THESIS

INNOVATION, INSTITUTIONS, AND THE IMPORTANCE OF LARGE LAND PARCELS: DRIVERS OF URBAN EXPANSION IN SAN DIEGO, CA, 1986-2017

Submitted by

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In partial fulfillment of the requirements

For the Degree of Master of Arts

Colorado State University

Fort Collins, Colorado

Fall 2019

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ABSTRACT

INNOVATION, INSTITUTIONS, AND THE IMPORTANCE OF LARGE LAND PARCELS: DRIVERS OF URBAN EXPANSION IN SAN DIEGO, CA, 1986-2017

Urban expansion and its drivers are an increasingly important focus for land change scientists. Expansion of built-up land cover reduces native plant and animal habitat, increases surface water runoff, and impacts local and global climate. However, an increasing proportion of the world's population is moving to urban environments and the demand for housing, commercial services, and employment in these environments is rising. Understanding where urban expansion occurs and the underlying drivers responsible for it is thus critical for social and environmental policy. This thesis utilizes spatial analysis to quantify urban land use change in two case areas of San Diego County, California between 1986 and 2017. The first case, focusing on the Otay Ranch community of Chula Vista, has a long history of agricultural land use linked to the Spanish Alta California Rancho system, and rapid residential development in recent years occurred as a direct result of this land tenure system. Expansion of industrial districts in this case study occurred along the U.S.-Mexico border as a result of NAFTA and subsequent international trade relations, while planning efforts to encourage a research-based economy in the region have so far failed. The second case study, focusing on the University of California, San Diego and surrounding communities, examines the economic drivers of urban expansion in the context of recent growth in the area's innovation economy. Sectors in the innovation economy are primarily research-driven, technology-based, and include industries like biotechnology, telecommunications, and aerospace engineering. This case study examines the role of the university in establishing this economy and quantifies the rapid urban expansion that occurred during the innovation economy's growth over the past 31 years. The relative roles of land tenure, planning institutions, economic growth, and physical geography are discussed in both case studies, and the results of both case studies' spatial analysis indicate the differing power of proximate causes of urban land change in different places.

ACKNOWLEDGEMENTS

As with any major project, this thesis would not have been possible without the help of numerous others who provided insight, feedback, inspiring conversations, and funding opportunities. Firstly, I would like to thank my advisor Dr. Stephen Leisz for two plus years of guidance in the nuances of human-land interactions, land tenure, remote sensing, and spatial analysis. This thesis benefitted greatly from his feedback, from initial analyses in his Spring 2018 Land Change Science class to suggestions for phrasing in this final draft. I also want to thank several others in the Anthropology and Geography Department for providing funding and intellectual challenge that contributed significantly to the final shape of my research. Thanks to Dr. Kathy Galvin for the opportunity to conduct literature reviews on a variety of human-environment topics, and Dr. Kate Browne for providing the opportunity to conduct qualitative research and analyze large quantities of spatial data at the Ethnographic Field School for Risk and Disaster. Huge thanks also to the Department of Anthropology and Geography for two years of funding as a Graduate Teaching Assistant, and to Dr. Melinda Laituri and Sophia Linn at the Geospatial Centroid for all the interesting and challenging projects I worked on as an intern. Thanks to Dr. Merrill Johnson for providing a great first semester as a teaching assistant and for offering feedback on the political and economic geography aspects of this thesis. Furthermore, I could not have finished this thesis or the rest of my master's program without the constant support, praise, deep questions, and lively dinner discussions with my parents, Ken and Sheri Molder, and grandparents, Ned and Shirley Russell. And finally, I want to thank my partner Amanda for her unwavering love and kindness, her critical mind, and her sense of humor for reminding me not to take things so seriously. I can't wait to see what's next.

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CHAPTER 1 – LAND CHANGE SCIENCE AND THE CASE OF URBAN EXPANSION IN SAN DIEGO, CA

LAND CHANGE SCIENCE

Land change science (LCS) emerged as an interdisciplinary focus area within the broader fields of global environmental change and sustainability science (Turner et al., 2007). However, as a topic of study the relationship between humans and our natural environment has a long history in the anthropology and geography literature. Early geographers like Alexander von Humboldt (1889) and Carl Sauer (1952) noted how human societies throughout the world utilized their surroundings for subsistence, shelter, and other cultural practices. George Perkins Marsh (1885) famously made some of the earliest observations of the link between human action and environmental effects in *Man and Nature*, and other early anthropologists and geographers like Carl Ritter, Franz Boas, Claude Levi-Strauss, Ellen Churchill Semple, Ellsworth Huntington, Griffith Taylor, and Élisée Reclus explored similar research on the role of the environment in human culture.

Julian Steward's (1955) foundational framework of cultural ecology sought to understand the dynamic interaction between human societies and their environment, and how this interaction shaped cultural evolution. In contrast to deterministic theories emphasizing the sole power of the environment (Thomas, 1925; Taylor, 1951) or culture (Goldenweiser, 1922) in shaping human societies, Steward's cultural ecology framework argued cultural evolution is a multilinear process of human agency acting within the confines of a given natural environment. Steward's emphasis on subsistence strategies and technology as a research focus laid the groundwork for later human-environment research within the broader disciplines of global environmental change, human ecology, and sustainability science (Turner and Robbins 2008).

Political ecology, for example, draws upon cultural ecology's focus on how humans utilize their environment for subsistence and adds a broader political-economic perspective to understand the power systems responsible for socio-environmental marginalization (Watts, 1983; Blaikie, 1985; Bryant and Bailey, 1997; Sullivan & Stott, 2000; Peet & Watts, 2004; Paulson & Gezon, 2005). Other research communities engaged in work to understand the terrestrial human-environment system include resource economics, institution governance, landscape ecology, and biogeography (Turner et al., 2007). However, land change science has emerged as the most comprehensive approach through its combination of social, environmental, and geographical information and remote sensing sciences (Turner et al., 2007).

LCS is particularly well-suited to global environmental change and sustainability research for its central emphasis on spatial patterns, as changes in the land surface are always rooted in specific place-based systems (Wilbanks & Kates, 1999). Paying attention to scale in land change research helps to uncover different processes that may be working simultaneously, with heterogeneous effects across the planet (Verburg et al., 2013). LCS, as a discipline at the intersection of physical and social sciences, leverages research from multiple scales to understand the dynamic processes responsible for patterns of change on the landscape. As such, linking the pattern of landscape change with processes of human action becomes a central goal of LCS (Nagendra et al., 2004) and follows landscape ecology's claim that "the landscape (like many ecological systems) represents an interface between social and environmental processes." (Turner 1989:
189).

LCS research is critical because changes in land use and land cover are among the most significant anthropogenic impacts to the Earth System. To clarify terminology, land cover refers to the biophysical attributes of the earth's surface, and land use refers to the human purpose or intent applied to these attributes (Lambin et al., 2001). Land use is the link between human activities and the terrestrial environment (Geist & Lambin, 2002) and changes in land cover as a result of land use have had wide-ranging consequences (Foley et al., 2005). For example, Gibbs et al. (2010) found that between 1980 and 2000, more than half of all new agricultural land in the tropics was created through the conversion of rainforest. This has significant implications for carbon emissions (van der Werf et al., 2009) and freshwater resources (Foley et al., 2007), as biomass in the tropics captures large quantities of anthropogenic CO2 and rainwater runoff. Globally, land use and land cover change were responsible for 12.5% of anthropogenic carbon emissions from 1990-2010, largely as a result of intensification and extensification of agriculture (Houghton et al., 2012).

Large-scale conversion of land cover also has implications for local biodiversity and ecosystem resilience. Newbold et al. (2015) found that ecosystem pressure associated with land use intensity, land use history, human population density, proximity to roads, and accessibility from the nearest large town significantly reduced local species biodiversity on several different metrics. This pattern is echoed throughout the world, with global anthropogenic pressures like resource consumption and overexploitation, invasive species, nitrogen pollution, and climate change driving species extinction at an unprecedented rate (Butchart et al., 2010). Humans have altered the face of the planet to such an extent that Ellis and Ramankutty (2008) proposed eighteen different "anthropogenic biomes" to describe human interaction with the planet's surface and ecosystems in different places. Even landscapes designated as "wilderness", whether dense native forest or barren desert, are only able to remain as such through human action like conservation policy. The precise quantity of land that has been transformed by human use is up for debate, but land change scientists agree that a vast majority of the terrestrial surface has been directly or indirectly altered through human action (Ellis, 2011; Crutzen, 2006; Hooke & Martín-Duque, 2012; Lewis & Maslin, 2015; Steffen et al., 2005).

Drivers of Land Change

Understanding the drivers of land change is one of the central goals of LCS as, with understanding, policy and decision makers can predict the outcome of structural change for the benefit of social-ecological systems like agriculture, forested landscapes, and urban environments. Theories of land change are wide-ranging, as the multitude of local contexts across the planet cannot be adequately explained by unified theories representing every dynamic. However, a number of underlying drivers (Geist & Lambin, 2002) are often cited as ultimately responsible for proximate land changes. Population growth is one of the most often referenced drivers of land change, as exemplified by Garret Hardin's (1968) "Tragedy of the Commons" and subsequent neo-malthusian perspectives on environmental change (Ehrlich, 1971; Meadows et al., 1972; Daly, 1973). These arguments essentially claim that the planet's finite supply of resources cannot indefinitely support a growing population, and that limiting population growth is the only way to prevent environmental catastrophe. These perspectives also inform "cornucopian" theorists who argue, rather, that the intrinsic ingenuity of human society will allow us to avoid population-driven environmental catastrophe through invention and adaptation (Boserup, 2014; Simon, 1981).

Population growth certainly has an effect on the environment, but these perspectives fail to consider more locally important, if complex, drivers of land change (Lambin et al., 2001). The rate of population growth is also heterogeneous across the planet and framing environmental degradation in terms of "global population" risks masking place-specific socio-political factors that respond to local population change and drive degradation. In the context of tropical deforestation, for instance, Lambin et al. (2001) found that in Latin America government policy on frontier development, competition between settlers, and existing attitudes toward indigenous inhabitants more adequately explained forest loss than simple metrics of population change. Likewise, forest loss in central Africa is linked to foreign trade revenue, weak enforcement policy, and corruption (Lambin et al., 2001). Both regions experienced simultaneous population growth and deforestation, but the mechanisms through which population growth leads to deforestation are geographically unique.

Economic growth, usually measured as a country's GDP or per-capita income, is also commonly recognized as an underlying driver of land change (Colsaet et al., 2018). Increasing industrialization has historically led to increased standards of living, which manifests as greater resource usage and environmental degradation. Some have argued, however, that this relationship is non-linear. Grossman & Krueger (1991) applied the "Kuznets curve" (Kuznets, 1955) to environmental impact as a result of increasing economic development, and numerous others have used the theory to explain the relationship between environmental and economic changes throughout the world (Stern, 2004). The theory holds that pollution and environmental degradation increase in the early stages of a country's economic development, but the trend eventually reverses after a certain level of per-capita income is met and demands for improvements in environmental quality increase. However, this theory has been challenged on a number of grounds, most notably for failing to consider the spatial displacement of polluting industries toward less developed countries as one country's economy grows (Stern, 2004). The telecoupling framework (Liu et al., 2014) can illuminate such a relationship between spatially disparate places and is an increasingly important LCS framework in our globalized society.

The transformation of land cover to that associated with urban uses is one of the most significant land use transitions (Grimm et al., 2008). Once vegetated land cover is paved over, as is the norm in most industrialized cities, it is rarely returned to a "natural" state so the effects of urban expansion on the landscape are permanent. In the remainder of this thesis, urban land use transitions and their drivers are examined within the broader theoretical context of land change science. A distinction is made between "urbanization" (Tisdale, 1941: *the process of population concentration*) and "urban expansion" (*the outward spatial extension of land cover associated with urban or suburban land use*). "Urban sprawl" has also been used to refer to urban growth processes (generally in regard to the outward expansion of suburban areas) but is avoided here due to the negative connotations of the term (Brueckner, 2000). Relevant literature on the drivers of urban expansion and its effects on water resources, biodiversity, and climate are discussed in the following chapters.

THE DRIVERS OF URBAN EXPANSION IN SAN DIEGO, CA

San Diego county is a region in California that has experienced significant urban expansion over the past several decades. Throughout much of the 20th century, the city of San Diego was known primarily for its deep-water port and its numerous military bases. As such, population growth was slow until the 1950s when military contracting sectors experienced a boom brought on by the Cold War and increasing interest in space exploration. These sectors attracted an influx of new residents, however the most striking growth in population occurred toward the end of the 20th century in tandem with the county’s rapidly expanding “innovation economy”.

San Diego county is also the site of Spain’s earliest settlements on the west coast of what would become the United States, and subsequent development was influenced by land ownership systems established early in San Diego’s history. In particular, the Alta California rancho system allocated large parcels of agricultural land in present-day California to high-ranking military officials, and these land holdings continued to be recognized after California gained statehood in 1850. As a result, most of these large and undivided parcels of land remained under single ownership within the county until relatively recently. Many communities and cities within the county retain names derivative of the original Ranchos allocated in those locations, including Rancho Bernardo, Rancho Penasquitos, El Cajon, National City, and Encinitas.

A growing population in the second half of the 20th century contributed to the subdivision and development of many of these parcels into the suburban residential areas present in San Diego county today. This combination of available land for development and a rapidly growing economy strongly contributed to much of the urban expansion San Diego has experienced in recent decades. However, the processes of urban expansion that occurred as a result of this interrelationship were influenced by numerous planning institutions, policies, and political drivers. As such, the focus of this thesis is to understand how different drivers of urban expansion contributed to growth in different regions of the county.

This thesis is composed of two case studies of urban expansion in San Diego county between 1986 and 2017, and is rooted in the broad central question: Where did urban expansion occur and what were its drivers? The cases were selected for their representation of commonly cited drivers of urban expansion as discussed in Colsaet et al.'s (2018) meta-analysis. The case study in chapter 2 is interested in San Diego's "innovation economy" that grew out of the University of California, San Diego (UCSD) during the late 70s and 80s and examines economic growth as a driver of urban expansion. San Diego experienced a significant shift in its economic base during this period, so understanding the degree to which this affected urban expansion more recently is of great interest. The two guiding questions for this case study are: 1.) Did the expansion of industrial areas occur as a result of economic growth in the innovation sectors? And 2.) Were the rates of residential and industrial expansion similar as a result of simultaneous growth in population and the innovation economy?

The case study in chapter 3 is interested in the historical geographic influence of the Spanish Rancho system on present day urban form. The presence of large, undeveloped parcels of land have generated great opportunity for developers to construct master-planned residential communities over short periods of time, and these communities are responsible for much of the urban expansion that has occurred in San Diego county in recent decades. This case study focuses on one specific parcel remnant of the Rancho system, namely Otay Ranch, and examines the impact of this parcel on recent urban development. Otay Ranch is located approximately twelve miles southeast of downtown San Diego and five miles north of the U.S. Mexico border. Thus, its development has been influenced by drivers associated with U.S.-Mexico relations and more local changes in the city and county of San Diego. The two guiding questions for this case study are: 1.) Did most residential development occur within the Otay Ranch parcel? And 2.) Did industrial growth occur primarily along the U.S.-Mexico and increase after 1994 and the signing of NAFTA?

Spatial analysis using geographic information systems (GIS) is utilized in both case studies to quantify the amount of urban land change between 1986 and 2017 associated with growth in residential, industrial, commercial, and other land uses. Land use data, provided by the City of San Diego, representing eight different study years are classified into six different land use classes. These are then combined in QGIS to determine the change vectors responsible for each case area's development. Semi-structured interviews with city planning officials inform interpretation of the GIS analysis and guide further document review to understand the role of institutional drivers on urban expansion.

The results of these case studies highlight a number of potential areas for future inquiry into urban expansion and its drivers in the context of San Diego, the U.S. west coast more broadly, and elsewhere. As urban populations in many parts of the world grow at an accelerating pace, it is increasingly important to understand the drivers of urban land use change in order to minimize effects on the natural environment, resources, and biodiversity while meeting the needs of the population. The case of San Diego county by no means represents the entire spectrum of urbanization throughout the world, but much can be learned from this case and applied in other contexts.

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CHAPTER 2 – SAN DIEGO'S "INNOVATION ECONOMY" AND THE ECONOMIC DRIVERS OF URBAN EXPANSION, 1986-2017

INTRODUCTION

The field of land change science is increasingly turning its focus to the study of urban growth and its drivers. As much of the world's growing population is moving to cities, it is necessary to understand where urban land use transitions occur on the landscape, and the proximate and underlying drivers responsible for them (Geist & Lambin, 2002).

Urban expansion, here defined as the transition from land uses not primarily associated with human settlement to land uses primarily associated with human settlement, has myriad effects (Grimm et al., 2008a). First, impervious surfaces are "hydrologically active", meaning that they generate surface runoff (Barnes et al., 2000). The impervious surfaces associated with industrial, commercial, and high-density residential land uses are nearly 100% hydrologically active, which has enormous implications for storm water runoff, soil erosion, water pollution, and the quality and quantity of urban water resources. Rapid expansion of impervious surfaces in recent years, e.g. as evidenced by Hurricane Harvey's impacts on Houston, has led to extreme flooding during torrential events (Zhang et al., 2018) and limits the infiltration of fresh water into aquifers (Shuster et al., 2005; Arnold & Gibbons, 1996). Impervious surfaces also increase the susceptibility of soil and water resources to pollution deposited in urban environments (Grimm et al., 2008b) which has implications for agricultural land quality and food systems (Chen, 2007). This is doubly impactful, as urban centers often expand into their most fertile agricultural soils (Satterthwaite et al., 2010), effectively removing this land from production.

Urban land cover transitions are also responsible for a loss of plant and animal habitat, with implications for local and regional biodiversity (Grimm et al., 2008b). This occurs most commonly through direct destruction of natural habitats (Mcdonald et al., 2008), but can also manifest through the fragmentation of ecosystems and the disruption of wildlife corridors. Trombulak & Frissell (2000) identify seven general effects of roads on non-human ecosystems: mortality from road construction, mortality from collision with vehicles, modification of animal behavior, alteration of the physical environment, alteration of the chemical environment, spread of exotics, and increased use of areas by humans. The ecosystem effects caused by roads and associated human usage is so extensive that the subdiscipline of "road ecology" has arisen at the intersection of landscape ecology and transportation geography (Coffin, 2007). If urban expansion continues in tandem with projections of global population and GDP growth, the total urbanized area throughout the world will be triple its 2000 extent by 2030 (Seto et al., 2012). Most of this expansion will likely occur in key biodiversity hotspots.

Further, transitions to urban land use and land cover also result in changes to the local and global climate system through loss of vegetation and soil moisture. The "urban heat island" effect has been well studied within the field of urban ecology (Arnfield, 2003; Oke, 1982; Chen et al., 2006), and urban environments may contribute more than 90% of global anthropogenic carbon emissions through transportation, industry, building heating and air conditioning, and cement production (Svirejeva-Hopkins et al., 2004). However, overemphasis on the net contribution of greenhouse gases by urban environments neglects the fact that per- capita contribution of carbon emissions by urban residents is significantly less than non-urban residents in the same country (Dodman, 2009). This is due primarily to the closer proximity of urban residents to amenities, per-capita energy efficiency of higher density residential units, higher concentration of service-industry jobs and, perhaps most significantly, the outsourcing of more carbon intensive industries like industrial agriculture, energy generation, and manufacturing to areas with lower residential density and land cost (Dodman, 2009). As such, efforts to measure the impact of urbanization trends on the global climate must consider the tele-coupled nature of contemporary resource systems (Seto et al., 2012).

The first step toward preventing detrimental ecological and environmental effects, while meeting the material and economic needs of an increasingly urban population, is to understand both the proximate causes and underlying driving forces (Geist and Lambin, 2002) of urban expansion in particular areas. This paper, thus, focuses on the change in urban land uses in central San Diego county, CA between 1986 and 2017 using geographic information system (GIS) tools to spatially analyze the changes that have taken place and investigate the drivers of those changes.

Economic Drivers of Urban Expansion

Colsaet et al. (2018) found economic growth and other economic forces to be one of the leading drivers of urban expansion. In highly industrialized regions like the U.S. west coast, economic growth drives both resource use (locally and globally) and urban expansion through rising demand for housing, production, and leisure spaces (Wassmer, 2006; Deng et al., 2010; Kuang et al., 2014). San Diego County, CA exemplifies these trends, particularly for its relatively recent economic growth associated with the "innovation economy". CONNECT, an organization founded in 2005 to help San Diego startups, defines the sectors that comprise the innovation economy as "knowledge-based sectors on the leading-edge of research, innovation, and development of technologies," (CONNECT, 2017:15). These sectors include physical engineering & life sciences, biomedical products (medical devices), biotechnology and pharmaceuticals, communications (telecommunications), computers & electronics, aerospace, navigation & maritime tech, environmental technology, recreational goods manufacturing, and software.

While much of the recent growth in the innovation economy is attributed to the biotechnology and telecommunications sectors, research-based industry in San Diego began with the United States (U.S.) military and military contractors funded through the Defense Advanced Research Projects Agency (DARPA). These foundations extend to the beginning of the 20th century. Since before World War I, San Diego was utilized for its natural deep-water port (Pryde, 1992). Following the opening of the Panama Canal in 1915, the port's value was recognized for its potential as a hub for westward shipping activity (Hennesy, 1993). The Canal's opening was celebrated in San Diego with the Panama-California exposition in Balboa Park, where numerous military officials and politicians gathered. As a result, and partially as a result of mounting military tensions in Europe, the US Navy established a base on the San Diego Bay. Other branches of the military soon followed, and with them grew a burgeoning local economy of military contractors.

The impact of the military in San Diego extended, naturally, to the conversion of undeveloped land to military bases. In 1915, San Diegans voted to transfer 500 acres of submerged land on Coronado Island to the establishment of a Marine Corps base (Erie et al., 2011). By 1935, all of the North Island of Coronado was under control of some military branch, and by 1939 there were eight Navy and Marine bases in the county on four thousand acres. Of particular note was the establishment of Camp Pendleton on the northern coast of San Diego county. Major General Joseph Henry Pendleton had long advocated for a West Coast training base for the Marine Corps in San Diego and, in 1942, the Marine Corps announced it would the land of the Rancho Santa Margarita into such a base (Christenson and Sweet, 2008; Engstrand, 2014). As a result, Camp Pendleton remains one of the largest contiguous undeveloped areas of land on the southern California coast.

Military employment increased from four thousand in 1935 to seventy thousand in 1943

(Erie et al., 2011). The value of industrial output associated with the military increased from $35 million to $1 billion in same time period. Following World War II (WWII), the military-based economy boomed, and major aerospace and ship manufacturers dominated the industry. One such company, Consolidated Aircraft Corporation, was founded in 1923 in Buffalo, NY, but relocated to San Diego in the early 1940s (Erie et al., 2011). General Dynamics purchased the company in 1953, and it experienced significant success designing and manufacturing aircraft carriers, fighter planes, and rockets throughout the remainder of the 20th century. Due largely to the space race and Cold War tensions between the Soviet Union and the U.S., aerospace manufacturing played an increasingly significant role in San Diego employment. This trend continued off and on throughout the remainder of 20th century, building momentum for the subsequent innovation sectors. General Dynamics opened its General Atomics division in Torrey Pines in 1959 on city-donated pueblo land (Erie et al., 2011). Jonas Salk opened the Salk Institute the following year and ushered in a new economic phase associated with biotechnology, communications, and other research-drive sectors associated with today's innovation economy. A major nucleus of this activity was the University of California, San Diego (UCSD), founded through the lobbying efforts of General Atomics chair John Jay Hopkins and Scripps Institute of Oceanography researcher Roger Revelle (Rainger, 2001).

Innovation Economy and Industrial Agglomeration

Walcott (2002) argues that five key factors were necessary for success in San Diego's innovation economy. These include access to an outstanding research university (UCSD), advocacy leadership by successful firms and organizations, risk financing, an entrepreneurial culture, and appropriate real estate. Three of these factors (advocacy leadership, risk financing, and entrepreneurial culture) are present in the UCSD area as a direct result of early successes by

Linkabit, the first major telecommunications firm in San Diego (West, 2009), and Hybritech, an early biotechnology firm that spawned dozens of startups in the area (Casper, 2007). Gordon & McCann (2000) similarly discuss agglomeration theory in the context of industrial growth. Their theoretical perspective is especially relevant to the clusters of innovation economy firms surrounding UCSD because the process of agglomeration occurred through transmission of information amongst researchers and entrepreneurs ("social-network model") rather than material exchange ("industrial-complex model") or the presence of an existing labor pool ("pure agglomeration model").

Allen Scott (1993) explores the history and theory of industrial agglomeration as it pertains specifically to the high-technology sector in southern California. Much of his discussion is focused on Los Angeles, but several chapters trace the development of San Diego's innovation economy. These high-tech centers developed, he argues, through the "logic of the production system" characterized as a "dynamic complex of interconnected producers articulated with a series of local labor market activities," (p.4). This articulation of "producers", as major employment centers in the innovation economy, and a local population is critical and has long been the source of debate in urban economic geography. Richard Muth (1971) notably addressed the interconnected roles of in-migration and employment opportunities in urban environment, questioning the degree to which one influences the other. Others have argued that natural amenities, specifically warmer January temperatures, rather than economic opportunities drove migration to the Sunbelt states in the 20th century (Borts and Stein, 1964; Partridge, 2010). Storper (2013) acknowledges the complex nature of these drivers of urban expansion in the context of economic growth, especially as innovations in communication technology have an increasingly global impact on the location of technology sectors (Leamer & Storper, 2014; Knox et al., 2014). He argues that cities develop first through networks of firms that attract employment-seeking migrants rather than through an influx of population. Chen and Rosenthal (2008) also found that cities with a growing business environment attract a larger share of working-age individuals than amenities-rich cities with less employment opportunity. Figure 1.1 shows a conceptual model of industrial and residential expansion in San Diego driven by growth in the innovation economy.

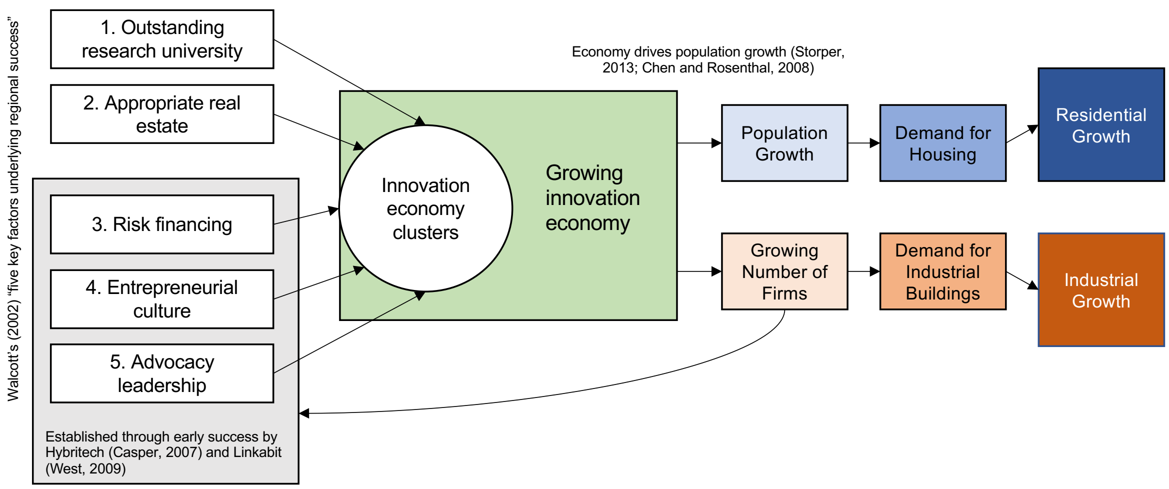

Figure 1.1 *- Conceptual model of growth in the innovation economy and its impacts on urban expansion.*

The remainder of this paper looks at the San Diego case to investigate how the conditions reviewed here manifest in the urban form surrounding San Diego's innovation economy. The two guiding questions for this case study are:

1.) Did the expansion of industrial areas occur as a result of economic growth in the innovation sectors?

2.) Were the rates of residential and industrial expansion similar as a result of simultaneous growth in population and the innovation economy?

METHODS

The San Diego Department of Government's (SANDAG) SanGIS data warehouse provided the primary data sources for this analysis. SanGIS archives land use layers for the entire county of San Diego at a five to six-year interval, starting in 1986. Several other layers from the

SanGIS archive were used for this spatial analysis including roadways, business sites, and city points. Major highways were downloaded from OpenStreetMap and a greyscale basemap was sourced from ESRI. All data sources are credited on the maps themselves.

First, all available land use layers were downloaded from the SanGIS database. These include data from 1986, 1990, 1995, 2000, 2004, 2008, 2013, and 2017. The Census Bureau's "sub-regional areas" (SRA) layer was also downloaded from the SanGIS database in order to create a bounding area for the analysis. The SRA layer divides San Diego County into 41 different areas based on population density. By selecting several SRAs from the data layer, a study area was delineated for the UCSD and surrounding "innovation economy" region. The SRAs included in this case area are: Miramar, San Marcos, Carlsbad, Del Mar-Mira Mesa, University, Poway, North San Dieguito, and San Dieguito. These SRAs were selected based on a preliminary change analysis between 1986 and 2017 residential and industrial areas for the entire county. They captured areas of most new industry within approximately 20 miles of the UCSD campus as well as several large residential communities constructed since 1986. SRAs further south were excluded because many of these represent older parts of the county that experienced relatively little urban expansion during the study period. SRAs to the east were excluded because these represent largely rural communities that also experienced little urban expansion. The SRAs included in the study area were selected from the main layer and extracted as the case study bounding area.

Land use layers from each study year were then clipped by the bounding area and land uses were classified into one of six classes using a numeric designator (*LUCode*). These include: Other (1), Residential (2), Agricultural (3), Industrial (4), Commercial (5), Open/undeveloped (6). Several land use attributes were ambiguous (e.g. "Residential Recreation" could fit equally well in Residential, Open/undeveloped, or Other classes; "Golf Course" could fit in Commercial or Open/undeveloped classes), but these represented a relatively small percentage of total land use in the study area, and so were assigned the most relevant class and kept consistent for each study year. See table 1.1 for land uses assigned to each *LUCode* for the 2017 and 1986 study years. 2017 contains the most unique land use designations of any study year, and interstitial years' land use designations are captured in the 2017 list. 1986 and 2017 are presented to show the significant increase in land use designations during the study period.

Table 1.1 *- Land use designations assigned to each land use class, 1986 and 2017.*

Land Use Attributes by Class, 1986 and 2017			Total/class
1986	Other	AIRPORTS, BAYS, LAGOONS, COMMUNICATIONS AND UTILITIES, ELEMENTARY SCHOOLS, FREEWAYS, HIGH SCHOOL, HOSPITALS, JUNIOR COLLEGE, JUNIOR HIGH SCHOOLS AND MIDDLE SCHOOLS, LAKES/RESERVOIRS/LARGE PONDS, MILITARY USE, OTHER PUBLIC SERVICES, OTHER TRANSPORTATION, OTHER UNIVERSITIES AND COLLEGES, PUBLIC SERVICES, RAIL STATION/TRANSIT CENTER, SDSU SMSU OR UCSD, UCSD/VA HOSPITAL/BALBOA HOSPITAL	18
	Residential	GROUP QUARTERS, MOBILE HOME PARKS, MULTI-FAMILY RESIDENTIAL, RESIDENTIAL UNDER CONSTRUCTION, SINGLE FAMILY RESIDENTIAL, SPACED RURAL RESIDENTIAL	6
	Agricultural	FIELD CROPS, INTENSIVE AGRICULTURE, ORCHARDS AND VINEYARDS	3
	Industrial	EXTRACTIVE INDUSTRY, HEAVY INDUSTRY, INDUSTRIAL UNDER CONSTRUCTION, LIGHT INDUSTRY	4
	Commercial	COMMERCIAL, COMMERCIAL RECREATION, COMMUNITY SHOPPING CENTERS, GOLF COURSES, HOTEL/MOTEL (LO-RISE), OFFICE, RACETRACKS, REGIONAL SHOPPING CENTERS, WHOLESALE TRADE	9
	Open/Undeveloped	OPEN SPACE PARKS & PRESERVES, PARKS, PARKS – ACTIVE, UNDEVELOPED LAND	4
2017	Other	Bay or Lagoon, Cemetery, Communications and Utilities, Elementary School, Fire/Police Station, Freeway, General Aviation Airport, Government Office/Civic Center, Hospital – General, Junior College, Junior High School or Middle School, Lake/Reservoir/Large Pond, Library, Military Airport, Military Barracks, Military Training, Military Use, Mixed Use, Other Health Care, Other Public Services, Other Recreation – High, Other Recreation – Low, Other School, Other Transportation, Park and Ride Lot, Parking Lot – Structure, Parking Lot – Surface, Post Office, Rail Station/Transit Center, Railroad Right of Way, Religious Facility, Residential Recreation, Road Right of Way, Road Under Construction, SDSU/CSU San Marcos/UCSD, School District Office, School Under Construction, Senior High School, UCSD/VA Hospital/Balboa Hospital, Water, Weapons Facility	41
	Residential	Dormitory, Jail/Prison, Mobile Home Park, Multi-Family Residential, Multi-Family Residential Without Units, Other Group Quarters Facility, Residential Under Construction, Single Family Detached, Single Family Multiple-Units, Single Family Residential Without Units, Single Room Occupancy Units (SRO's), Spaced Rural Residential, Spaced Rural Residential Without Units	13
	Agricultural	Field Crops, Intensive Agriculture, Orchard or Vineyard	3
	Industrial	Extractive Industry, Industrial Park, Industrial Under Construction, Junkyard/Dump/Landfill, Light Industry – General, Warehousing	6
	Commercial	Arterial Commercial, Automobile Dealership, Commercial Under Construction, Community Shopping Center, Golf Course, Golf Course Clubhouse, Hotel/Motel (High-Rise), Hotel/Motel (Low-Rise), Neighborhood Shopping Center, Office (High-Rise), Office (Low-Rise), Office Under Construction, Other Retail Trade and Strip Commercial, Public Storage, Racetrack, Regional Shopping Center, Resort, Service Station, Specialty Commercial, Tourist Attraction, Wholesale Trade	21
	Open/Undeveloped	Beach - Active, Beach - Passive, Landscape Open Space, Open Space Park or Preserve, Park - Active, Undevelopable Natural Area, Vacant and Undeveloped Land	7

To understand where and when change occurred during the study period, change analyses were conducted between each adjacent year (e.g. 1990 and 1995; 2008 and 2013) in QGIS 3.8 using the GRASS GIS v.overlay tool. The resulting change layers contained *LUCode* attributes from both years, and these were added together into an *"LUChange"* value representing the change vector between the two years. Lastly, overlays were by dissolved by *LUChange* to produce the final change layers containing one record for each change vector. Geometry attributes were added to these and exported as CSV files. See figure 1.2 for the spatial analysis workflow.

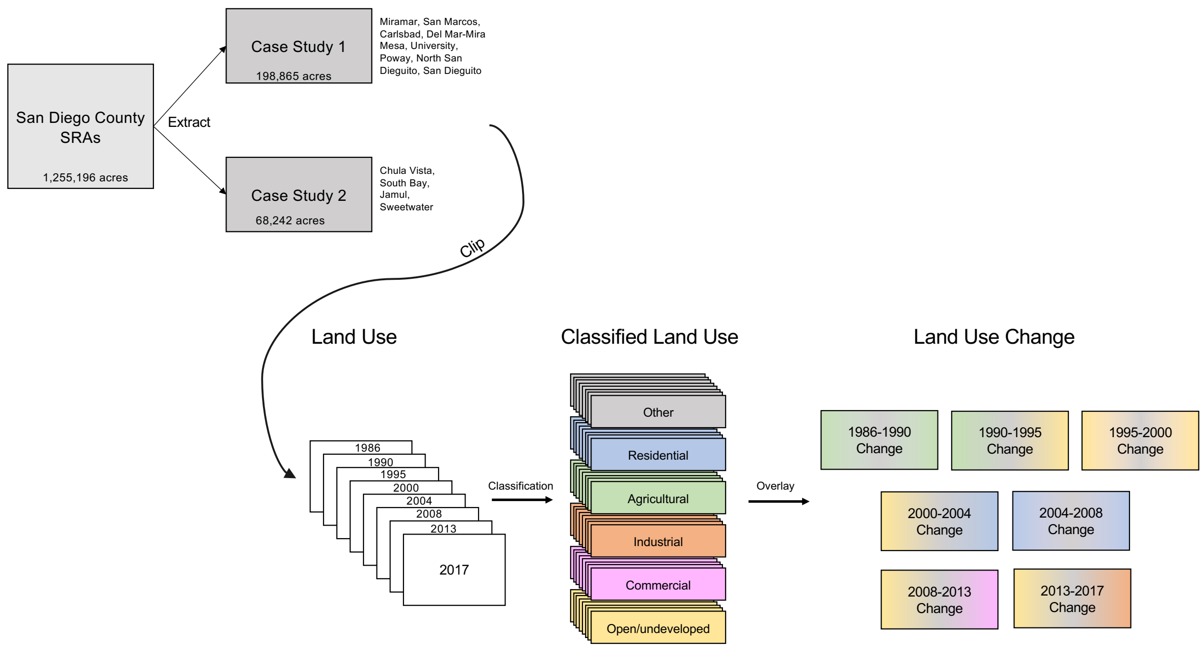

***Figure 1.2** - Spatial analysis workflow for clipping, classifying, and overlaying land use data from both cases studies within this thesis.*

RESULTS

As expected, myriad changes occurred in the study area between 1986 and 2017. Figure 1.3 shows transitions from open/undeveloped to residential, industrial, and commercial land uses. Figure 1.4 shows a closer view of the same map focused on the highway-56 corridor, and Figure 1.5 is focused on the northern section of the study area including the cities of San Marcos, Carlsbad, and Encinitas. Figure 1.6 plots the area of each land use class by year, and Figure 1.7 similarly plots the percentage of total study area occupied by each land use class per year. Figure 1.8 plots the area of change for four major change vectors over the course of the study period. Broadly speaking, residential growth occurred throughout the study area (Figures 1.3-1.5), with major foci of development in the Carmel Valley area (between Rancho Peñasquitos and Del Mar), San Elijo Hills (between San Marcos and Encinitas), Black Mountain Ranch and 4S Ranch

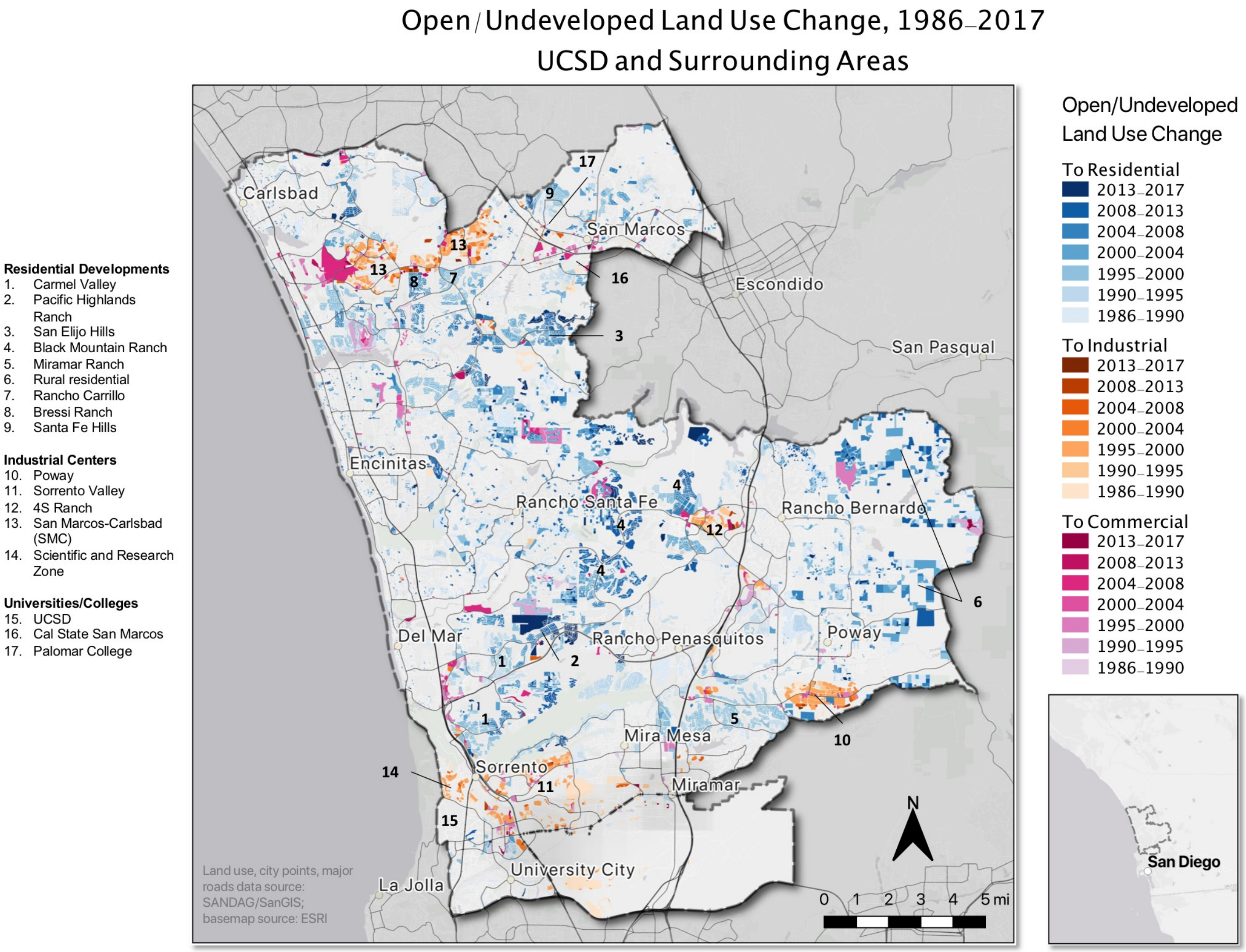

***Figure 1.3** - Open/undeveloped transition to residential, industrial, and commercial land uses.*

Open/Undeveloped Land Use Change, 1986–2017
Sorrento, Carmel Valley, and Rancho Santa Fe

Residential Developments
1. Carmel Valley
2. Pacific Highlands Ranch
3. Black Mountain Ranch
4. Miramar Ranch

Industrial Centers
5. Poway
6. Sorrento Valley
7. 4S Ranch
8. Scientific and Research Zone

Universities/Colleges
9. UCSD

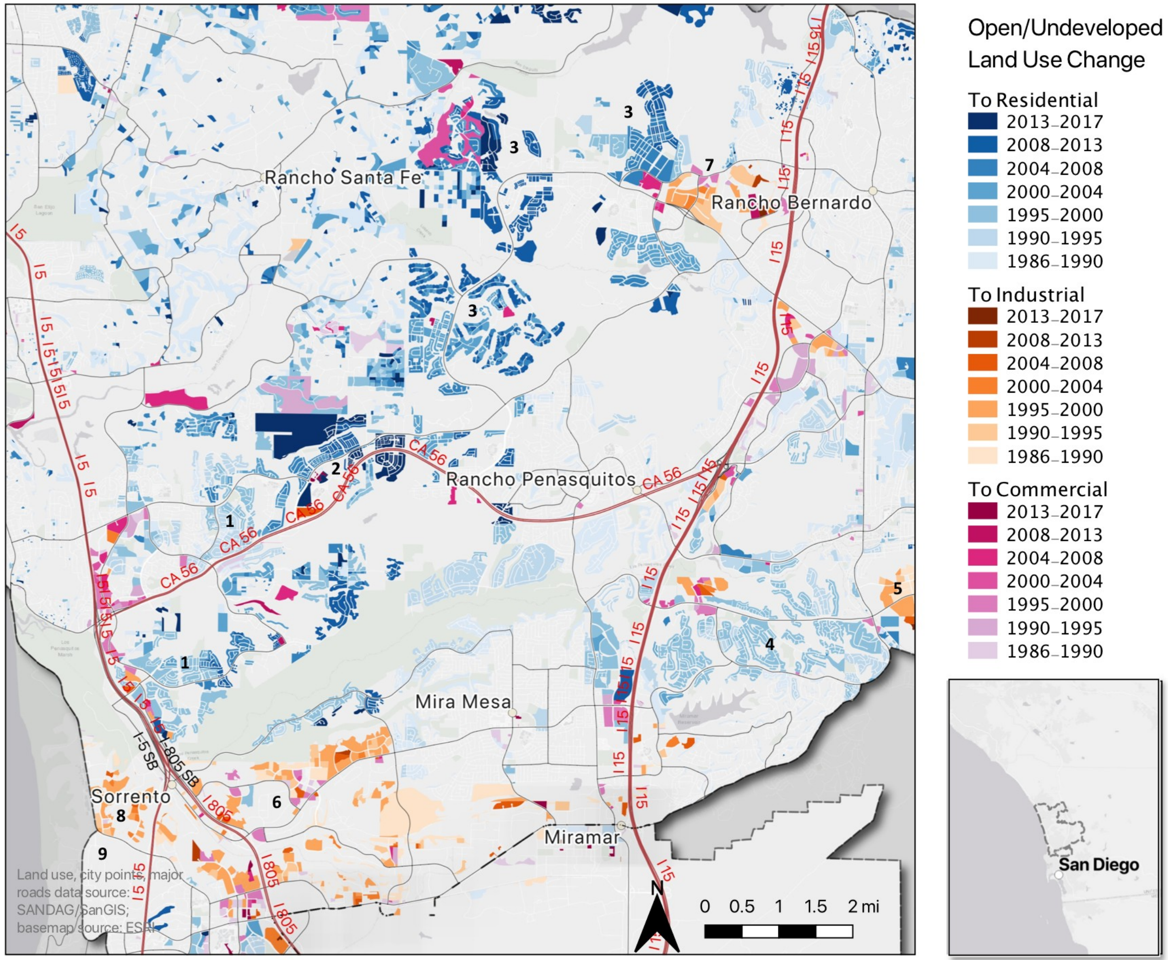

__Figure 1.4__ - Open/undeveloped transition to residential, industrial, and commercial land uses in the highway-56 corridor region.

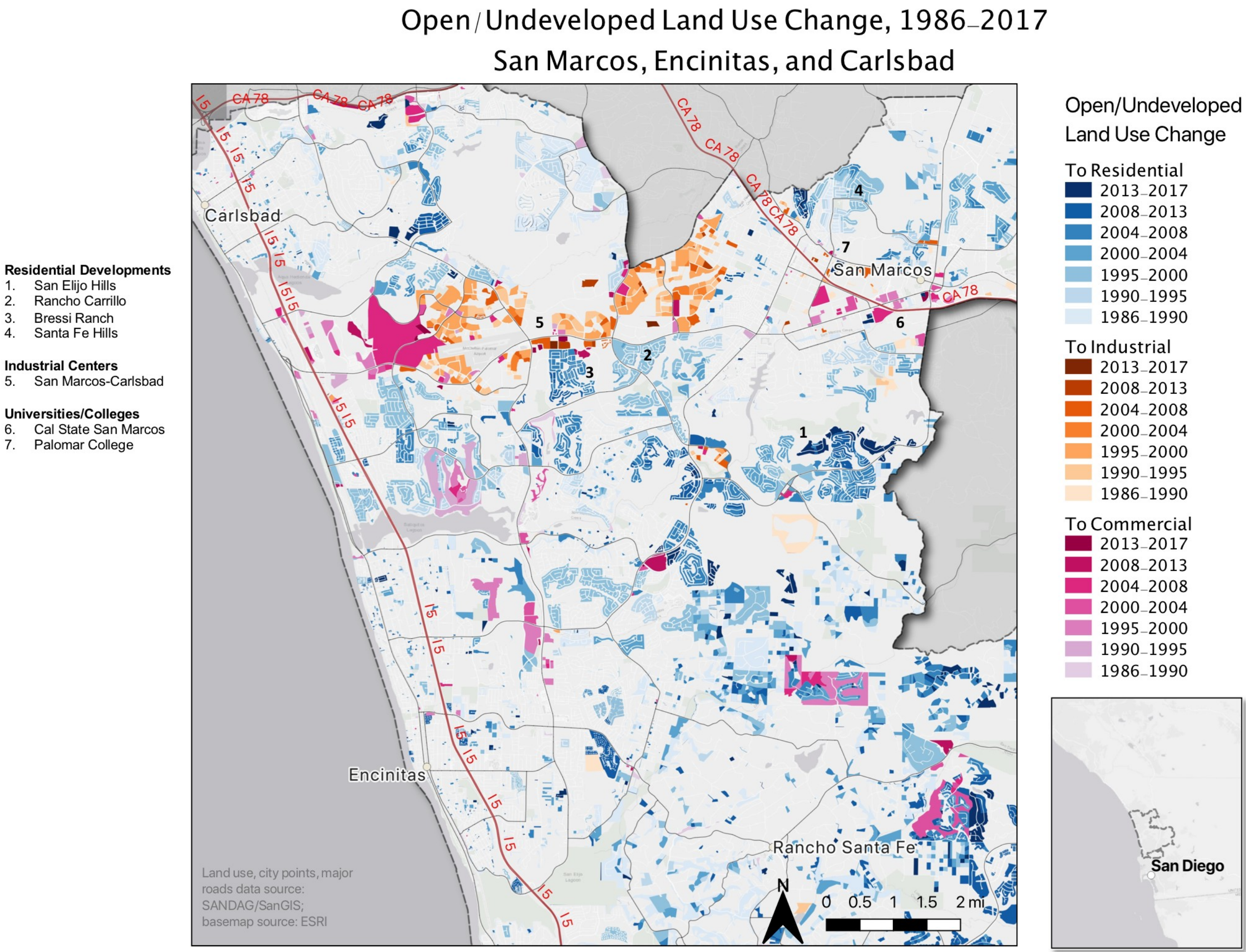

Figure 1.5 *- Open/undeveloped transition to residential, industrial, and commercial land uses in the highway-78 corridor region.*

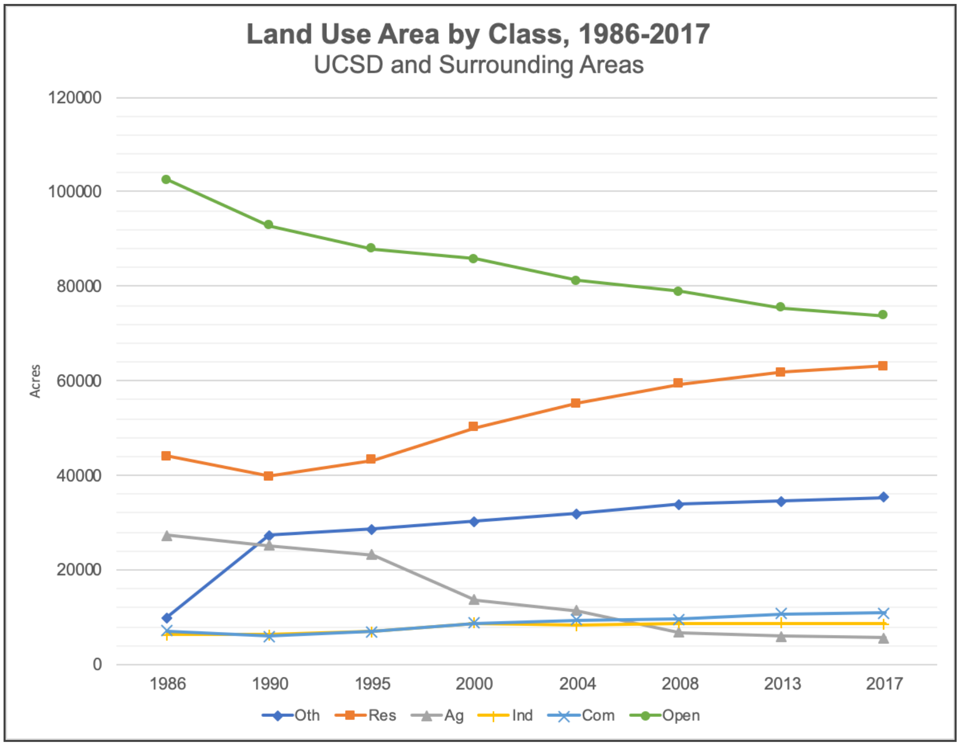

Figure 1.6 - Land use area by class, 1986-2017.

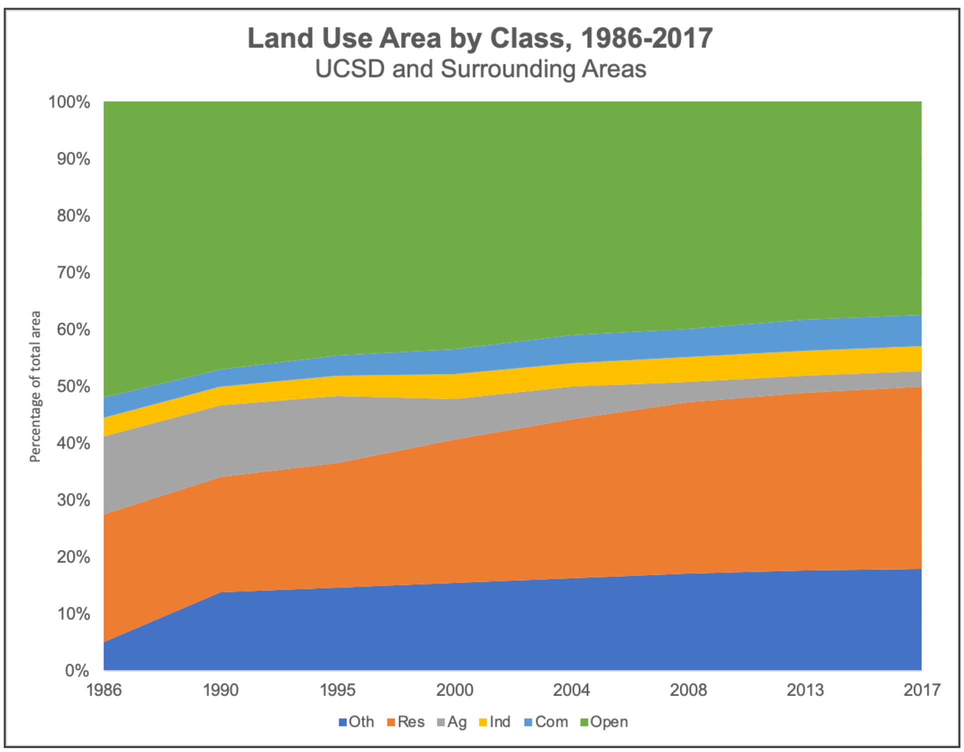

Figure 1.7 - Proportion of land use area by class, 1986-2017.

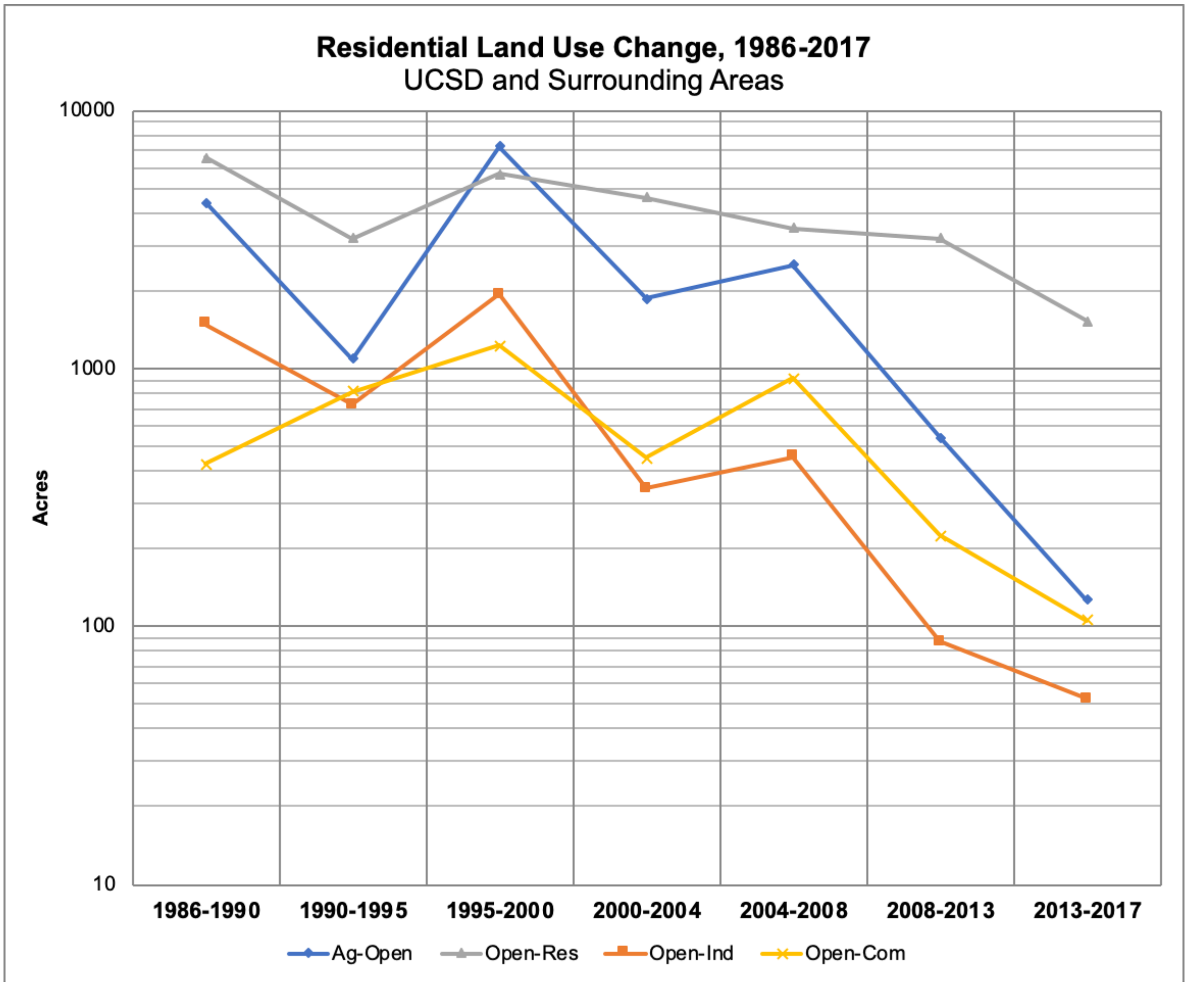

Figure 1.8 *- Changes in land use area representing agricultural to open/undeveloped, open/undeveloped to residential, open/undeveloped to industrial, and open/undeveloped to commercial change vectors.*

(between Rancho Bernardo and Rancho Santa Fe) and Miramar Ranch (east of Mira Mesa). Most of these foci were developed across several time periods since 1986, with the most recent developments occurring in Carmel Valley, Black Mountain Ranch, and San Elijo Hills.

The residential areas furthest east mostly represent spaced rural residential land uses, as indicated by the large rectangular polygons. In contrast to the mostly planned residential developments elsewhere characterized by numerous winding roads and irregularly shaped neighborhoods, spaced rural residential areas contain fewer dwelling units per acre and significantly more open space between built-up areas. As such, the land cover represented by "residential" land use in this analysis is variable across the study area. Figure 1.7 shows the total area of change from open/undeveloped to residential land uses (*open-res*) peaked during the first sub-period (1986-1990). Residential growth declined between 1990-1995, increased again between 1995-2000, then declined again for the remainder of the study period. However, the area of change represented by the other three change vectors declined more than the open-res area, indicating more sustained growth in residential areas than others. The notable peak in open-res area during the 1995-2000 sub-period corresponds with the recovering economy following the early 1990s recession, while the 2004-2008 subperiod corresponds with the period leading up to the subprime mortgage crisis of 2008.

DISCUSSION

There were four main foci of industrial growth during the study period: Sorrento Valley, Poway, 4S Ranch (between Rancho Bernardo and Rancho Santa Fe), and the extensive industrial area between San Marcos and Carlsbad (SMC). There existed significant industrial area in Miramar prior to 1986, so this does not appear in the analysis. In contrast to the dispersed pattern of residential growth between 1986 and 2017, most industrial development occurred in very localized areas. Outside of the Sorrento Valley area, most occurred relatively recently as well. Nearly all of the Poway industrial center was built between 1995 and 2000, and much of the SMC area was built during the same sub-period. This pattern is echoed in Figure 1.8, as *open-ind* land use change spikes between 1995 and 2000. There was significantly less growth during the 2000-2004 sub-period, then a slight increase during the 2004-2008 sub-period before dropping off through the end of the study period. However, it should be noted here that less spatial growth of industrial land uses does not necessarily mean less change. In many cases, large industrial buildings are subdivided into multiple units following their construction, resulting in greater economic activity but no visible change in the building's area.

Many of the major centers of commercial growth during the study period represent golf courses, as San Diego county is well known for its golf culture. The comparatively larger size of polygons representing golf courses attracts more attention on the land use change map (Figures 1.3-1.5) than other commercial uses like shopping centers or arterial commercial areas. However, as golf courses do not have significant areas of built-up or impermeable surfaces like other commercial land uses, the types of land cover associated with each land use are not strictly comparable. As this chapter is most interested in the relationship between economic growth and land use changes associated with urban and suburban environments, golf courses were classified as commercial for their impact on the local economy and their association with neighborhoods of higher median income. If this chapter's focus was centered more on the biophysical effects of land use and land cover change, the physical attributes of golf course land cover would be of greater importance and these polygons would be classified as open/undeveloped. As a result, the overall loss of open/undeveloped land during the study period would be less significant as open/undeveloped space would be preserved in golf courses.

Most commercial growth of other types (neighborhood, community, and regional shopping centers, arterial commercial, offices, and other retail trade and strip commercial) occurred close to major highways and roads in proximity to residential areas that grew during the same time period. The commercial center southeast of Del Mar was built where the newly developed Carmel Valley and Pacific Highlands Ranch neighborhoods meet Interstate 5. Small polygons of commercial growth also appear within recently developed industrial centers. The Sorrento Valley, south Poway, and SMC industrial centers contain numerous polygons of commercial growth between industrial growth areas. These commercial growth areas may be associated with the construction of office buildings rather than other types of commercial land use, and thus may be more associated with "industry", broadly speaking. These may also represent commercial businesses that operate out of industrial buildings like Costco, Home Depot, or Ikea. Further, commercial recreation businesses like indoor skydiving or rock-climbing gyms require buildings with a large footprint, and thus are often found in industrial parks.

Figure 1.8 also shows the influence of the larger area of golf courses in the overall change in land use from open/undeveloped to commercial (*open-com*). The three other plots of land use change decline between the first and second sub-periods, while the *open-com* plot increases. This is due largely to the fact that two major golf courses were established in the study area between 1986 and 1990 (Del Mar Country Club and Aviara Golf Club). Besides these, commercial growth was minimal until the 1995-2000 sub-period. Total area of commercial growth roughly follows the trend of the other three change plots throughout the rest of the study period, indicating a similar relationship to broader economic or political trends as residential and industrial development processes. The spike in the 2004-2008 sub-period was also driven largely by the development of a single golf course (The Crossings at Carlsbad), and speaks to the fact that the transition from open/undeveloped land to a golf course requires far less material and time investment than development of a residential area. As a result, golf courses are developed more quickly and the plot of *open-com* development in Figure 1.8 varies more between sub-periods than the *open-res* plot. A similar pattern is evident in the *ag-open* plot in Figure 1.8. The fact that the *ag-open* line in Figure 1.8 has the greatest range over short periods of time (e.g. almost 6000 more acres were changed from *ag-open* between 1995-2000 than between 1990-1995, compared to *open-res'* 2500 acres) indicates that this is largely the result of policy or land ownership change, rather than a change tied to physical conditions on the ground. In the case of a large cattle pasture owned by a single landowner, land use change would occur as soon as the landowner sells their land to the city and the city rezones the parcel.

While it is difficult to determine the direct drivers of particular areas of growth within the study area without further data, certain relationships can be inferred. First, there was significant industrial growth in several locations within the study area, and numerous residential communities were constructed in close proximity to these centers. Economic growth in the innovation economy grew substantially between 1986 and 2017, and major firms in the innovation sectors were established in the study area's industrial centers during the same time period. Figure 1.9 shows venture capital investment in the healthcare sector since 1995, and Figure 1.10 shows the results of Casper's (2007) social network analysis of biotechnology firms in San Diego between 1978 and 2007. Using total investment in the sector and the number of biotechnology firms in the area as

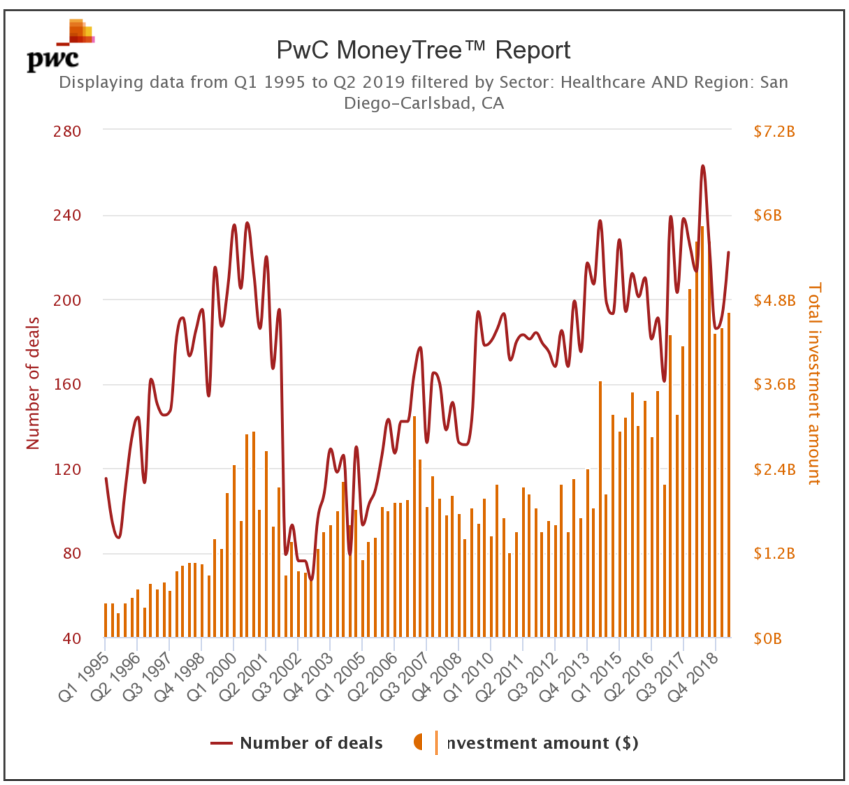

Figure 1.9 *- Venture capital investment in San Diego's healthcare sector, 1995-2019. From PWC Money Tree Report (https://www.pwc.com/us/en/industries/technology/moneytree.html).*

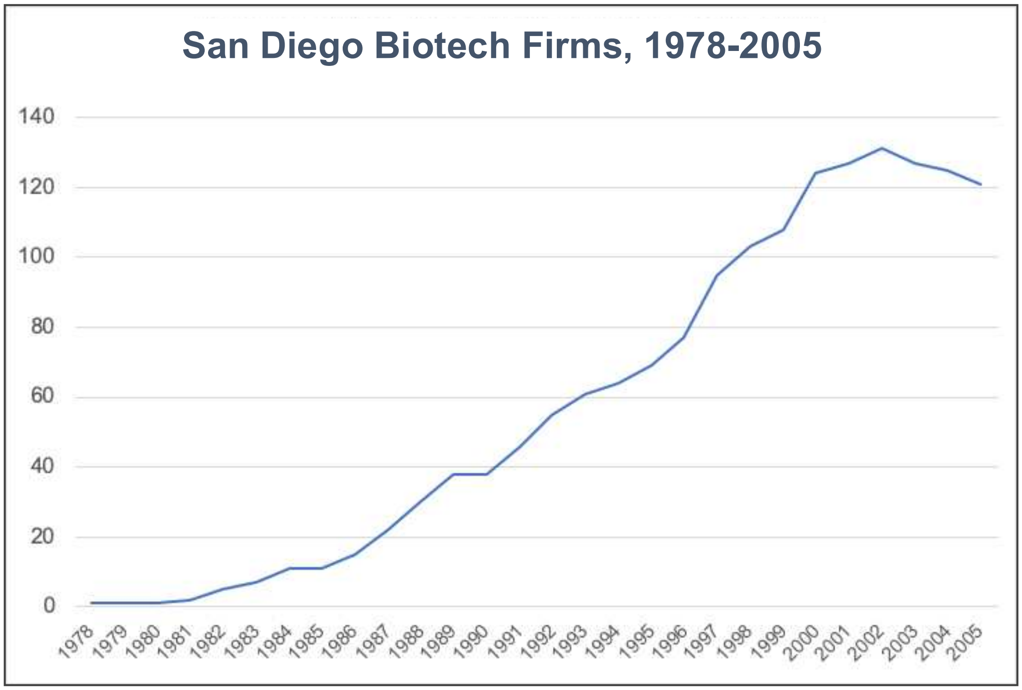

Figure 1.10 *- Number of biotech firms in San Diego, 1978-2005. Data from Casper (2007).*

proxies for economic growth in the innovation sector, it is clear that San Diego experienced substantial growth in recent decades. Further, Walcott's (2002) five key factors for regional economic success in high-tech industries (access to an outstanding research university, advocacy leadership, risk financing, entrepreneurial culture, and appropriate real estate) were arguably present in each of the industrial centers within the study area. Population in the municipalities within the study area also grew significantly and, following Storper's (2013) argument that cities develop first as a network of private firms that drive in-migration, this is likely the result of economic development in the innovation sector.

The Sorrento Valley industrial center was established earliest in the study area. This is most likely because it is closest to UCSD and benefitted from the "social network" industrial cluster processes associated with development in tech sectors (Gordon & McCann, 2000). An industrial cluster produced through the social-network model, as opposed to a "pure agglomeration" or "industrial complex" model, is built upon human capital and shared networking opportunities rather than the maximization of profits or resource extraction. In a social-network cluster, individuals rely upon one another for investment opportunities or research assistance, and thus firms within such a cluster benefit from operating in the same place. There are several significant examples of early UCSD researchers and graduates establishing successful technology firms in the area and providing the foundation for subsequent development in the innovation economy in the manner of Gordon and McCann's (2002) social network model of clustering. Two of these examples are discussed here. First, Irwin Jacobs, a UCSD professor, and Andrew Viterbi founded Linkabit in Los Angeles in the late 1960s (West, 2009). They moved the business to Sorrento Valley in 1970 and spent the next decade building communications technology for NASA and the Department of Defense. Linkabit worked closely with UCSD's engineering department and hired numerous recent graduates. The business was successful, and it expanded to fill several buildings in the area until it was purchased by M/A-COM of Boston, MA. Following the merger, Jacobs and Viterbi, along with several other former Linkabit employees, founded Qualcomm (now a Fortune 500 company) in Sorrento Valley. Another former employee founded ViaSat in Carlsbad, CA and others went on to form their own satellite and communications technology companies in the area. The area remains a globally recognized center of research and development in the field, and its success is linked directly to UCSD and Jacobs' and Viterbi's early work at Linkabit.

Much the same story can be told about the origins of Sorrento Valley's biotechnology sector. Hybritech was founded in 1978 by Ivor Royston, an assistant professor of Immunology at UCSD, and Howard Birndorf, a research technician at the University (Chi, 2007; Kim 2015). Hybritech's early success led to the formation of over 150 other biotechnology firms in the area in subsequent decades through venture capital investment, advocacy by Hybritech leadership, and technology exchange with UCSD research laboratories (Casper, 2007). Much of this sectoral growth occurred before the study period began in 1986, and thus change in Sorrento Valley between 1986 and 2017 largely reflects the later success of firms started through the broader Hybritech social network.

Figure 1.11 shows industrial land uses existing in the Sorrento Valley area in 1986 prior to the change analysis in this study, with the locations of 2017 SANDAG business sites for electronics and biotechnology companies. The electronics business sites fall largely within the areas of industrial development since 1986, while most of the biotechnology businesses are within the 1986 existing industrial area. While the locations of these businesses in 2017 does not necessarily reflect the geography of businesses in 1986 as startups in these environments are commonly unsuccessful, the spatial clustering of business types reflects Gordon and McCann's (2002) social network model. Thus, a certain degree of continuity of localized industrial activity can be inferred. Many of the biotechnology business sites in Figure 1.11 have ties to Hybritech's early 1980s success (Casper, 2007; Chi 2007), while the founding of the electronics companies has more connection to Linkabit's, and then Qualcomm's, success throughout the 80s and 90s. The differential timing of both sectors' spatial proliferation, represented by business site location, is also likely the result of broader trends in the evolution of technology. Early biotechnology firms relied far less on computing power and microelectronics than did electronics firms like Linkabit. The technology that contributed to Linkabit's success did not exist when Hybritech experienced its early achievements, so the presence of biotechnology companies in the older industrial areas may indicate this technological lag. The fact that the other three industrial centers expanded later than the Sorrento Valley center indicates that they benefited more from the already existing regional success of the innovation economy than from interaction with UCSD researchers and Department of Defense contracts.

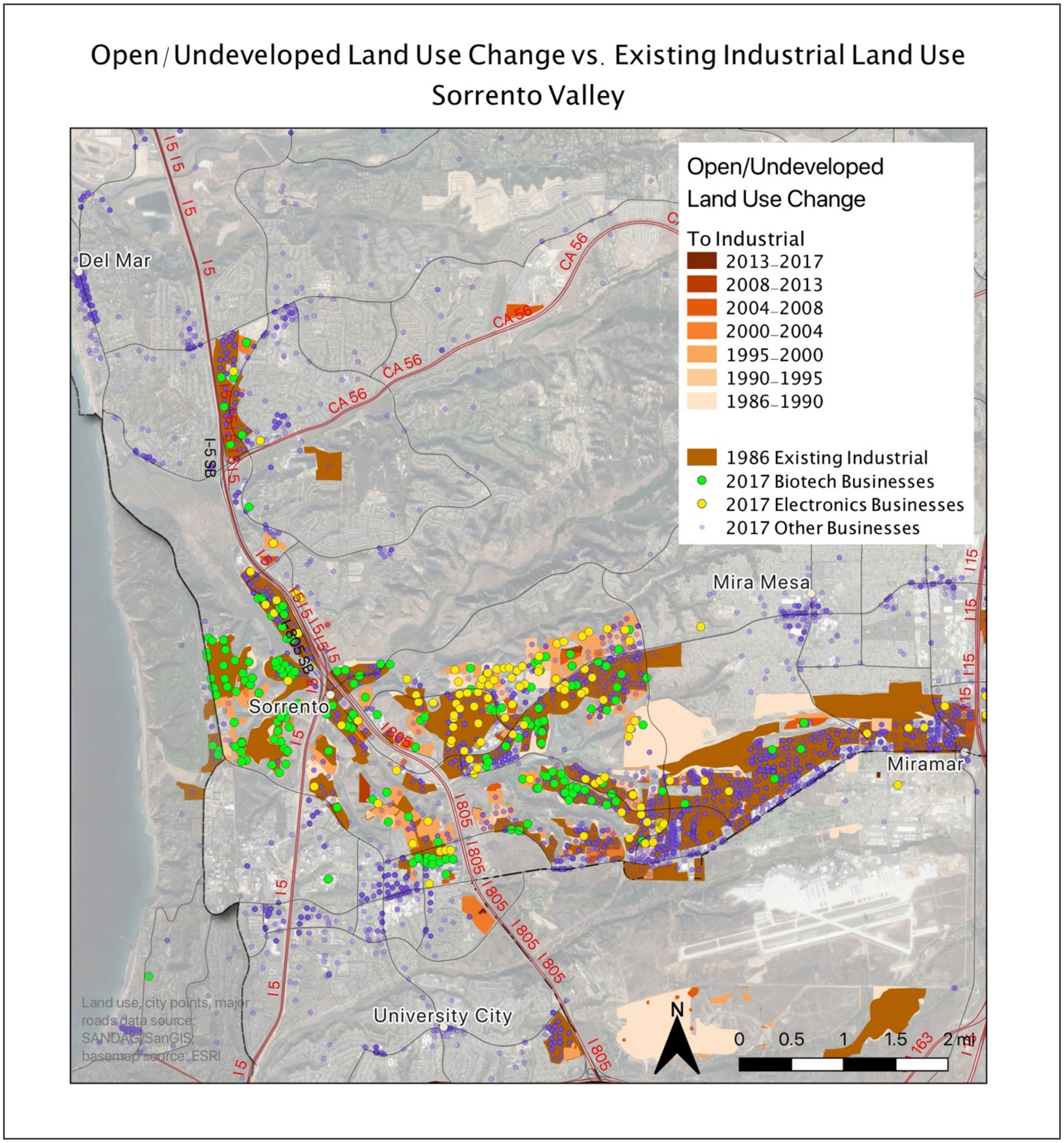

Figure 1.11 *- Open/undeveloped to industrial land use change in the Sorrento Valley area, with 2017 biotechnology and electronics business sites*

Walcott's (2002) five key factors contributed to the development of the biotechnology and electronics sectors where access to a research university was greatest, and where real estate was most appropriate. As the Sorrento Valley and surrounding areas closest to UCSD were largely undeveloped in the 70s and 80s, industrial clusters associated with the university could form in close proximity. Early planning efforts in the area established the Scientific and Research Zone adjacent to the university in Torrey Pines in which only research-related and supporting facilities may be located (Kim, 2015). As residential and other built-up areas expanded in response to rising population and the growing economy, new industrial clusters had to develop further away in concert with growing regional planning efforts. The Poway industrial center exemplifies this trend, as it was almost entirely undeveloped prior to 1986, and most development occurred after 1995. The businesses in this area also seem to be more associated with consumer goods, retail, and other professional services than research-based technology of the innovation economy. General Atomics' Aeronautical Systems Inc. is headquartered in the business park, as are a number of other electronics manufacturers and laboratories, but most are smaller businesses, public storage facilities, and indoor recreation centers. Figure 1.12 shows industrial land use change in the Poway business park and 2017 business sites, with electronics and biotechnology businesses highlighted yellow and green, respectively.

The differences between the Sorrento Valley and Poway industrial centers, in terms of types of businesses and timing of development, illustrates the multidirectional nature of economic and population growth as drivers of urban expansion. The Sorrento Valley industrial center may be understood through the social-network model of agglomeration (Gordon and McCann, 2000) supported by Walcott's (2002) key factors for regional success in the innovation economy. Successful development of the biotechnology and electronics sectors in the area strongly contributed to population growth in the county as a whole throughout the 80s and 90s, as employment opportunity is a strong driver of in-migration (Storper, 2013; Chen & Rosenthal, 2008). Sufficient population growth then drove demand for housing, and residential development occurred through master-planned communities like Carmel Valley, Miramar Ranch, and Pacific

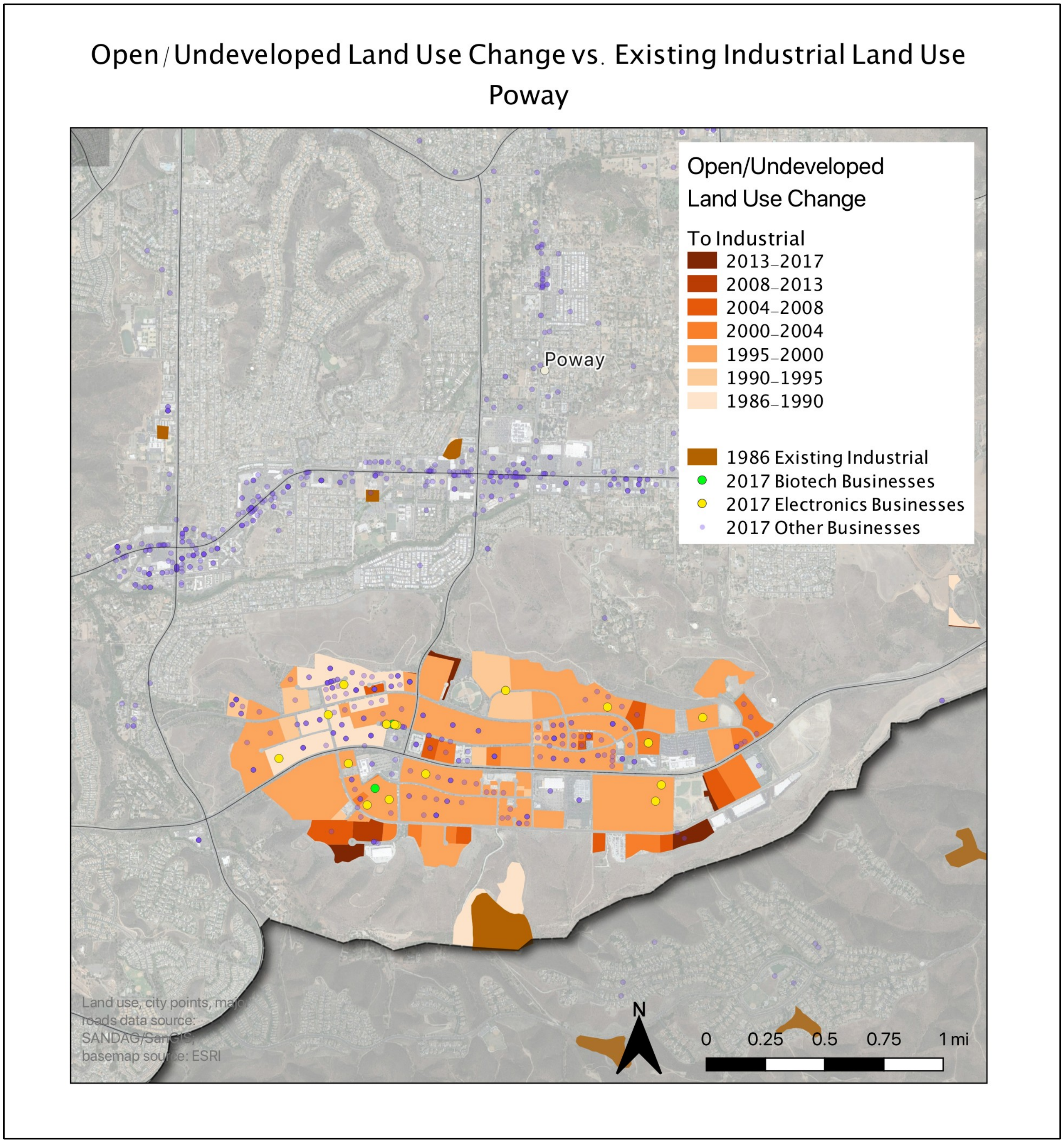

Figure 1.12 *- Open/undeveloped to industrial land use change in the Poway industrial center, with 2017 biotechnology and electronics business sites.*

Highlands Ranch. Development of the Poway business park amidst this residential expansion in the surrounding areas may be understood as a response to growing demand for an industrial center that caters to local residents, rather than as a driver of population growth through employment opportunities. This would explain the presence of many more retail businesses and consumer goods suppliers than the Sorrento Valley industrial center. Further research is needed to confirm this relationship, but the evidence from this analysis seems to indicate a multidirectional relationship between industrial and residential growth.

The SMC industrial center, while furthest from UCSD, has elements of the five key factors (Walcott, 2002) necessary for regional success in the innovation economy. This area, also referred to as the 78-corridor for state highway 78 that runs through it, includes areas of Carlsbad, Oceanside, San Marcos, Vista, and Escondido. The study area only includes San Marcos and Carlsbad, as much of the area included in the SRAs for Escondido, Oceanside, and Vista was already built-up before 1986 or includes a large portion of the rural residential area to the east and thus was not of interest for this analysis. Most of the industrial developments in this region were built after 1995, and major employers include IT and telecommunications companies Viasat, MaxLinear Inc., Ipitek, Verisk3E, and Leidos, and biotechnology companies Genoptix, ThermoFisher Scientific, OptumRX, and Genentech.

Two major establishments in north San Diego County are significant in the SMC region's growth in the innovation economy in terms of research, financing, and leadership. The first is Camp Pendleton, the Marine Corps base that occupies a vast swath of northern San Diego county. The southern entrance to Camp Pendleton is in Oceanside, several miles north of the SMC industrial center in Figure 1.5. As a locus for military training and technology testing, the base works closely with San Diego county companies to produce command and control systems, weapons detection systems, unmanned vehicles, and cybersecurity. In a sense, Camp Pendleton fills the critical role of Walcott's (2002) risk financing body, as Department of Defense contracts support numerous technology companies in the area. As the region's single largest employer, Camp Pendleton is also directly responsible for some of the residential development in the study area, as Marines seeking housing off-base drive demand for new homes within commuting distance.

Second, major centers of higher education in the area including Cal State San Marcos, Palomar College, and MiraCosta College draw students and researchers to the area and serve as Walcott's (2002) key factor of "access to a research university". Cal State San Marcos was established in 1989 following its founding as a North County satellite campus of San Diego State University in 1978. As a fully accredited 4-year research university, there is significant information sharing amongst researchers and local startups. Further, Innovate78 claims that 83% of alumni remain in the area after graduation. This contributes to the "entrepreneurial culture" and, following initial success of regional tech firms like Viasat, "advocacy leadership" by individuals invested in the successful development of the region.

Residential expansion in the areas surrounding the SMC industrial center may also be evidence of the region's industrial growth. The San Elijo Hills development, located roughly due south of the center of San Marcos, was built most recently and will have 3466 homes when it is complete (www.san-marcos.net, n.d.). The Santa Fe Hills community, located northwest of San Marcos, and Rancho Carrillo and Bressi Ranch communities, located just south of the industrial center, are also examples of recent master-planned community developments. The fact that new residential developments were constructed is not itself strong evidence that industrial growth in the area drove residential growth during the study period. Taken together, however, the two forms of growth point to a broader system of economic development that has attracted people to the area. It is likely that particular residential developments were then constructed to meet regional demand, while the developments' specific form on the landscape was shaped by city or county institutions and planning efforts.

Much of northern San Diego County, including rural areas outside of the 78-corridor cities, contributed significantly to the county's agricultural production until at least the 1990s (Pryde, 1992). This meant that large parcels of undeveloped land remained in private ownership while numerous other suburban areas throughout the county were being developed to meet housing demands. As demand continued to grow with a rising population and economic growth in the innovation sectors, landowners in San Marcos, Carlsbad, and the undeveloped region between them were in a position to sell their land to developers. As such, recent residential development in much of the study area, and the county as a whole, is likely the result of early success in the industrial areas surrounding UCSD that drove a regional demand for housing beyond these areas. It may also be the case that industrial growth in the SMC area was driven in part by a growing local population of specialists with ties to the "innovation" economy associated with UCSD. However, further research is needed to understand the specific directions of influence in this context.

CONCLUSION

Urban expansion, defined as the transition of land uses not primarily associated with human activity to land uses that are primarily associated with human activity, is a complex process. In San Diego county, urban expansion over the previous three decades was the result of several interconnected drivers operating at multiple scales. In the context of economic growth in the county's innovation sectors, urban expansion may be understood as both a driver and a result of in-migration by people seeking employment. Land use planning and policies also influence where urban expansion occurs, resulting in a spatially heterogeneous urban form in a county as large as San Diego. In this chapter I examined the drivers of urban expansion in one region of San Diego County primarily associated with the innovation economy and UCSD. I utilized spatial analysis in QGIS to quantify land use transitions of six different land use classes: residential, industrial, commercial, agricultural, open/undeveloped, and other. The results indicate that industrial growth occurred first in the Sorrento Valley area, closest to UCSD, with large areas of residential expansion further away. Industrial centers in Poway, 4S Ranch, and San Marcos-Carlsbad developed in subsequent years, as did residential infill throughout the study area.

Following Walcott's (2002) framework for the five key factors necessary for success in the "innovation" economy, I posed the question of whether industrial expansion in the study area was driven by growth in the innovation economy, and whether simultaneous growth in population and the innovation economy were reflected in similar rates of residential and industrial expansion throughout the study period. The results of this analysis seem to indicate that both are true, as early development and economic success of the innovation sector in Sorrento Valley created the conditions for later success in other parts of the county. This also drove demand for housing beyond the communities surrounding Sorrento Valley, particularly in the northern section of the study area where undeveloped land was more plentiful. The degree to which these relationships are true for particular areas of growth is difficult to determine without further research. However, the results of this study indicate that growth in San Diego's innovation economy was a primary driver for overall urban expansion in the study area between 1986 and 2017.

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CHAPTER 3 – OTAY RANCH, SAN DIEGO: POLICIES, INSTITUTIONS, AND PATH DEPENDENCY AS DRIVERS OF URBAN EXPANSION, 1986-2017

INTRODUCTION

Land change scientists are increasingly interested in urban growth and the drivers responsible for urban land use transitions (Heilig, 1994; Seto & Fragkias, 2005; Cohen, 2006; Seto, Sánchez-Rodríguez, & Fragkias, 2010). The transition of native or vegetated landscapes to built environments associated with urban systems has significant consequences (Grimm et al., 2008a), particularly for water resources (Shuster et al., 2005; Arnold & Gibbons, 1996), flooding (Zhang et al., 2018), biodiversity (Mcdonald, Kareiva, & Forman, 2008; Grimm et al., 2008b), and local (Chen et al., 2006) and global (Svirejeva-Hopkins, Schellnhuber, & Pomaz, 2004; Dodman, 2009) climate change. Understanding the drivers responsible for urban expansion is crucial if these challenges are to be addressed.

Myriad drivers of urban expansion have been explored in the literature (Seto et al., 2011; Colsaet et al., 2018). While population and economic growth are often studied as primary drivers of urban expansion (Deng et al., 2008; Angel et al., 2011; Kuang et al., 2014), Colsaet et al. (2018) found that the most commonly cited drivers of urban land change are policies and institutions related to regulation, incentives, direct public intervention, and governance (Pendall, 1999; Chou and Chang, 2008; Wassmer, 2016). The authors also review several articles in which path dependency played a significant role in urban expansion (e.g. Hernando et al., 2014; Paulsen, 2014). These case studies found that urban density in the past was negatively correlated with future spatial expansion while less dense areas expanded further, keeping density consistent in both cases. The momentum of path dependency in an urban expansion context, however, results in spatial heterogeneity of more-dense and less-dense areas as urban expansion encounters physical or political boundaries (steep slopes, water, protected areas, etc.). Thereafter, demand for development rises in those areas of lower density resultant of past path-dependent land systems that limited urban expansion. Rapidly growing cities of heterogeneous density are more likely to experience urban expansion in these low-density areas simply because they contain more land to develop.

The case of Otay Ranch and the surrounding areas of Chula Vista, CA (located between the city of San Diego and the U.S-Mexico border) offers a unique instance of urban expansion in which policies and institutions (PIs) and path dependency (PD) were the drivers primarily responsible for local urban form. In this chapter, I review the literature on PIs and their role in regulating urban expansion, and PD and the impact of the past on present land use. I then briefly outline the history of land tenure in Otay Ranch in the context of the Alta California Rancho system and trace the land tenure changes and accompanying PIs that drove urban expansion to its present form. I utilize GIS to quantify the locations and types of urban land use transitions that occurred in Otay Ranch between 1986 and 2017 and discuss the specific drivers responsible for these transitions using qualitative interview data and a review of documents pertaining to Otay Ranch's history of change and development. I argue that, while population growth related to economic development is the underlying driving force (Geist & Lambin, 2002) of urban land change, the interrelated mechanisms of path dependency, policies, and institutions are the proximate causes that determine how and where urban expansion actually happens.

DRIVERS OF URBAN EXPANSION

Policies and Institutions

Policies and institutions are the most mentioned instrument of urban expansion in Colsaet et al.'s (2018) meta-analysis, as central planning institutions are ultimately responsible for regulating how land is used. Competition and lack of coordination between local municipalities also contributes to urban expansion through what the authors call a "classic prisoner's dilemma" (Colsaet et al., 2018: 346). Each regional administrative unit pursues development policies that provide the greatest local benefits, allowing a greater amount of land use change than is optimal in terms of balancing societal needs and landscape conservation. The degree of fragmentation amongst administrative units in an urban area similarly contributes to greater expansion through lack of communication and coordination of efforts (Hersperger & Bürgi, 2009). For example, Carruthers (2003) found that local planning agencies enact land use regulations that reflect their residents' preference for low density suburban living, which manifests as greater development on the unincorporated fringes of urban areas where land is inexpensive or undeveloped. Further, the more that fragmented administrative units rely on local taxes for their budget, the more they offer inexpensive land and incentives to developers in order to bolster their tax base (Downs, 1999).

In the case of San Diego County, planning has had an enormous influence on the County's present-day urban form. In *Paradise Plundered: Fiscal Crisis and Governance Failures in San Diego,* Erie et al. (2011) argue that fiscal mismanagement and political competition in the city indirectly drove urban sprawl while government actors neglected much needed infrastructure improvements and redevelopment of inner-city neighborhoods. Caves (1992) traces the revolution of voter-driven land use planning initiatives as a response to political inaction and irresponsible development in San Diego, with the ultimate goal of accommodating "smart growth" rather than simply regulating growth regardless of type or location. Calavita et al. (2016) offer an updated perspective on smart growth in San Diego including specific challenges arising from smart growth planning, while Troutman (2015) details the political, economic, and administrative conflicts that undermined planning efforts toward smart growth during the 1990s and 2000s. Despite these conflicts, decision-making power remains with planning officials and local political actors guided by land use policies, and actually occurring urban expansion in San Diego is ultimately the result of these policies and institutions.

Path Dependency, Historical Land Tenure, and the California Rancho System

Colsaet et al. (2018) also discuss the concept of path dependency as a driver of urban expansion. As a theoretical framework, path dependency offers an approach to understanding the present form of a landscape as the outcome of a series of sociopolitical actions on the landscape throughout its history (Zarina, 2010; Palang et al., 2011). In the context of San Diego County, and much of California, the development of urban and peri-urban areas has direct ties to the Spanish Rancho system. Starting in 1784, Spanish officials began allocating large parcels of land in Alta California to high-ranking military officials and other allies of the government (Brackett, 1939; Christenson & Sweet, 2008). Allocation increased after Mexican independence in 1821, and most of the ranchos in San Diego county were allocated during this time. See figure 2.1 for a map of San Diego county Ranchos.

The present form of Otay Ranch as a late-20th century suburban development has direct historical ties to the 23,000-acre Rancho Otay, originally allocated to Doña Magdalena Estudillo in 1829. Throughout San Diego County's development history, the presence of other Ranchos as large, undeveloped pastoral landscapes offered significant possibilities for developers once an adequate market of new homebuyers had been established in the county. The community of Rancho Peñasquitos, for instance, was developed in the 1970s after Irving Kahn, a major San Diego real estate developer, purchased the Rancho land from two cattle ranchers who were themselves only the latest owners in a long history of land transfer (Friends of Los Peñasquitos Canyon Reserve, n.d.). The communities of Rancho Santa Fe, Rancho

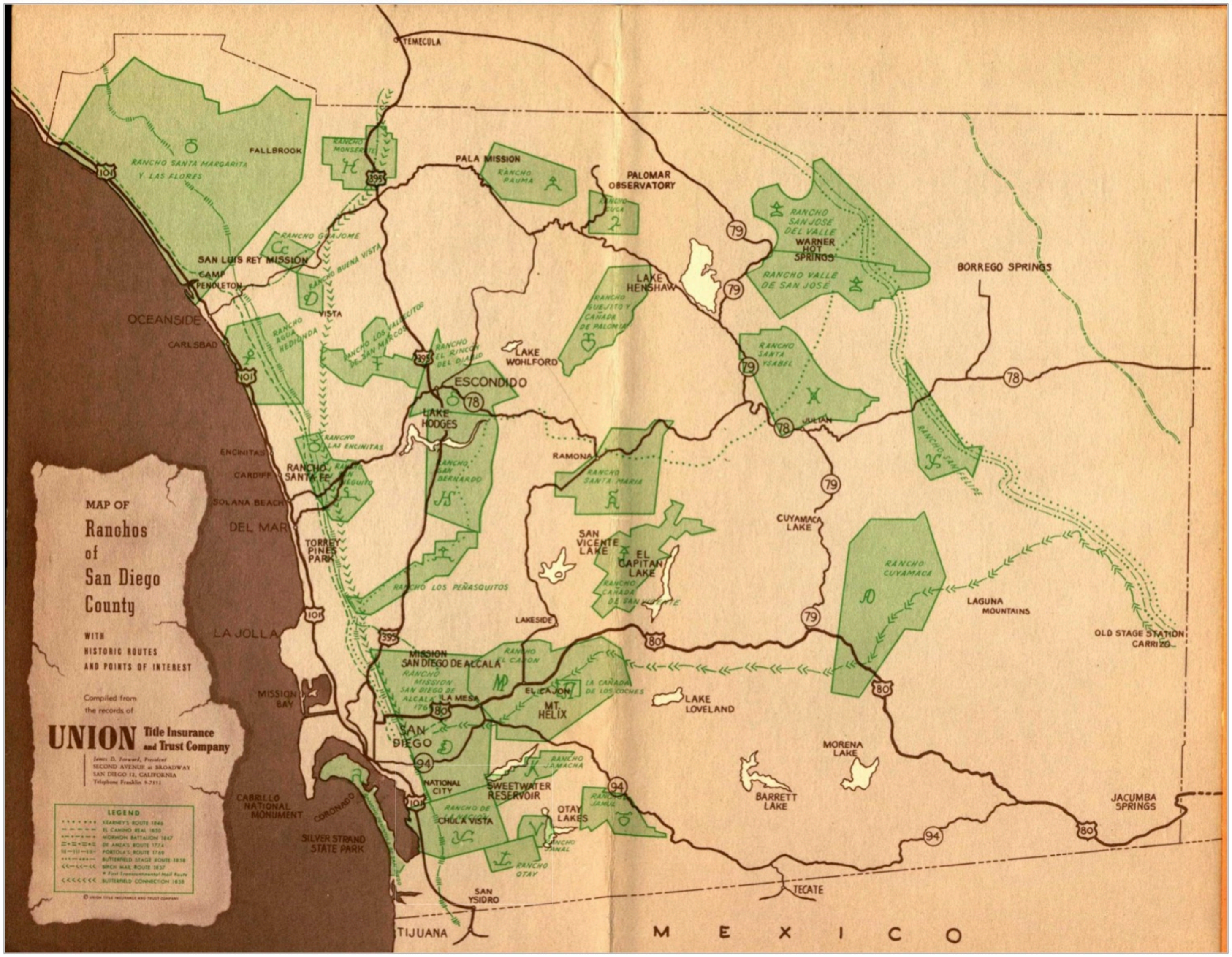

***Figure 2.1** - The Ranchos of San Diego County. Rancho Otay is visible as the rectangular land parcel closest to the U.S.-Mexico border. Map from Brackett (1939).*

San Diego, Rancho Bernardo, Encinitas, El Cajon, and National City were built on land previously allocated in the Rancho system and retain names derived from the original Rancho title. Other authors have traced the historical geographic influence of the Spanish Rancho system (Hornbeck, 1978) and examined its influence in agricultural systems in California more broadly (Allen, 1935), and the urban form of Los Angeles (Nelson et al., 1964), but no research that I am aware of contextualizes the contemporary urban form of San Diego within this historic land tenure system.

PIs and PD as a Framework for Urban Expansion in Otay Ranch

As two commonly cited drivers of urban expansion, path dependency and policy/institutional factors (including urban planning) offer a powerful framework for understanding urban expansion in Otay Ranch and surrounding areas. Landscape path dependency is related to land use planning and governance in the case of San Diego through the preservation of large rancho parcels through recent history when land use planning grew in importance vis a vis the need to regulate where residential, commercial, and industrial developments could happen. A single thousand-acre parcel in San Diego county in the 1950s had little consequence on where development happened because demand for housing could be met through existing parcels already owned by the city. As population and local economy grew, demand for housing (especially single-family units) also grew and developers began soliciting the sale of these large, single-owner parcels for master-planned community development. These proposed developments had to then be approved by city planning processes, and thus the developments most responsible for spatial expansion of San Diego county’s urban areas are planned communities sitting on land previously allocated under the Spanish Rancho system many decades before. In this sense, landscape path dependency is perhaps more significant than policies or institutions in determining *where* urban expansion occurs at a regional scale, while PIs determine *how* development plays out. Figure 2.2 shows the conceptual framework for urban expansion at different scales in the Otay Ranch area, highlighting the path dependent role of historical land tenure on geographies of potential urban development, and political and institutional factors responsible for regulating the form of urban development that actually takes place.

In the remainder of this chapter, I quantify urban expansion in the Otay Ranch area between 1986 and 2017 and argue that the combination of historic land tenure associated with the Rancho system and local planning and institutional practices ultimately drove urban expansion to its present form. The two guiding questions for this case study are: 1.) Did most residential development occur within the Otay Ranch parcel? And 2.) Did industrial growth occur primarily along the U.S.-Mexico and increase after 1994 and the signing of NAFTA?

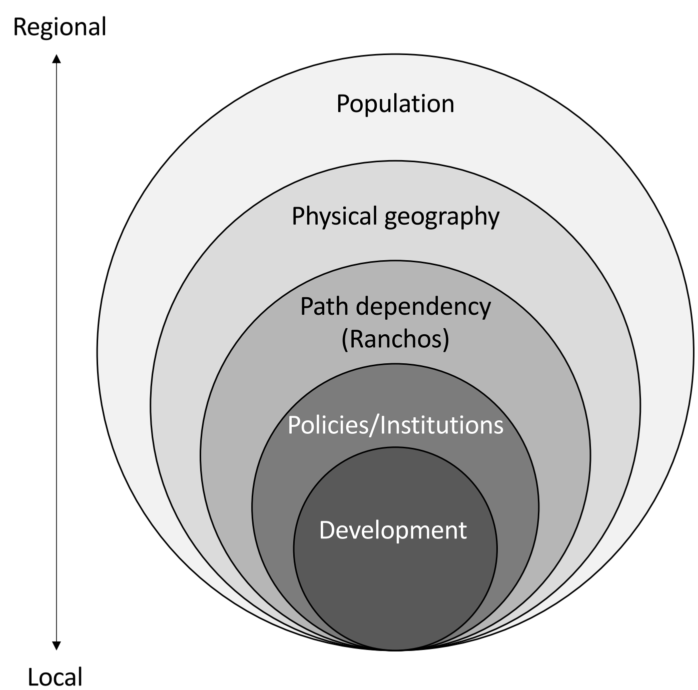

Figure 2.2 – *Conceptual model of the drivers of urban expansion at different scales within the Otay Ranch region.*

METHODS

The San Diego Association of Government's (SANDAG) "SanGIS" data warehouse archives numerous GIS layers for the county of San Diego including land use, major roads, and municipal boundaries, and much of this data was used for the analysis. First, land use shapefiles were downloaded for the years 1986, 1990, 1995, 2000, 2004, 2008, 2013, and 2017, as were the county's sub-regional areas (SRAs) layer adopted from the Census Bureau. A smaller study area boundary was created from the SRA layer to narrow the focus of this analysis to Otay Ranch and the surrounding areas. The SRAs included in the study area are "Chula Vista", "Jamul", "South Bay", and "Sweetwater". The eight land use layers were clipped to this study area and were used as the basis for remaining analyses.

Polygons within each land use layer were then classified into one of six classes: residential, commercial, industrial, agricultural, open/undeveloped, and other. Several land use attributes were ambiguous (e.g. "Residential Recreation" could fit equally well in residential, open/undeveloped, or other classes; "Golf Course" could fit in commercial or open/undeveloped classes), but these represented a small percentage of total land use in the study area, and so were assigned the most relevant class and kept consistent for each study year. See table 2.1 for land use designations assigned to each class in 1986 and 2017 (2017 contains the most unique land use designations of any study year, so interstitial years' land use designations are captured in the 2017 list. 1986 and 2017 are presented to show the significant increase in land use designations during the study period). Each class was assigned a land use code (LUCode) (1-6), and codes were added to each layer's attribute table. In order to facilitate change analyses between years, each year's LUCode was assigned a unique factor of ten starting with 1986 in the ten million's place (e.g. "10000000") through 2017 in the one's place (e.g. "1"). As a result, it was possible to conduct overlay analyses with layers from multiple years and retain land use class information from each year in the output. Once each year was classified by land use type, area attributes for each land use were calculated and extracted as CSVs for analysis in Microsoft Excel.

Table 2.1 *- SanGIS land use designations assigned to each class. All study years between 1986 and 2017 include land use designations represented by the 2017 table, so are not shown here.*

Land Use Attributes by Class, 1986 and 2017			Total/class
1986	Other	AIRPORTS, BAYS, LAGOONS, COMMUNICATIONS AND UTILITIES, ELEMENTARY SCHOOLS, FREEWAYS, GOV'T OFFICE/CIVIC CENTER, HIGH SCHOOL, HOSPITALS, JUNIOR COLLEGE, JUNIOR HIGH SCHOOLS AND MIDDLE SCHOOLS	11
	Residential	MOBILE HOME PARKS, MULTI-FAMILY RESIDENTIAL, RESIDENTIAL UNDER CONSTRUCTION, SINGLE FAMILY RESIDENTIAL, SPACED RURAL RESIDENTIAL	5
	Agricultural	FIELD CROPS, INTENSIVE AGRICULTURE	2
	Industrial	EXTRACTIVE INDUSTRY, HEAVY INDUSTRY, INDUSTRIAL UNDER CONSTRUCTION, JUNKYARD/DUMP/LANDFILL, LIGHT INDUSTRY, LIGHT INDUSTRY-GENERAL	6
	Commercial	CASINO, COMMERCIAL, COMMERCIAL RECREATION, GOLF COURSES, HOTEL/MOTEL (LO-RISE), OFFICE, REGIONAL SHOPPING CENTERS, WHOLESALE TRADE	8
	Open/Undeveloped	OPEN SPACE PARKS & PRESERVES, PARKS, PARKS-PASSIVE, UNDEVELOPED LAND	4
2017	Other	Bay or Lagoon, Cemetery, Communications and Utilities, Elementary School, Fire/Police Station, Freeway, General Aviation Airport, Government Office/Civic Center, Hospital - General, Junior College, Junior High School or Middle School, Lake/Reservoir/Large Pond, Library, Marina, Military Airport, Military Use, Mixed Use, Olympic Training Center, Other Health Care, Other Public Services, Other Recreation - High, Other School, Other Transportation, Park and Ride Lot, Parking Lot - Structure, Parking Lot - Surface, Post Office, Rail Station/Transit Center, Railroad Right of Way, Religious Facility, Residential Recreation, Road Right of Way, Road Under Construction, School District Office, Senior High School, Water	35
	Residential	Jail/Prison, Mobile Home Park, Multi-Family Residential, Multi-Family Residential Without Units, Other Group Quarters Facility, Residential Under Construction, Single Family Detached, Single Family Multiple-Units, Single Family Residential Without Units, Spaced Rural Residential	10
	Agricultural	Field Crops, Intensive Agriculture	2
	Industrial	Extractive Industry, Heavy Industry, Industrial Park, Industrial Under Construction, Junkyard/Dump/Landfill, Light Industry - General, Warehousing	7
	Commercial	Arterial Commercial, Automobile Dealership, Casino, Commercial Under Construction, Community Shopping Center, Golf Course, Golf Course Clubhouse, Hotel/Motel (Low-Rise), Neighborhood Shopping Center, Office (Low-Rise), Other Retail Trade and Strip Commercial, Public Storage, Regional Shopping Center, Service Station, Specialty Commercial, Wholesale Trade	16
	Open/Undeveloped	Beach - Active, Beach - Passive, Landscape Open Space, Open Space Park or Preserve, Park - Active, Undevelopable Natural Area, Vacant and Undeveloped Land	7

Change analyses between each adjacent study year (e.g. 1990 and 1995; 2008 and 2013) were then conducted in QGIS 3.8 using the GRASS GIS v.overlay tool. The resulting change layers contained LUCode attributes from both years, and these were added together into an "LUChange" value representing the change vector between the two years. Lastly, overlays were dissolved by LUChange values to produce the final change layers containing one record for each change vector. Geometry attributes were added to these and exported as CSV files.

To understand the drivers of the change evidenced by the land use change maps, two semi-formal interviews were conducted with city planners from San Diego county. The first (hereafter referred to by the pseudonym "G.G. Planner") works for the city of San Diego and has worked most recently on planning in the Carmel Valley region but began her career on the Otay Ranch development in the 1990s. The second (hereafter referred to as H.H. Planner) works for the city of Chula Vista and has spent his entire planning career on the Otay Ranch development. The information obtained from these interviews guided further document analysis and review of news articles, land and resource management plans, and other "grey" area literature pertaining to urban development in Otay Ranch and the surrounding areas. In the remaining sections I first present the findings from the GIS analysis, then discuss the drivers of land use change in the context of information gathered through these interviews and review of other literature.

RESULTS AND DISCUSSION

Figures 2.3 through 2.10 show maps of classified land use for each study year, and table 2.2 shows the areas for each class per year. Figures 2.11 and 2.12 plot the total area of each land use class by year, and relative proportion of each class by year within the study area, respectively. Figure 2.13 shows open/undeveloped change to residential, commercial, and industrial land uses, and figure 2.14 shows agricultural to open/undeveloped change. Figure 2.15 plots the areas of '*ag-op*', '*op-res*', '*op-com*', '*op-ind'*, and '*ag-res*' change vectors during each sub-period. As expected, there are myriad areas of change between 1986 and 2017 representing dozens of specific case studies of land use change. A survey of each case of change is beyond the scope of this research, so I will focus on broad trends of change within land use classes and highlight specific examples where necessary to illustrate a point.

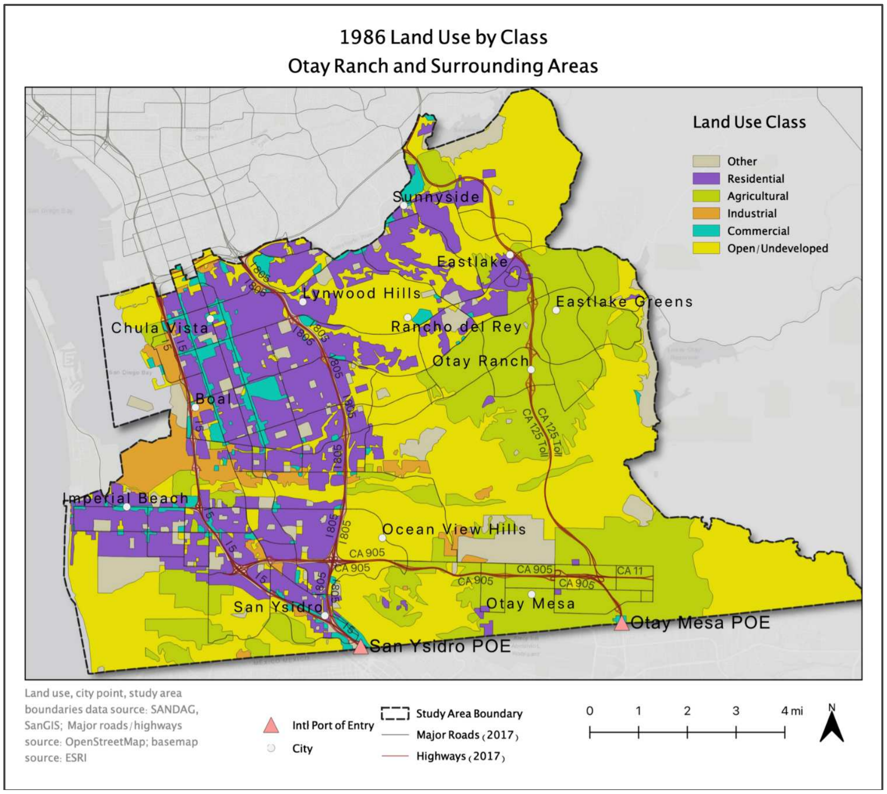

Figure 2.3 *- 1986 land use by class*

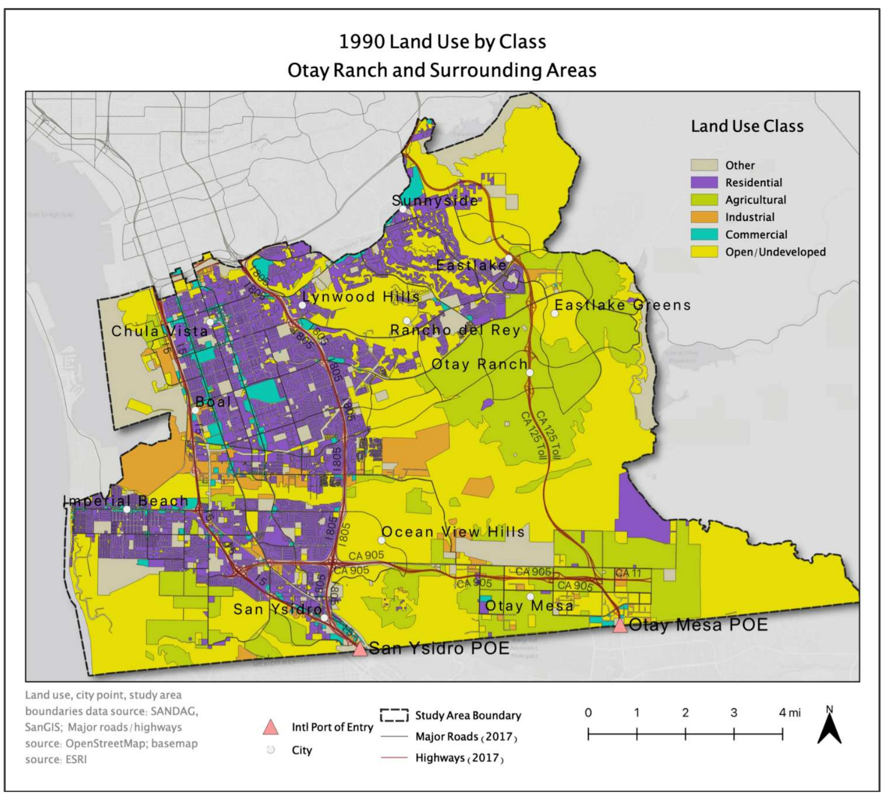

Figure 2.3 *- 1990 land use by class.*

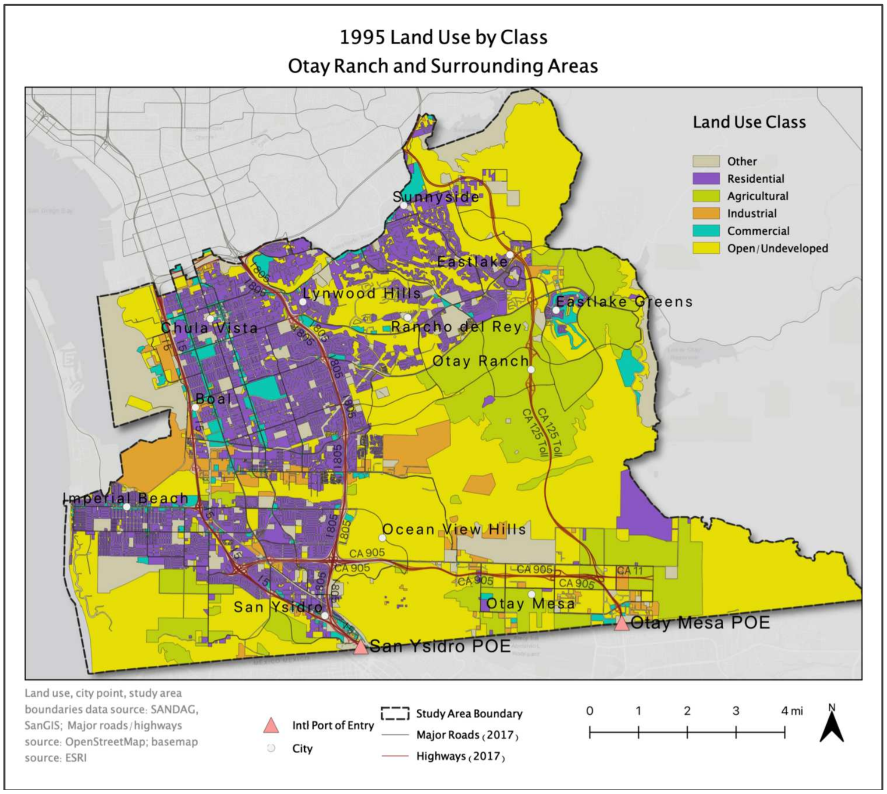

Figure 2.4 - *1995 land use by class.*

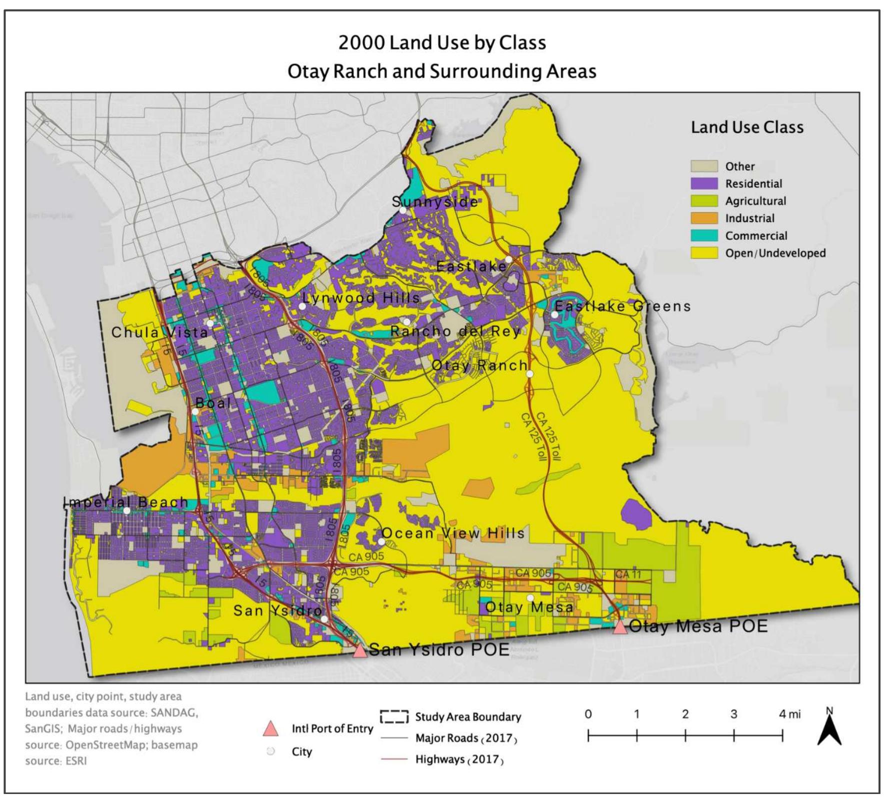

Figure 2.5 - *2000 land use by class.*

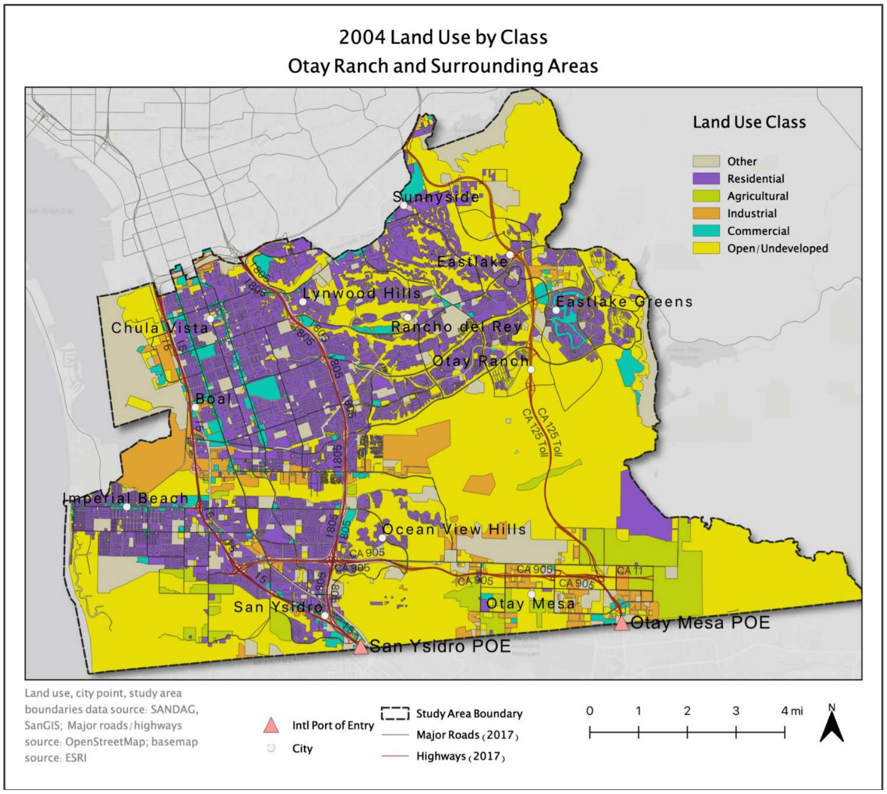

Figure 2.6 *- 2004 land use by class.*

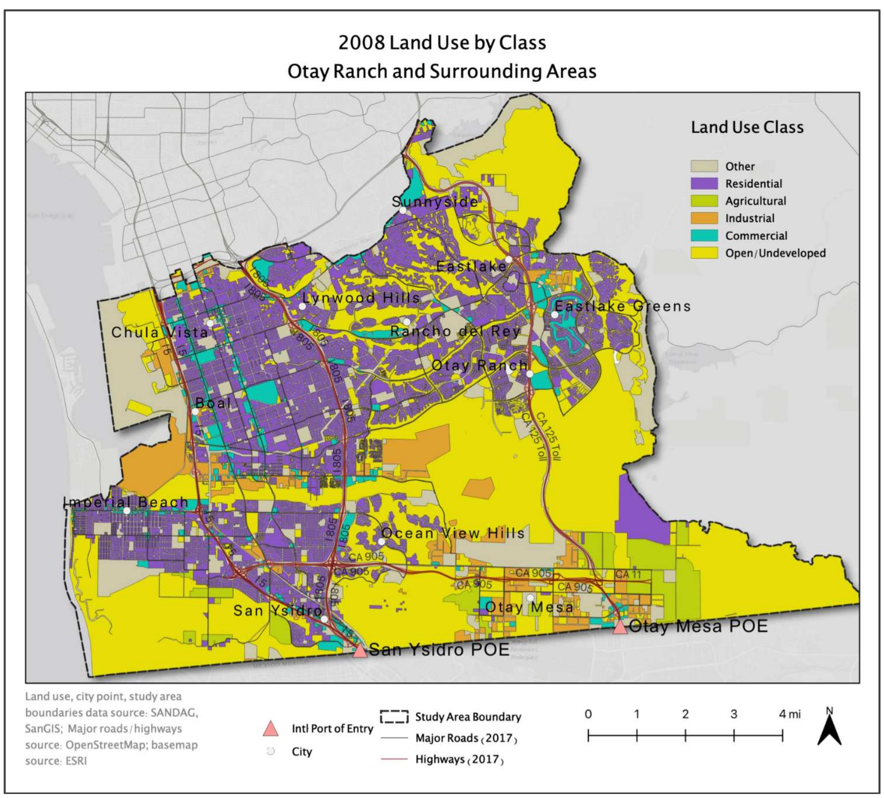

Figure 2.7 *- 2008 land use by class.*

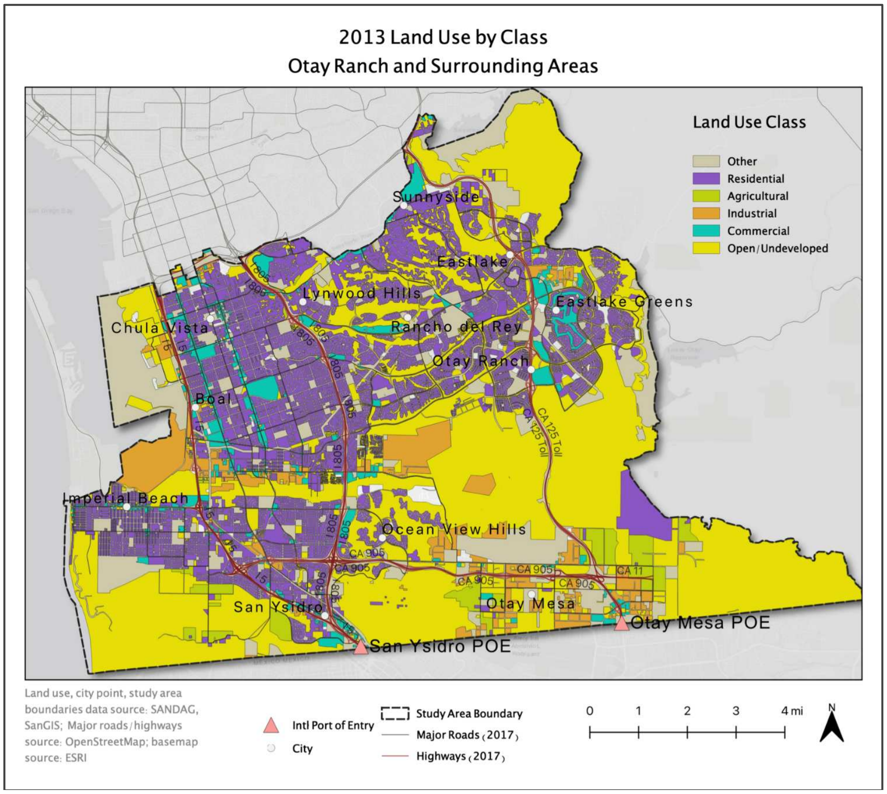

Figure 2.8 *-2013 land use by class.*

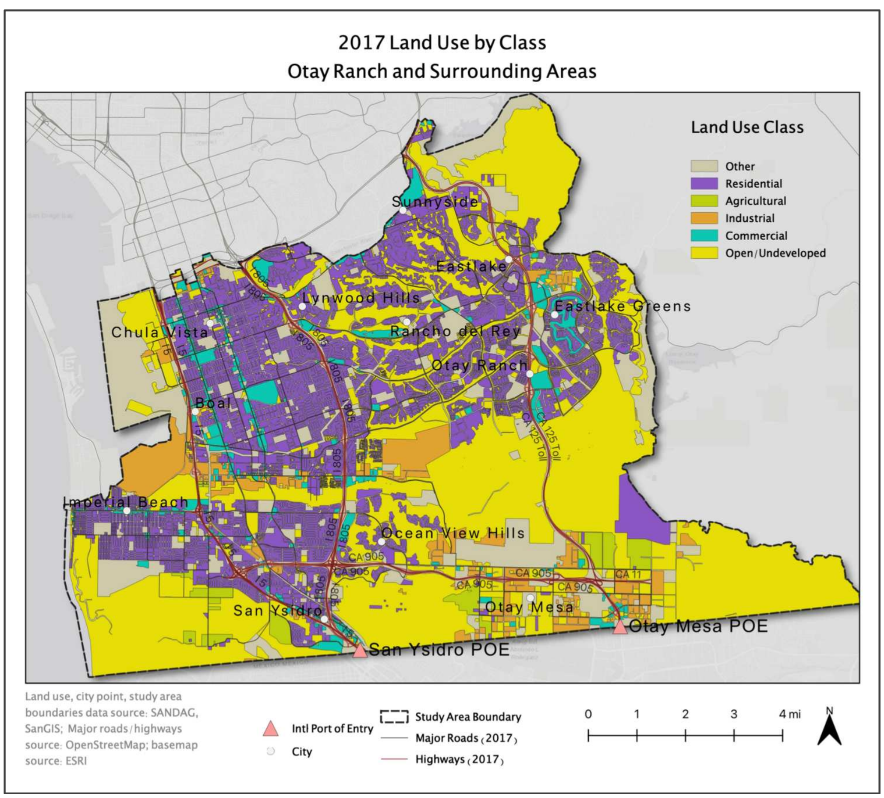

Figure 2.9 *- 2017 land use by class.*

Table 2.2 - *Land use class acreage by study year.*

	1986	1990	1995	2000	2004	2008	2013	2017
Oth	5147.10	11709.09	12124.43	13487.21	14198.61	16090.05	16549.45	17161.89
Res	13769.83	11163.88	11600.51	12353.44	14164.37	14964.80	15313.87	15740.87
Ag	16383.46	13005.94	10324.13	3301.83	2969.81	2155.60	1437.42	1171.51
Ind	2298.43	2735.98	2972.05	3281.11	3445.07	3648.73	3615.54	3503.53
Com	2083.32	1408.08	1897.63	1813.81	2167.40	2291.46	2282.10	2374.55
Open	26949.29	27889.21	28991.95	33674.06	30966.90	28729.85	28118.46	27960.30
TOTAL	**66631.43**	**67912.19**	**67910.72**	**67911.47**	**67912.15**	**67880.48**	**67316.84**	**67912.66**

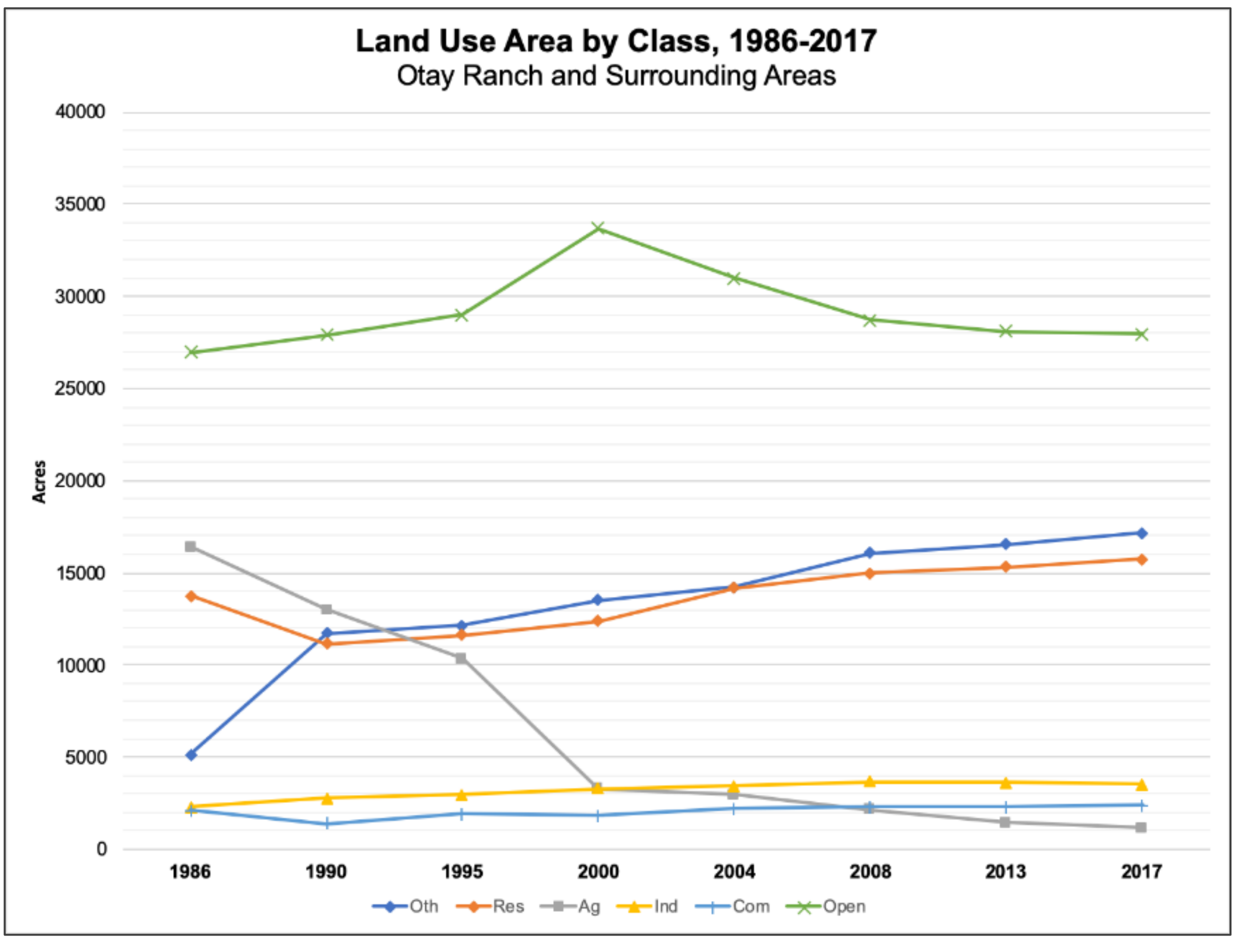

Figure 2.10 *– Line plot of land use class acreage by study year.*

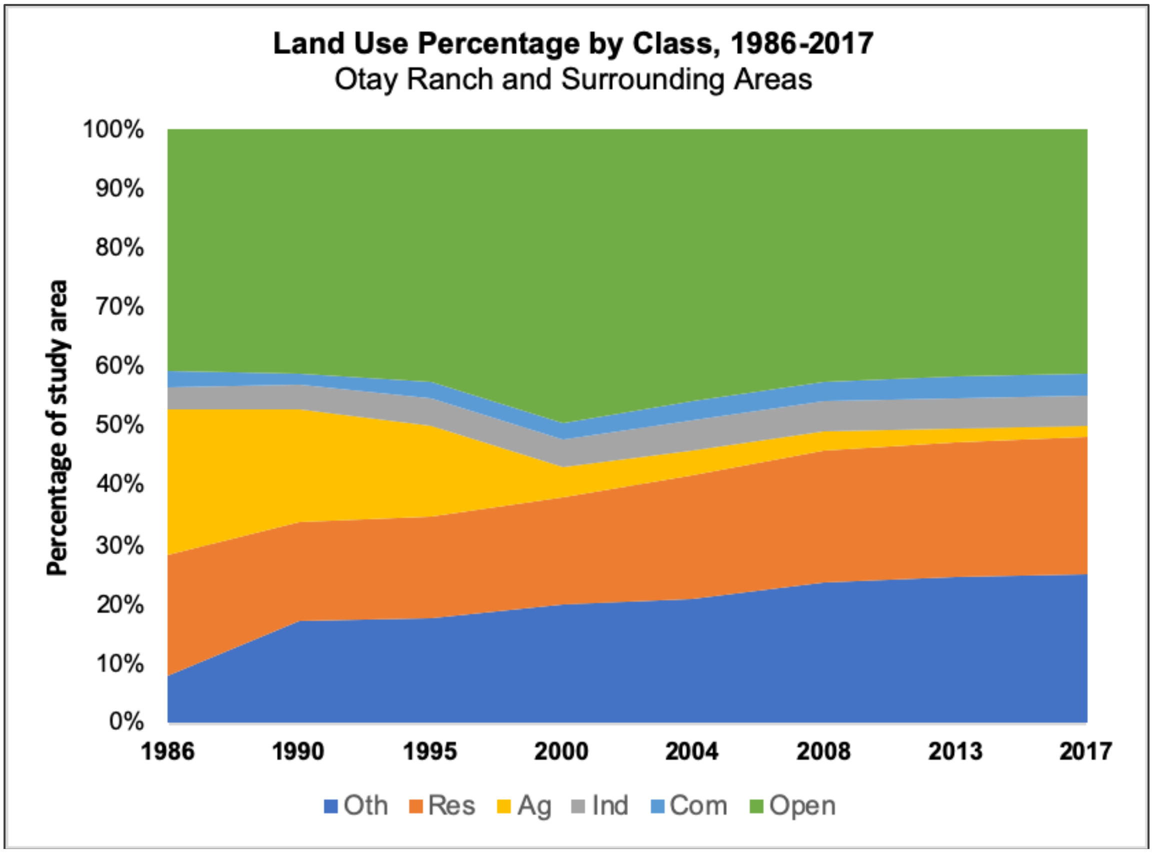

Figure 2.11 *– Land use class area as a percentage of study area.*

There are several aspects of the methodology used here that might contribute to uncertainty in the analysis. First, changes in the number of land use designations each year leads to uncertainty as to how the land actually changed on the ground. In several cases, land uses were separated in subsequent years (e.g. warehousing and public storage became two separate designations after 2004) leading to separate land use classes that were once the same. The land use layer from 1986 for the entire county contains 58 land use attributes, while the 2017 layer contains 103 attributes. Considering the total area remained constant between 1986 and 2017, this increase in land use designations is the result of three processes: actual change that occurred in the study area (e.g. the Richard J. Donovan correctional facility was opened in 1987 so there are no land use polygons designated “Jail/Prison” until 1990), an increased discernment by

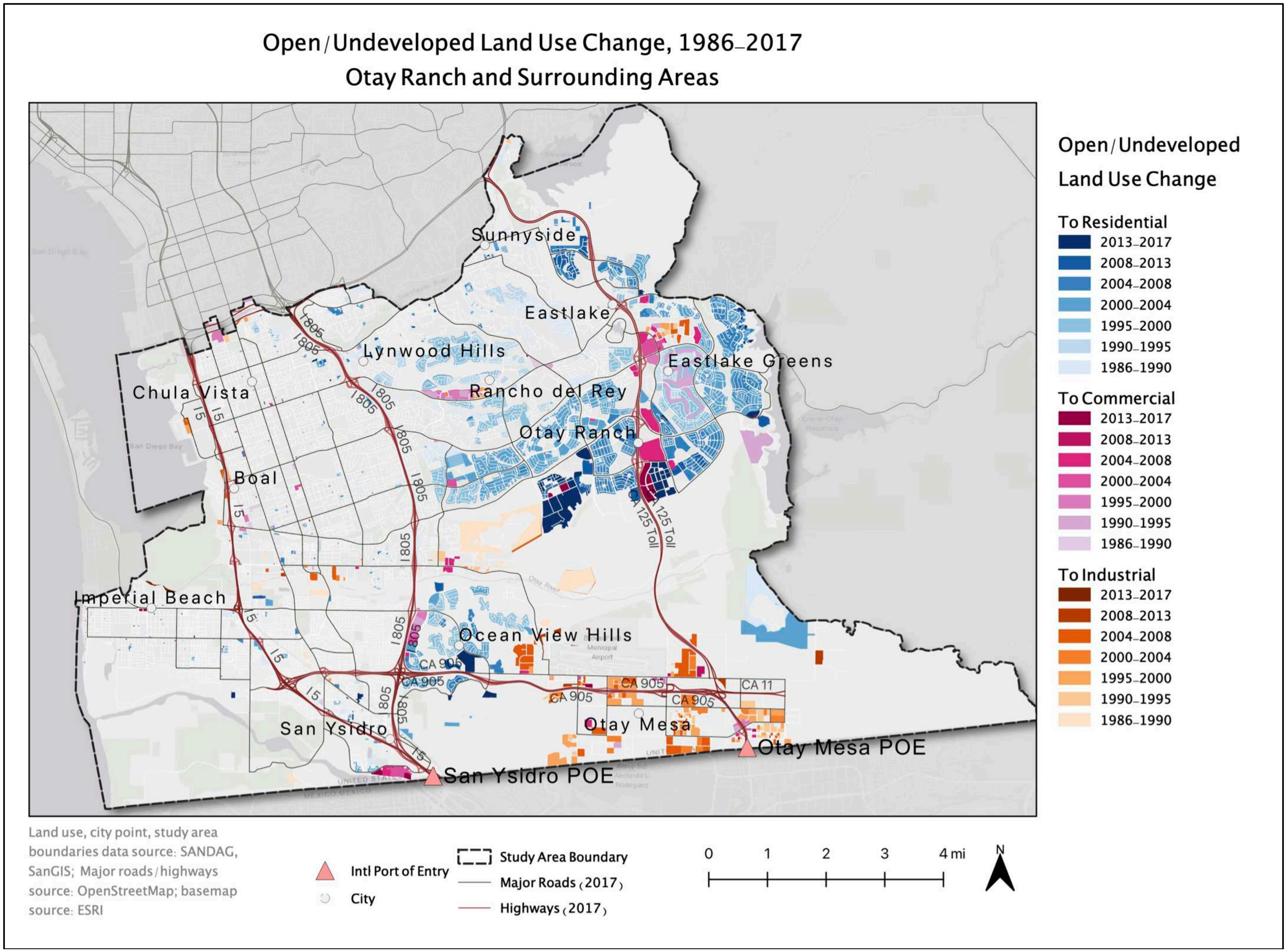

Figure 2.12 *–Map of changes from open/undeveloped to residential, commercial, and industrial land use. Darker polygons represent more recent change.*

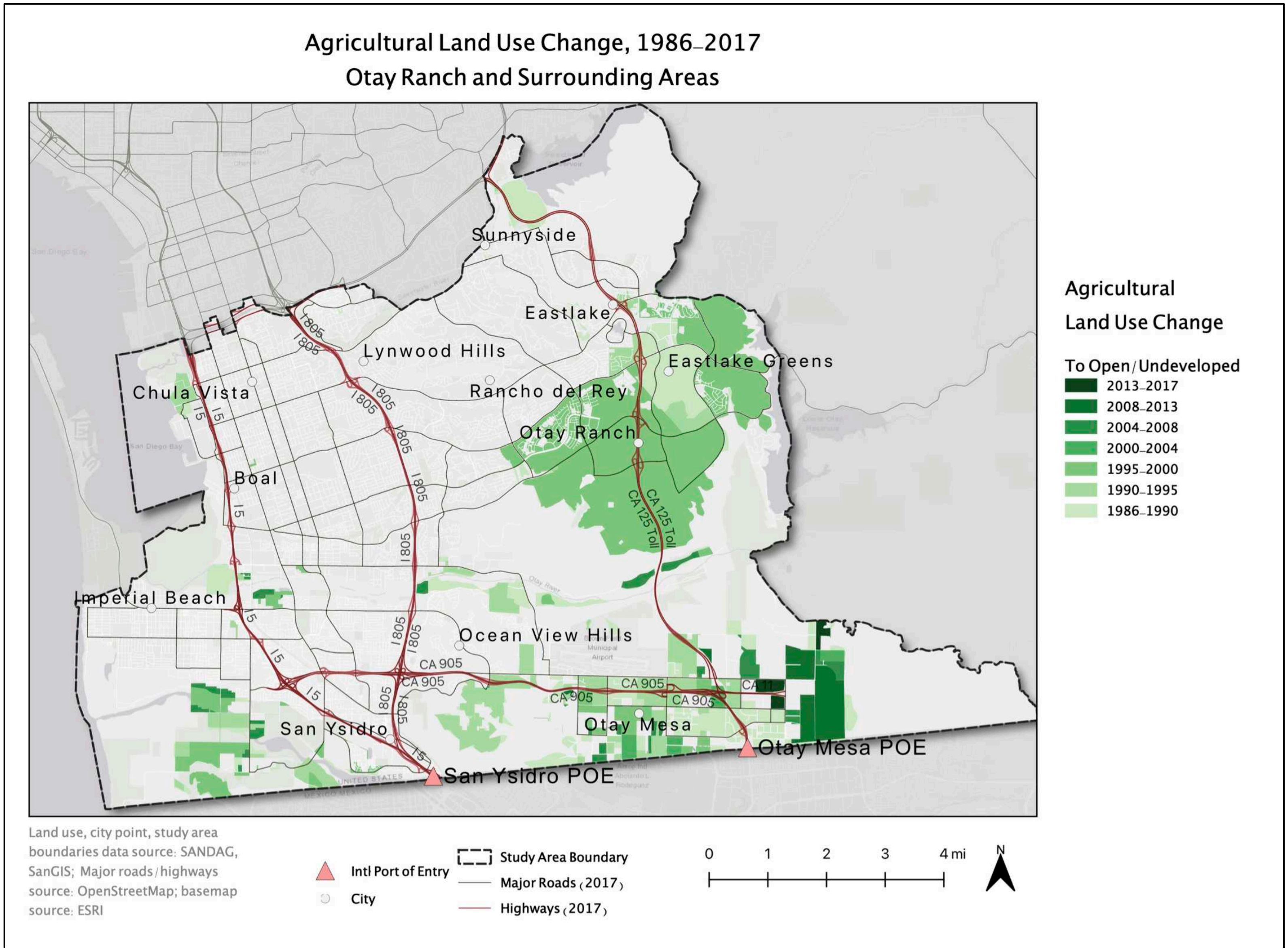

Figure 2.13 *- Map of changes from agricultural to open/undeveloped land use. Darker polygons represent more recent change.*

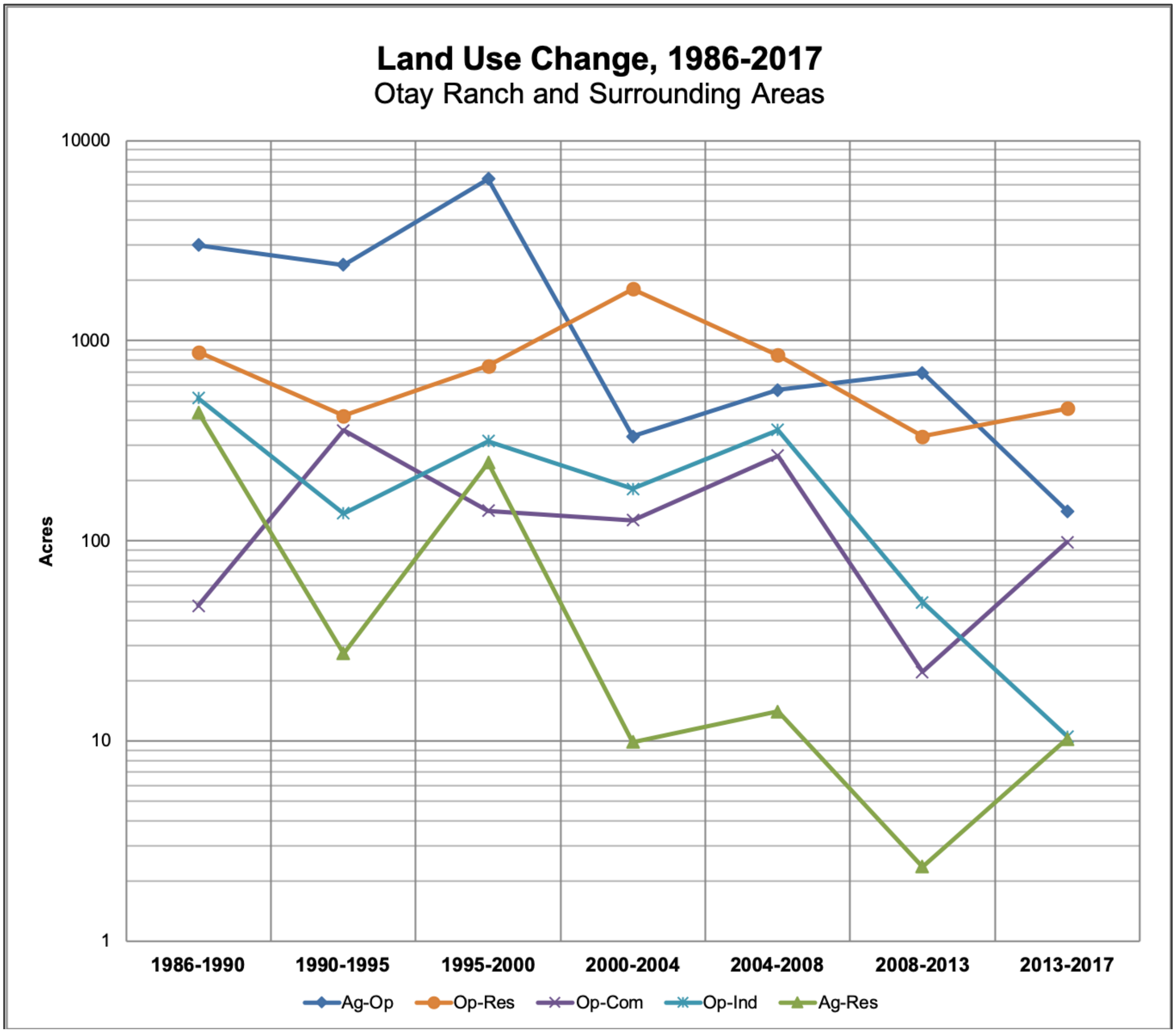

Figure 2.14 *– Acreage of selected change vectors during each sub-period, 1986-2017.*

county officials responsible for recording land uses, and an improvement in technology aiding land use designation processes (e.g. through remotely sensed data, higher spatial resolution GPS, crowdsourced mapping technologies like OpenStreetMap, etc.).

To expand upon this last process, metadata for the 1986 land use layer indicates land use polygons were digitized from 15' USGS quad mylars, while the 1990 and subsequent layers were created through a combination of primary (digital orthophoto imagery, satellite imagery, and local jurisdiction data) and secondary (telephone books, Haines Directory, Thomas Brothers Map Guides and Aerial Photography Atlases) sources. As such, land use designations represent a triangulated best guess at the reality of land use on the ground for each year. The process of land use designation by SANDAG and SanGIS was variable for each time period, so it is difficult to know whether land use change between years represents actual change or an outcome of this process. However, in combination with other sources, the results of analyses based on the SanGIS land use archive are useful, especially at the landscape scale.

Residential and Agricultural Change

The expansion of residential and reduction of agricultural land uses through time is one of the most notable results of this analysis. Broadly speaking, residential expansion occurred relatively quickly throughout the study period following sale of the Otay Ranch parcel to the Baldwin Company in 1989. Between 1986 and 1990, the polygon representing agriculture within the Otay Ranch was subdivided and the parcel that would become Eastlake Greens was reclassified as undeveloped. Much of the remainder of this parcel remained classified as agricultural until 2000 when it became open/undeveloped. Subsequent residential communities were developed in large tracts with winding streets, central commercial centers, and schools characteristic of many master-planned housing developments.

Construction on the twelve villages in Otay Ranch began in the north with Village 1 between 1995 and 2000 and moved south in subsequent years following the original Otay Ranch General Development Plan (GDP) (City of Chula Vista, 2018a; see figure 2.16 for the Otay Ranch GDP villages map). One of Chula Vista's main goals in the GDP was to disincentivize transportation in and out of the area in order to minimize regional traffic impact. The GDP sought to accomplish this through its village-centric design, providing all the amenities necessary for suburban life within a short walk or drive. Originally, the GDP planned to connect to the

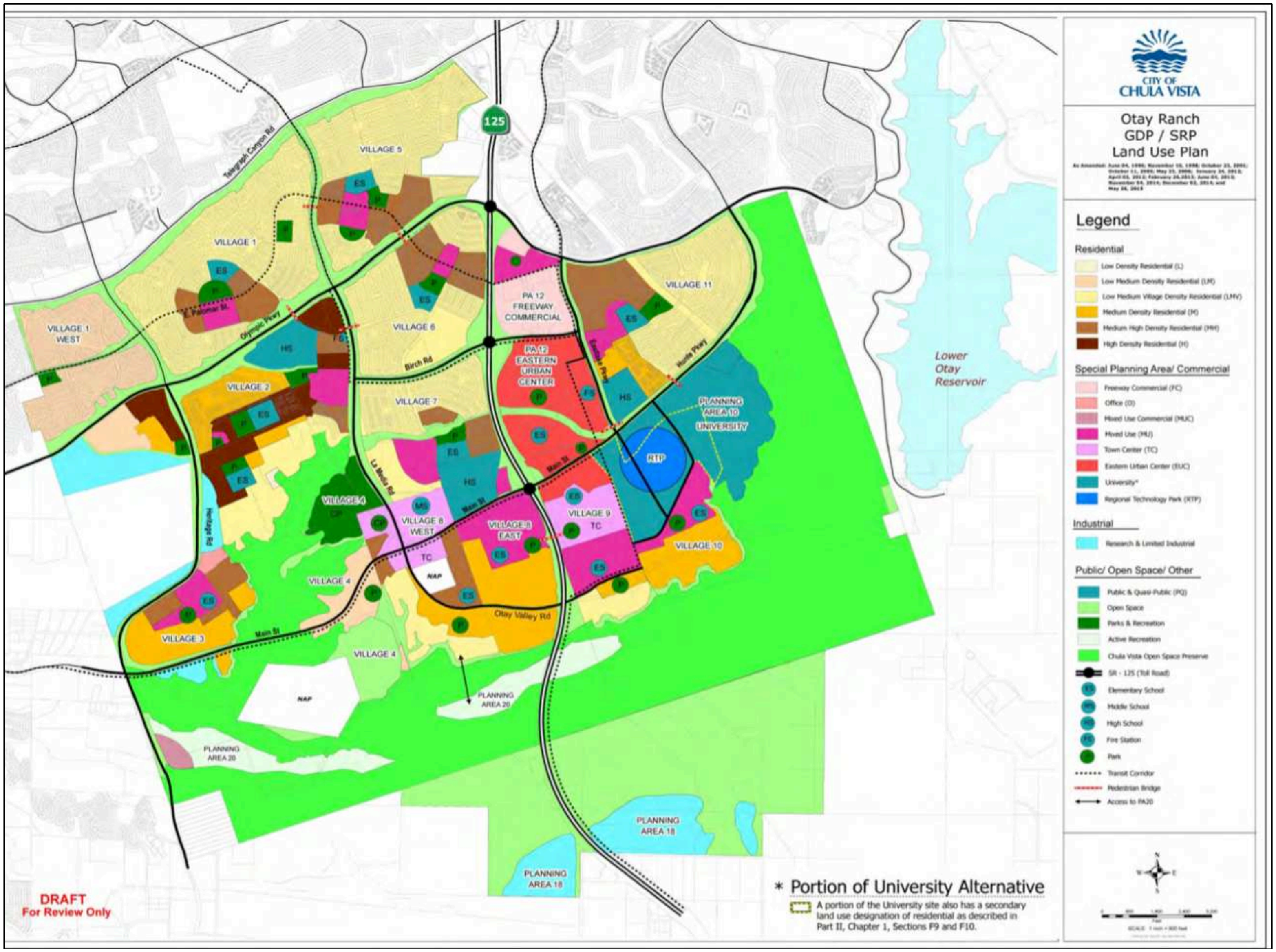

Figure 2.15 - Otay Ranch General Development Plan (p.II-20). From City of Chula Vista (2018a).

city's existing trolley rail system with stops in each village center, but the plan was ultimately scrapped in favor of a bus system (H.H. Planner, personal communication).

The rate of residential expansion varied throughout the study period as a result of broader economic trends that manifested at the local level. Following the sale of Otay Ranch to the Baldwin Company in 1989, several years of planning and environmental assessment occurred before San Diego county and Chula Vista adopted the GDP in 1993. Toward the end of this period, the United States economy entered a recession and the construction sector in San Diego slowed significantly. As a result, the Baldwin Company declared bankruptcy in 1995 before construction could begin on the first village (Weisberg, 1997). Development was also complicated by a controversial court case involving settlement of the Mary Birch Patrick estate. Patrick was the owner of Otay Ranch and United Enterprises until her death in 1983, after which time her ranch hands Pat and Rose Patek gained control of the multimillion-dollar estate (Cantlupe, 1997). They eventually agreed to sell the land to the Baldwin Company for $150 million in 1988 (Lawrence, 1988). Patrick's heirs claimed entitlement to this and the remainder of Patrick's estate, and the ensuing probate case lasted 15 years, partially because the Baldwin company failed to pay the remainder of their debt accrued from the Otay Ranch transaction.

The entire narrative of this transaction and the myriad actors involved is far more complex than is described here, but its connection to this research lies in the fact that financial troubles stemming from the purchase of Otay Ranch, in tandem with the early-90s recession, drove the Baldwin Company to bankruptcy. To help pay their debt, the Baldwin Company sold several large parcels of Otay Ranch land to other developers including Homefed, Brookfield Shea, and McMillin. This process of subdivision led to competition between developers and ultimately complicated the fulfillment of the GDP (H.H. Planner, personal communication). In at least one case, competing developers failed to communicate about grading plans within a village, resulting in a vertical offset at the boundary between each developer's parcel. It is possible the differential rate at which villages were developed within Otay Ranch is the result of this competition, or at least lack of communication, between developers. Each developer has distinct financial goals and existing assets that inform their development process. Homefed, for example, "doesn't seem to be in a rush" to complete many of their developments on Otay Ranch land (H.H. Planner, personal communication), while other developers mobilize huge amounts of capital to complete model homes and begin home sales to compete with neighboring villages where homebuyers may also be shopping. The extent to which this is the case for specific areas of residential expansion in the study area is unclear, but future research may benefit from understanding the role of developer competition in the rate of residential expansion in a master-planned community context.

Residential expansion outside of the Otay Ranch planning area was also notable during the study period. The Eastlake Company purchased the Janal Rancho, originally granted to the Estudillo family with Rancho Otay, from the Western Salt Company in 1979 and began planning a 3000-acrea residential development. Construction began in the mid-80s and continued throughout the early 1990s and can be seen as the earliest residential developments in figure 2.13, west of the Eastlake city point. Residential expansion associated with the Rancho Del Rey and Lynwood Hills neighborhoods is visible in figure 2.13 as residential growth that occurred between 1990 and 2000. These communities experienced similar development trajectories as Otay Ranch and Eastlake in that the parcel on which the developments now sit was purchased in a single sale and was developed over a short period of time. Rancho Del Rey is geographically distinct, however, for its location amongst steep sloped canyons and flat-topped mesas on which the neighborhoods were built. As a result, large contiguous tracts of open space were preserved between the residential and commercial developments. These are evident starting in the 2000 land use map (figure 2.6).

Industrial and Commercial Growth, Employment Centers, and the "Innovation District"

Aside from Otay Ranch, few large parcels within the study area experienced a transition from agricultural to built-up or open/undeveloped land uses. Along the international border near Otay Mesa and the Otay Mesa Port of Entry (OMPOE), the same process of agricultural subdivision and transition to open/undeveloped land uses as occurred in the Otay Ranch parcel ultimately resulted in the construction of commercial and industrial developments. Much of this development followed the signing of NAFTA in 1994 and is linked to increased international trade and the maquiladora sector. As NAFTA also had significant effects on the agricultural sector in the U.S., it is not surprising to see such a rapid transition from agricultural to industrial land uses in this area since 1994.

Many of the businesses established in this area since 1994 are in the logistics, manufacturing, and industrial warehousing sectors that tailor to transnational companies and international trade. Industrial development along the US-Mexico border can be traced back to the Bracero and Border Industrialization Programs (1942 and 1965, respectively) (Calavita, 2010; Schwartz, 1987). These programs incentivized US-based companies to hire Mexican labor, and as a result many companies established assembly plants, or maquiladoras, on both sides of the border. Companies from a wide range of sectors took advantage of the maquiladora system for its economic benefits, including electronic, medical device, and furniture manufacturers. In many ways, NAFTA expedited the expansion of industrial areas along the border, as increased crossborder trade drove market demand for the products that maquiladoras produced. 1994's Operation Gatekeeper, a measure implemented by the Immigration and Naturalization Service, further drove maquiladora expansion to the Mexican side of the border through increased border security that prevented cross-border travel by Mexican day laborers (Nevins, 2001).

In sum, the border experienced a significant transition from agricultural to industrial land uses starting in the 1960s, with accelerated activity in the 1980s and 1990s. Planning played a significant role in the form and rate of development in the border region during this period, as planners from the City of San Diego recognized the border's growing economy and associated construction of industrial and commercial buildings needed for it. The Otay Mesa Community Plan was first adopted in 1981 and aimed to facilitate a more regular development pattern, with residential and commercial land uses in the West, and industrial land uses in the center and East (City of San Diego, 2014). The ultimate form of land use in the area closely follows the Community Plan, as evident in the land use maps produced for this analysis. In the 2017 land use map (figure 2.10), industrial and commercial land uses are concentrated around the OMPOE while most recent residential development occurred further north around the Ocean View Hills neighborhood.

City planners' motivations for strict planning guidelines in the border region are tied to the city's desire to facilitate employment opportunities and limit regional traffic impact. The San Diego City Council adopted the "City of Villages" planning strategy in 2002 to help combat unchecked growth and limit the distance between residents and their places of work (City of San Diego, 2008). The village concept played a central role in Otay Ranch's GDP, with each village centered around a commercial or industrial district to provide local residents opportunities for work, shopping, or entertainment. However, H.H. Planner (personal communication) expressed the challenges of establishing sustainable employment centers in the area. Parcels that were planned for light industry or professional service offices attract enterprising companies, but often transition to more commercial uses like movie theaters and shopping malls. These employers have difficulty competing against other areas of the county with higher concentrations of educated young people- namely the communities surrounding University of California, San Diego and San Diego State University. The presence of a four-year research university keeps alumni in the area and facilitates regional entrepreneurial culture that further drives business development (Walcott, 2002). Universities themselves are major employment centers, too, and offer steady, well-paying jobs to a much greater extent than predominately commercial sectors like retail.

Planners from Chula Vista recognized the importance of a university for local employment, as early planning efforts for the Otay Ranch GDP started with a proposal to establish a University of California campus in the area (Hefferman, 1989). Following their purchase of Otay Ranch, The Baldwin Company donated a portion of the land for a future university site and submitted a joint proposal with the city of Chula Vista to the UC board of regents. The board did not select this site for a new campus but the 375-acre planning area, called the "University and Innovation District", remains undeveloped as Chula Vista continues to seek a university interested in establishing a campus in there.

Another major planning effort aimed at creating sustainable employment centers in Otay Ranch is the Eastern Urban Center, or "Millenia" development (figure 2.17) (City of Chula Vista 2018b). Millenia is located adjacent to the future university site and includes a 30-acre "campus" of corporate offices designed to "serve as a breeding ground for innovation and collaboration among academia, life science, research and technology," (Milleniasd.com). The city of Chula Vista submitted a proposal soliciting Amazon's second corporate headquarters to the campus in 2017, but the proposal was not accepted. As of September 2019, the office campus has yet to break ground.

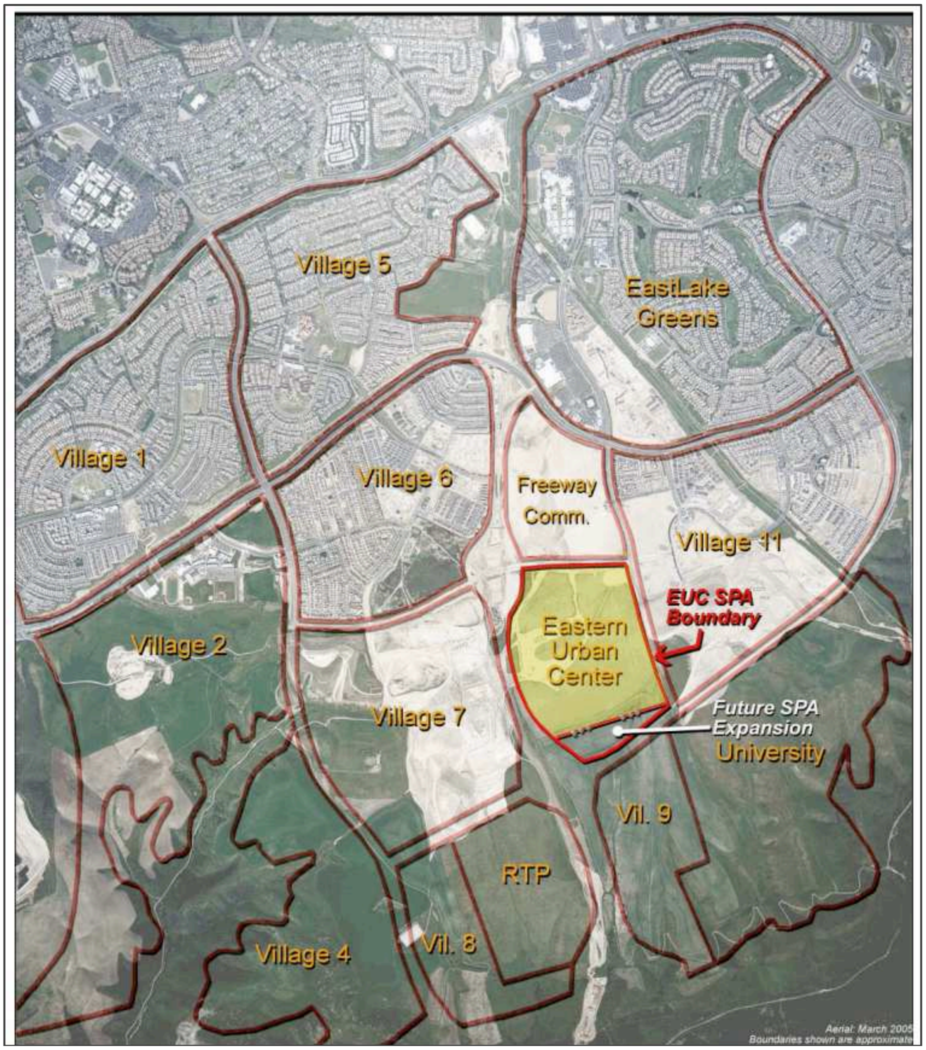

Figure 2.16 *- Eastern Urban Center in context with Otay Ranch villages and Eastlake Greens. Imagery was captured in March 2005. From City of Chula Vista (2018b).*

It is possible the city of Chula Vista and the developers responsible for Millenia are awaiting an official commitment by a university to establish a campus on the university site before beginning office construction on the Millenia site. Formal commitment by a university would ideally entice research-based firms to Millenia's "breeding ground for innovation and collaboration", as the firms could more reasonably anticipate an innovative academic environment than without a university located nearby. H.H. Planner indicated that the future of Millenia's development is linked to the establishment of a university campus. It is difficult to say what would happen if a university does not locate there, but it is possible consumer-centric commercial developments (retail, entertainment, food service, etc.) would take the place of high employment centers based in the tech sector, as the former are more profitable to the developer than undeveloped land.

Open Space, Conservation, and Physical Geography

While significant residential and industrial growth occurred in the study area, there remain large swaths of open/undeveloped land in several regions. Indeed, much of the open/undeveloped land in 1986 remained as such in 2017. The largest of these include the Otay River valley near the center of the study area, the Tijuana River Valley in the southwest, and the extended section of undeveloped land to the east of Otay Mesa. A smaller, but still significant, parcel of open space remains between San Ysidro and Otay Mesa. Numerous smaller parcels of open space also exist within new residential developments as landscaping and parks. Most prominently, the Otay Ranch villages are buffered from the main east-west thoroughfares by landscaped slopes, represented by thin strips of open/undeveloped land (figures 2.6 through 2.10). The large open/undeveloped parcel on the northeast border of the study area represents the foothills of Mount San Miguel. Much of this is protected open space and is unlikely to be developed.

The plot of open/undeveloped land use in figure 2.11 shows a distinct increase of almost 5000 acres between 1995 and 2000 before falling off to the 1995 level by 2008. This indicates the land allocated as open space in 1995 was completely transformed to other uses and was likely the result of planned development of residential and commercial or industrial areas. Figure 2.15 shows that the increase in open/undeveloped land between 1995-2000 came directly from agriculture, and figure 2.14 shows that the largest area of change from agriculture to open/undeveloped land use was the Otay Ranch area that would be developed in subsequent years. The remaining area of ag-open land use transitions in figure 2.15 represent transition of agricultural lands in Otay Mesa, much of which later became industrial or commercial.

Several critical factors rooted in San Diego's physical geographic characteristics drove development of Otay Ranch, and limit where future development may occur. First, wildfire risk in San Diego county's wildland-urban interface (WUI) strongly influences city planning officials' decisions to approve certain development projects. San Diego has a substantial housing deficit, so county officials put pressure on local administrative units like Chula Vista to approve mass-housing projects within their municipal boundaries where there is less risk for wildfire (H.H. Planner, personal communication). Otherwise, the county must develop the more fire-prone rural land under its jurisdiction in order to meet county housing demand. At present, however, nearly all of the safe and easily developed land in the county's municipalities has been built-out, so county planners' decision-making is becoming more difficult (G.G. Planner, personal communication). At the beginning of the 1990s, Otay Ranch was in a unique position to meet housing demands for a large portion of the county's growing population because it was a large tract of undeveloped land far enough from the WUI that wildfire risk would be minimal. The parcel's geographic character (flat, few areas of dense vegetation, and close to existing urban areas) also made it desirable for developers, as grading and subsequent construction would be relatively inexpensive, and demand would be high.

Second, San Diego's native ecology presented a hurdle for developers, especially in areas surrounding the Otay River Valley. San Diego is characterized by a mix of coastal sage scrub and chaparral ecological communities and is home to numerous endemic species that require native landscape for survival (Stein et al., 2000). During the initial planning phase for the Otay Ranch GDP, planners and developers worked concurrently on a resource management plan that would preserve 11,000 acres of undeveloped land in the region. This plan was adopted in 1996.

Listing of the coastal California gnatcatcher as endangered in 1993 also complicated development efforts and stalled construction for several years while officials worked to implement a series of Habitat Conservation Plans through the county's Multiple Species Conservation Program (RECON, 2018). These were eventually adopted by the City of Chula Vista in 2003. Conservation efforts beyond these plans include the work by conservation groups who purchased several parcels of land put up for sale following the Baldwin Company's bankruptcy filing (RECON, 2018). Similar groups have worked to reunite parcels of native or formerly agricultural land cover that have been fragmented by subdivision. In some cases, the undeveloped land parcels were scarred by off-road vehicle driving and illegal dumping (H.H. Planner, personal communication). Conservation and habitat restoration organizations have worked to clean these areas and maintain their protected status to benefit local biodiversity.

Lastly, both H.H. and G.G. Planners mentioned that the county's climate action plan (CAP) (County of San Diego, 2018) plays a significant role in where development is allowed within the county. The CAP was built upon the 2011 county general plan and adopted in 2018, so urban expansion during the 1986-2017 study period was not directly shaped by the CAP. However, the CAP is responsible for managing development processes in the largely undeveloped unincorporated regions of eastern and northern San Diego county where there exists the most potential for future residential developments on the scale of Otay Ranch. As such, most significant development in the near future will be affected by the CAP. Rancho Guejito, for example, is the last remaining undivided Mexican land grant, and it is still operated as a cattle ranch today (Jones, 2009). However, the Rancho's owner has expressed interest in developing the property despite local residents' opposition. As the 22,000-acre parcel contains significant swaths of native habitat and carbon capturing vegetation, the CAP would likely limit the amount of development that could occur. Much of the county's native vegetated space has been transformed to built-up uses or otherwise fragmented by roads, so remaining native landscapes like that on Rancho Guejito are far more valuable now in terms of their carbon-sequestering qualities than they were thirty years ago. The present possibility of development, therefore, comes down to competing value systems between economic growth and housing provision on the one hand, and conservation and climate change mitigation on the other.

CONCLUSION

Urban expansion and its drivers are an increasingly important area of research within the field of land change science. In rapidly growing areas of the United States, particularly southern California, urban expansion significantly impacts native plant and animal habitat, freshwater resources, and local and global climate. At the same time, housing demand remains high and there is a growing need to find balance between unchecked urban growth and strict conservation of all undeveloped land. San Diego, CA has experienced a significant amount of urban expansion in the past several decades as a result of growing population and employment opportunities. The particular areas in which these underlying drivers manifest as urban land use change are determined by the path dependency of previous land tenure systems and local policies and institutions that guide the form of urban development.

The Otay Ranch area exemplifies these interconnected drivers of local urban expansion. Rancho Otay was a 23,000-acre parcel originally allocated to the Estudillo family under the Alta California Rancho system in 1829. Since that time, the land has changed hands numerous times until the Mary Birch Patrick estate sold it to the Baldwin Company in 1988. The Baldwin Company and the city of Chula Vista created a general plan for development on the parcel and surrounding areas, but subsequent economic and political factors slowed development and resulted in the land's subdivision into ownership by several different developers. Other institutional factors, including San Diego county's Climate Action Plan and habitat conservation plans also limited development, and will likely play an increasingly significant role in the region's development into the future.

In this study, urban expansion in Otay Ranch and the surrounding areas was quantified using spatial analysis in QGIS and the San Diego Department of Government's land use data between 1986 and 2017. The study sought to answer whether most residential development occurred within the boundaries of the Otay Ranch parcel, and whether most industrial growth occurred along the U.S.-Mexico border following 1994 and the signing of NAFTA. The results indicate that the vast majority of residential development in the study area did indeed occur in the Otay Ranch parcel that was sold to the Baldwin Company in 1988. Rates of expansion varied during the study period as a result of economic recessions in the 1990s and late 2000s and may also be linked to competition between developers of adjacent parcels within the broader Otay Ranch planning area. Industrial expansion did occur primarily along the U.S.-Mexico border in Otay Mesa following the signing of NAFTA in 1994. Two interviews with city planning officials familiar with the Otay Ranch development indicated that efforts to generate industrial and other employment centers in Otay Ranch's "Eastern Urban Center" have so far failed due to competition with industrial clusters elsewhere in the county. The Otay General Development Plan set aside a 375-acre plot of land for a 4-year research university to facilitate industrial development in the area, and efforts to attract a suitable university are ongoing while the parcel remains undeveloped.

Residential and industrial expansion continues in the Otay Ranch area while development in much of the remainder of San Diego county is nearing physical or institutional boundaries. As such, there is pressure on development in Otay Ranch to meet regional housing demands while minimizing environmental impact and wildfire risk. Large swaths of open space adjacent to Otay Ranch have been preserved by city, county, and private organizational action, so urban expansion is approaching physical and intuitional boundaries in this area as well. Continued growth remains likely in the near future, as several of the General Plan's villages have yet to be built, but prospects beyond that will certainly be driven by evolving policies and planning institutions enacted at the local level.

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CHAPTER 4 – CONCLUSION

This study has examined the drivers of urban expansion in two regions of San Diego California. These two regions were chosen as areas of study because their recent growth seemed to represent three significant drivers commonly cited in the literature (Colsaet et al., 2018). In particular, economic growth is often cited as a driver of increased resource use and demand for higher standards of living that manifests as greater spatial expansion of built-up areas. Economic growth is also related to population growth through the in-migration of job seeking individuals who then generate demand for housing. The first case study in this thesis examined these drivers in the context of UCSD and the "innovation economy". The most commonly cited drivers of urban expansion, however, are policies and institutions related to governance, planning, conservation, intra-administrative conflict, etc. (Colsaet et al., 2018). The second case study of Otay Ranch and the areas surrounding it exemplified some of these drivers within the context of landscape and land tenure path dependency. In this case, the presence of the Otay Ranch parcel as an undeveloped and economically desirable plot of land drove the Baldwin Company to purchase the parcel in 1988. The parcel was only economically desirable, however, as a result of broader-scale trends in the innovation economy that grew out of the UCSD area. Policies, planning, and governmental institutions then steered local-scale development within Otay Ranch and shaped its present-day form. Together, these two case studies present the drivers of urban expansion at different scales and highlight the ways in which the story of urban expansion in a particular area is linked to multiple factors working simultaneously to shape the ultimate outcome on the landscape.

Spatial analyses were used to quantify where growth occurred in the study areas, and two interviews with city planners and subsequent document analysis qualified these findings and aided interpretation of the drivers responsible for particular areas of growth. Following Walcott (2002), Chen and Rosenthal (2008), and Storper (2013) among others, urban expansion in the UCSD case study was examined in the context of growth in the region's innovation economy. Residential areas also grew substantially, likely to accommodate the growing demand for housing associated with new employment opportunities. The role of the university was central to development in this area, as university researchers and former students form social networks and venture capital firms critical to the development of industrial clusters (Gordon and McCann, 2000). The success of early companies like Hybritech (Casper, 2007; Kim, 2015) and Linkabit (West et al., 2009) provided the necessary network of researchers and venture capitalists to fuel a thriving innovation economy grounded in the biotechnology and telecommunications sectors in subsequent years.

Most industrial growth elsewhere in this study area occurred later than that in the Sorrento Valley area directly adjacent to UCSD, likely as a result of the Sorrento Valley area's earlier success. Significant industrial centers now exist in the area between San Marcos and Carlsbad, as well as in 4S Ranch and Poway. Cal State San Marcos and Camp Pendleton, the Marine Corps Base in northern San Diego county, contributed to the region's innovative capacity through local investment in technology companies and provision of a skilled labor force. Residential development is more recent in this region than much of the remainder of the study area, likely as a result of the region's relatively recent industrial expansion.

The industrial areas in Poway also developed more recently than the Sorrento Valley industrial center, and many of the businesses in Poway are retail, entertainment, and professional service companies in contrast to Sorrento Valley's biotechnology and telecommunications companies. This may indicate that industrial development here is predominately associated with the service economy, and might be more accurately classified as commercial within the context of Fisher's (1939) three-sector model of the economy. In this context, primary (producing raw materials) and secondary (manufacturing materials into products) sectors are the greatest drivers of population growth, while tertiary or service sector businesses arise to cater to residents employed in the primary and secondary sectors. This three-sector model is complicated by the information and knowledge economies, of which San Diego's innovation economy is a part, as these sectors produce value through largely non-material and non-service means but employ large portions of the population. Nonetheless, traditionally tertiary sectoral businesses like retailers, restaurants, and commercial recreation arise in response to market demand driven by the innovation economy. This seems to be the process responsible for the expansion of industrial-classified land uses in Poway.

The results of the analysis in the Otay Ranch area show that most urban expansion occurred on land previously allocated under the Spanish Rancho system. The Otay Ranch parcel was an undeveloped tract of cattle pasture owned by United Enterprises until the Baldwin Company purchased the land in 1988. The company and the city of Chula Vista worked together on a development plan for the parcel over the following several years, while a downturn in the U.S. economy in the early 1990s drove the Baldwin Company to file for bankruptcy and sell portions of the parcel to other developers. The land change analysis reveals that the Otay Ranch parcel remained agricultural land until after 1995 under the San Diego Association of Governments' land use designation scheme. After this time, it was redesignated as undeveloped, and construction of the first villages began. Most residential development occurred between 2000 and 2008, prior to the 2008 housing crisis and its negative repercussions in the San Diego construction sector. Residential development outside of the Otay Ranch parcel was also evident in the study area, however this represented a small minority and occurred over relatively short time periods. Residential expansion continues to this day, and at least two villages in the Otay

Ranch General Development Plan have yet to be built.

Industrial expansion in the Otay Ranch study area occurred mostly along the U.S.-Mexico border in the community of Otay Mesa. These developments were built on land designated as agriculture in the earliest land use maps included in this analysis, and many developments were built after 1995. This indicates that the signing of NAFTA in 1994 and the increased cross-border economic interaction that resulted from it may have been responsible for the region's rapid industrialization. More data is needed to understand whether other drivers like a changing agricultural market or increased border security contributed to the loss of agricultural land uses, but this research shows that city planning efforts and other institutions certainly played a role in the area's urban development. The Otay Mesa Community Plan designates certain parcels as dedicated industrial land uses and allocates residential zoning further to the west. As Otay Ranch approaches its planning area boundaries, demand for development appears to remain high and city planners continue to look toward smart growth strategies for urban expansion in southern San Diego.

The two planners interviewed for this study stressed the Otay Ranch area's need for more employment centers in order to reduce regional traffic impacts and keep residents in the area. The industrial areas in Otay Mesa can certainly fulfill some of this need, but the Eastern Urban Center, or Millenia, planning area in Otay Ranch seems to hold the most promise as a foundation for regional industrial growth. Plans for the Millenia development include several high-density housing units, a shopping mall, and over 2 million square feet of office buildings in a campus setting meant to house biotechnology and research-based firms. Planners and developers gained inspiration for Millenia from the cluster of innovation economy firms surrounding UCSD as these offer large numbers of stable, high-paying jobs and draw residents to the area. The Otay Ranch GDP also allocated space for a 4-year university on a parcel adjacent to the Millenia development as planners recognized the importance of a university for facilitating growth in research-based industries. At present, however, both Millenia and the university site remain undeveloped.

GENERALIZABILITY OF FINDINGS

As a city in southern California, San Diego represents a relatively small fraction of world cities in terms of wealth, public infrastructure, regulation, and resource access. The median household income in San Diego county in 2017 was ~$70,000 while the median home value was $484,900, both of which are higher than the state of California's average (Census Bureau, n.d.). These are outliers even in the United States, a wealthy industrialized country by most measures. As such, the degree to which the findings from these case studies may be generalized is limited. However, many cities in rapidly developing countries like China, India, Brazil, Indonesia, and Mexico are experiencing industrial expansion similar to that of the United States during the 20th century. Further, many of these cities, particularly in China, are heavily involved in the technology and research-based innovation sectors that characterize San Diego, San Francisco, Boston, and elsewhere in the United States. Much of the literature exploring the economic drivers of urban expansion focus on China as a case study because of the unprecedented growth rate many Chinese cities have experienced. Therefore, the results of the case studies presented in this thesis may apply to other cities experiencing growth driven by economic forces, but differences in political institutions and other governance factors must be considered. Urban expansion in San Diego cannot simply be written off as the outcome of free market forces interacting on a landscape, as significant planning regulations, political conflicts, and historical factors confined growth to particular areas at particular times. Urban expansion in a region with similar economic characteristics but different political, institutional, and historical constraints will yield a different outcome than that of San Diego.

Urban expansion in other U.S. cities experiencing growth related to research-based sectors like biotechnology, information technology, communications, aerospace, or software development may be more effectively analyzed using similar methodology as that utilized here. The case of Silicon Valley, CA, for example, may tell a similar story of urban expansion to that in San Diego, as both cities have historical roots in the Spanish Mission system, and both are governed by California's state-level planning regulations. Further, most major cities in the western U.S., particularly California, are unique for their relatively young age in contrast to major cities on the east coast. As a result, large swaths of land still remain undeveloped outside of metropolitan areas. This study showed that the presence of these large areas of undeveloped land is a significant contributor to future urban expansion, so analyses of urban expansion in the context of growth in research-based sectors should consider this as a factor. For example, comparison of urban expansion between San Diego and Boston, MA, where there also exists a thriving biotechnology cluster, would likely show much greater growth in the urban extent of San Diego simply because there was more room to expand.

AREAS OF FUTURE RESEARCH

The two case studies in this thesis have generated several areas for future research on the topic of urban expansion as it relates to economic, political, institutional, and historical drivers. First, the Otay Ranch case study revealed that the legacy of the Spanish Rancho system is evident on present-day urban form. Many cities within San Diego county retain names derived from Ranchos originally allocated under the Spanish system, so further examination of where the original Rancho boundaries overlap with present-day built-up area might yield interesting correlations. There also exists significant potential for future development in a manner similar to that which occurred in Otay Ranch. As mentioned in chapter 3, Rancho Guejito is the last remaining undeveloped parcel remnant of the Rancho system and may be such a sight of future urban expansion. The Rancho's owners have been in recent conversation with developers and county decision-makers who may ultimately allow such development to occur. Attention to the institutional and economic factors that influence this development process will be critical.

Another area of potential research is to more explicitly examine the relationships between locations of residential developments and locations of employment centers in the innovation economy. This study employed GIS to quantify the amount of certain types of growth and where these occurred, but further spatial analyses and spatial statistics would allow for correlations to be made between specific industrial areas and surrounding residential areas. A guiding question in this context might be whether the amount of residential growth during the study period decreased with distance from areas of industrial growth. Paying more explicit attention to the timing of different regions of development would also inform these relationships, as specific areas of industrial growth that preceded residential growth in adjacent areas would indicate a potential causal relationship between the two. To move beyond correlation between industrial and residential growth, a survey could be employed to gather employment location data from residents of recent residential developments in different regions of the county. If these data yield a positive correlation between housing location and distance to employment centers, the argument that industrial development drove residential development would be strengthened. As they stand, the results of this study are limited in this context and it is only possible to make inferences based on the relative timing of different types of development.

The analyses employed in this study were also limited in terms of temporal resolution. As the land-use data from the city of San Diego is only provided at 4 to 5-year intervals, large areas of land transitioned from undeveloped to built-up within a single interval. This makes it difficult to know exactly when the development began and how long it took to finish. Utilizing data over shorter time intervals would allow for more fine-grained analysis and facilitate more accurate correlations between specific events and their resulting outcomes on the landscape. The use of remotely sensed multispectral imagery like Landsat may be useful in this context, as imagery captured twice per year may be classified using SanGIS land-use polygons as training data. These classified images would yield more temporal information and illuminate areas of rapid expansion that are not visible in an analysis based on data from every five years. On a similar note, carbon sequestration calculations may be estimated using this method as a classified Landsat image can effectively estimate land cover, particularly that which is vegetated. These land cover images may then be used in a carbon capture model to estimate the effect of land use and land cover change on the carbon cycle. In the context of San Diego county's climate action plan, such a calculation would be highly valuable for city planners and policymakers.

Lastly, the effects of roads and other transportation networks on change in built-up land use within the study areas were not examined, and this is a potentially useful area of future research. Much land change science research, especially that which employs spatial models to understand land use and land cover change, explicitly include road networks as a function of land change (Cropper et al., 1999; Barber et al., 2014; Damania et al., 2018). Von Thunen's (1966) *Isolated State* proposed a spatial model that estimated land cover as a function of rent and distance to a central market, and this model has proven useful in many other more complex contexts such as urban expansion in a rapidly growing city (Sinclair, 1967; Quigley, 1998; Livanis, 2006; Colantoni et al., 2017). An explicit focus on the role of roads on urban land change would be particularly useful for this study because traffic impacts and transportation needs were mentioned several times during my interviews with city planners, and regional transit plans played a central role in planning documents. City planners recognize the role that roads play in urban change and seek to limit transportation in and out of a planning area such as Otay

Ranch. Construction of a transportation corridor through an undeveloped landscape is also often followed by rapid development. The degree to which this development is planned in tandem with the transportation corridor or occurs as a direct result of increased access to the area is a potential area of further study.

CONCLUSION

Within the field of land change science, understanding the drivers of urban expansion in particular areas is increasingly important. Urban expansion results in effects on water resources, biodiversity, climate change, and numerous other social and environmental effects. The literature on the drivers of urban growth recognize several significant drivers of urban expansion including those related to economic growth, planning policies, governance and other institutions, and political conflicts. In San Diego the drivers of focus in this study include economic growth associated with the innovation economy surrounding UCSD, historical land tenure associated with the Spanish rancho system, and planning efforts by the cities of San Diego, Chula Vista, and the county of San Diego. Other drivers certainly played a role in San Diego's recent urban expansion, but these seem to be the most significant for the two case studies within this thesis. Spatial analysis was utilized to quantify areas of growth in six different land-use classes, while semi structured interviews and document analysis informed the drivers of this growth. In the UCSD area, four significant industrial centers arose during the 1986 to 2017 study period. These were linked to the innovation economy and social network agglomeration of research-based sectors in the area. It is likely that residential growth in the same area grew in association with this economic growth, however further research is needed to understand the degree to which this relationship is causal. The Otay Ranch analysis showed that the Spanish rancho system played a significant role in where urban expansion occurred, while planning and other institutions steered the growth that actually occurred within the former Rancho planning area. Residential and industrial development continue today within Otay Ranch as well as in Otay Mesa along the U.S.-Mexico border, and significant urban expansion is likely to occur here within the next decade. Future research on the drivers of urban expansion in San Diego might include a more statistically rigorous analysis of the relationship between industrial and residential expansion, quantification of land cover associated with land use change to estimate effects on the carbon cycle, and the use of remotely sensed imagery to improve temporal resolution and facilitate a better understanding of the relative timing of different areas of growth.

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