resources and Combined Flooding Risk

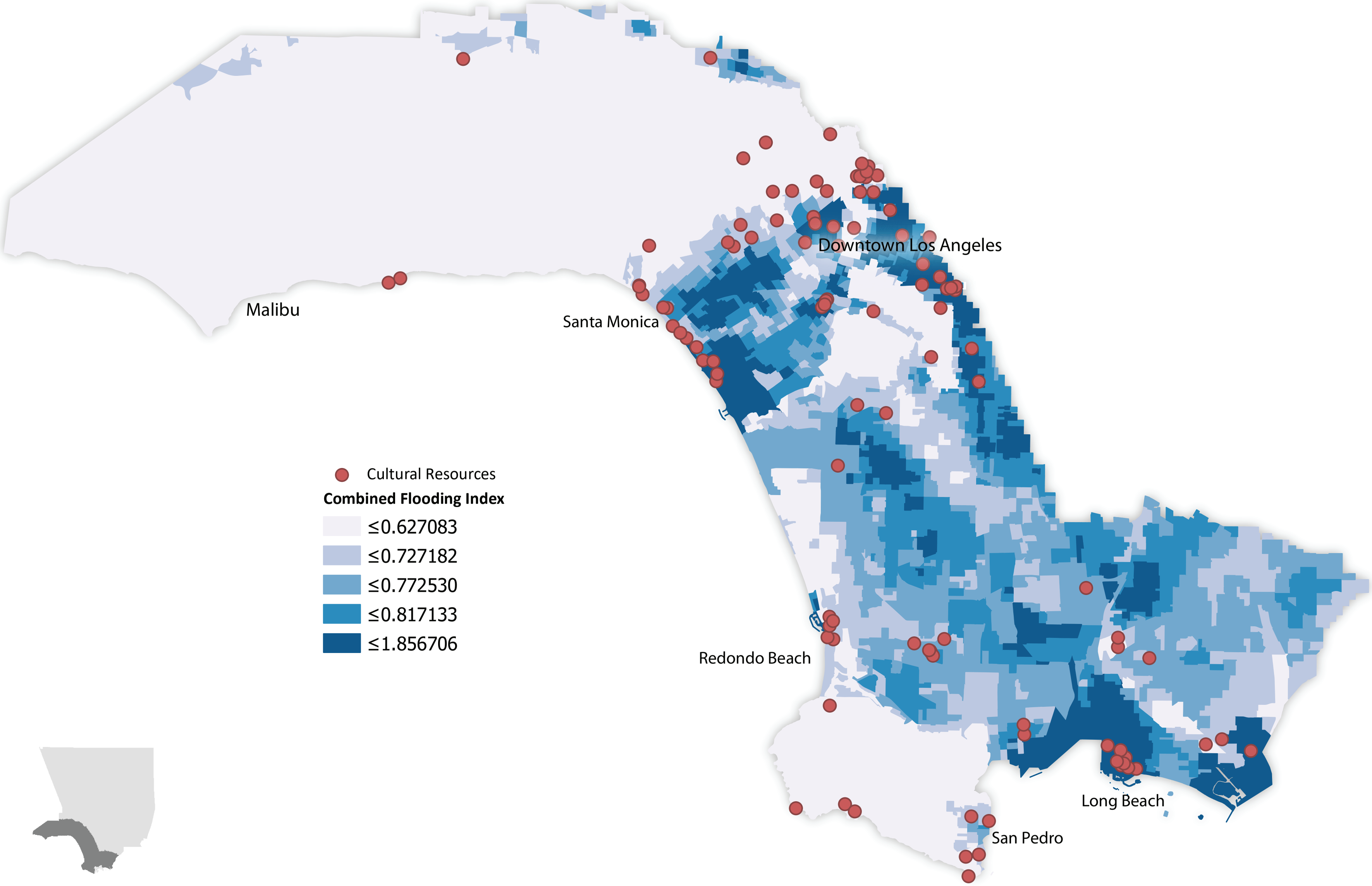

Fig 50

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Figure D46. (Figure 5.8. in Chapter 5)

Disaster Routes and Erosion Risk

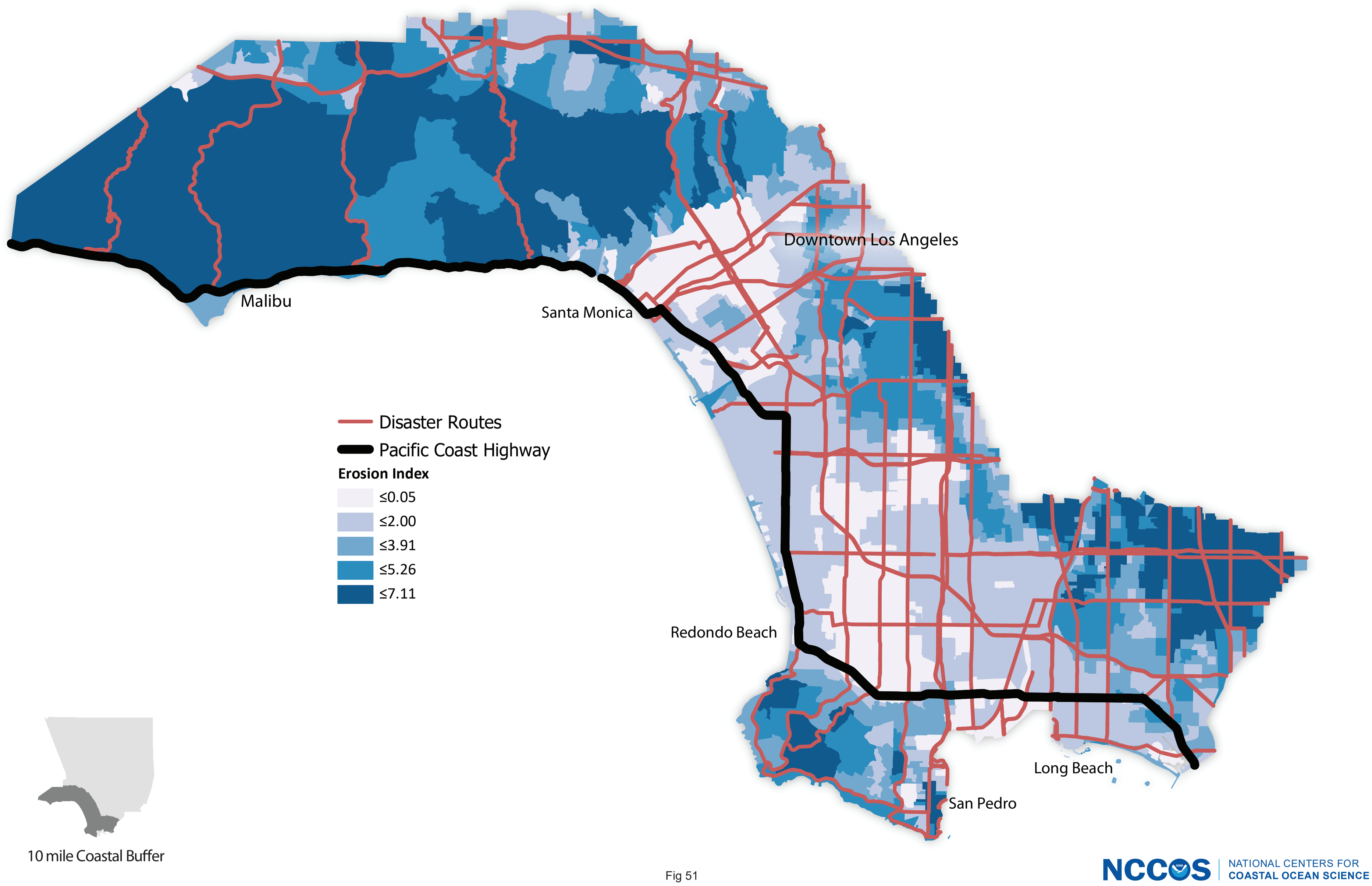


Figure D47. (Figure 5.9. in Chapter 5)

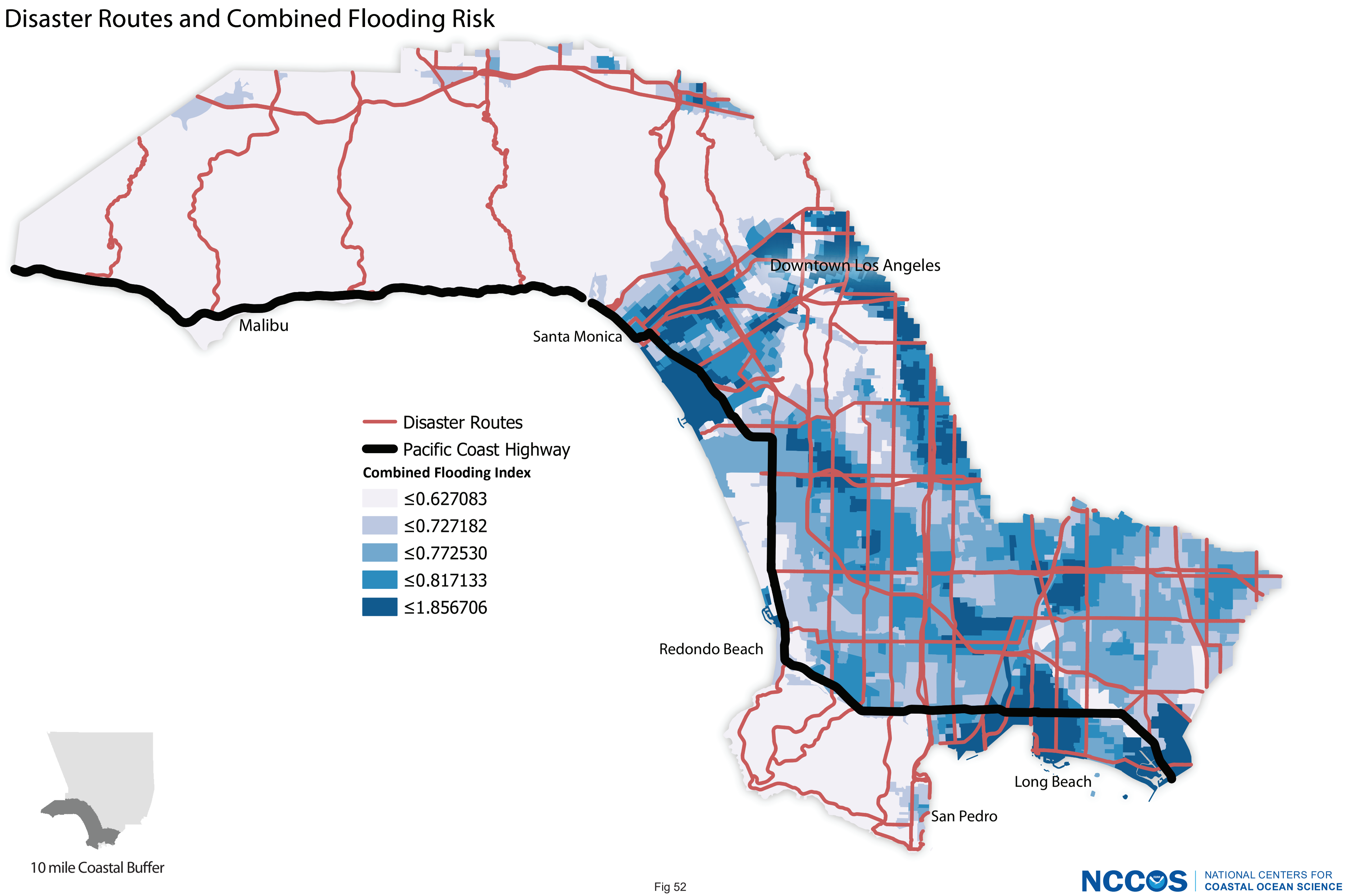
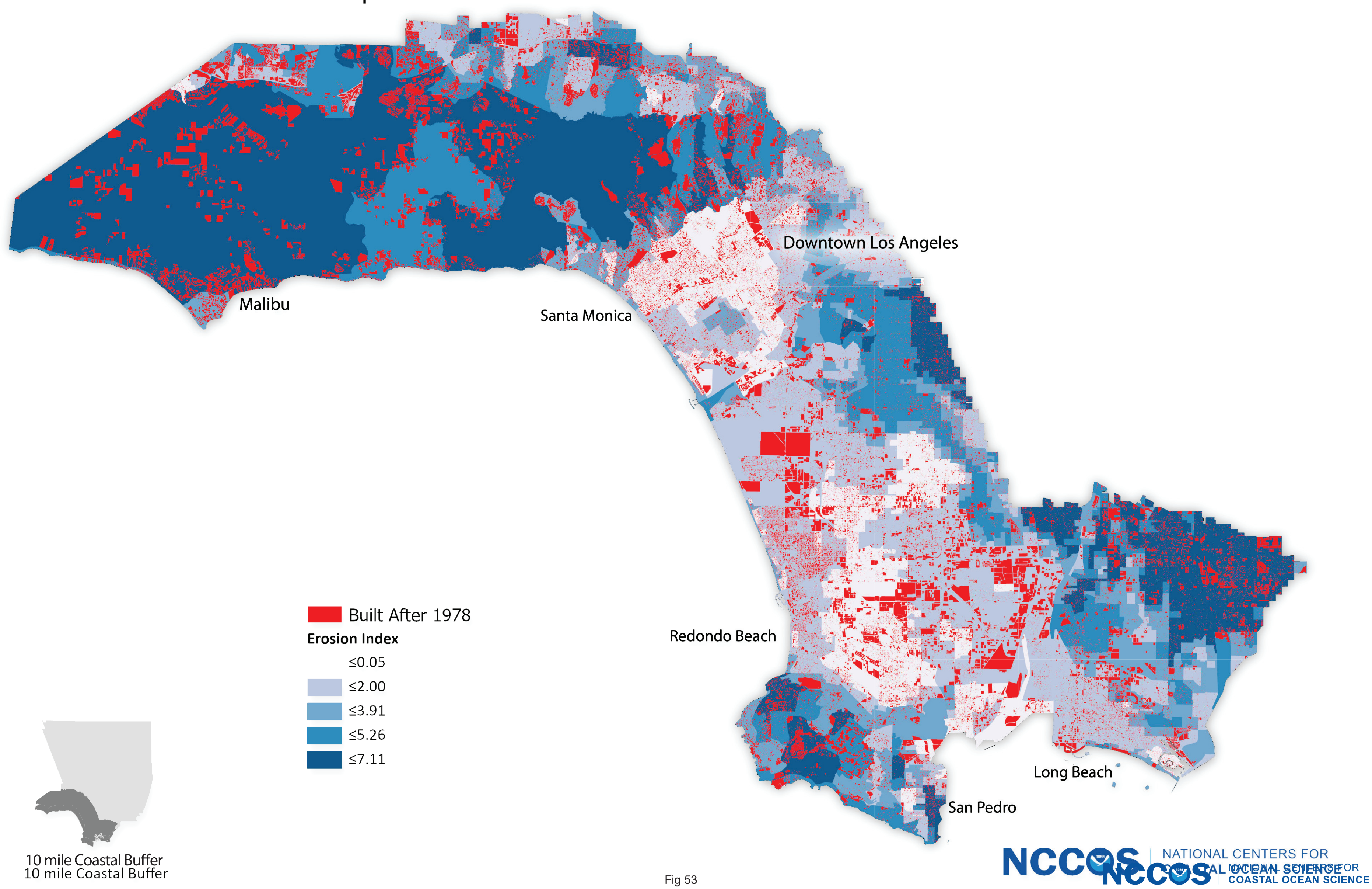


Figure D48. (Figure 5.10. in Chapter 5)

Erosion Risk with Coastal Development



U.S. Department of Commerce

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Assessing The Geographic Variability In Vulnerability To Climate Change And Coastal Hazards In Los Angeles County, California

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