Transformations in California's Dairy Industry:
Mapping Regional Variations in Milk Production and Operations

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Abstract

California has a central role in U.S. and global dairy: it leads the U.S. in dairy production and milk is the state's largest-revenue agricultural commodity. Changes in the structure and geography of dairy farming in California may be indicative of changes elsewhere. California's position at the leading edge of the large-scale intensification of dairy production was achieved during a relatively short history. Over the last seventy years, government regulations, research and development, technical innovation, and changes in market demand have encouraged increased herd size, specialization, and mechanization of dairy production in many places around the world, perhaps nowhere more profoundly than California. The climate, topography, and agricultural productivity of the state has created an exceptional setting for rapid growth of the dairy industry, but has also resulted in substantial air and water pollution and many environmental and resource concerns including contentious politics around land and water use. This research examines the spatial change of dairy production in California over the past four decades. I use county agricultural reports and USDA Census of Agriculture data to demonstrate, through a series of original maps and animations, the dramatic increase in production of milk in California and especially in the San Joaquin Valley, the rapid fall in number of farms, and the concurrent spatial redistribution of production within the state. These visualizations reveal illustrative spatial patterns and insights into rapid changes in the geography of dairy production within California. Based on these visualizations and analyses, I propose a framework for understanding the intersecting transformations seen in California and other major dairy producing states: regional concentration, industry consolidation, and farm-level intensification. In explaining how these processes are nested, overlapping, and multi-scalar, I offer an account of California's past and current trajectory, while examining the applicability and implications of these findings for other dairy-producing regions into the future.

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1. Introduction

The dairy industry is central to California agriculture – milk is the largest agricultural commodity from the state and more milk is produced here than in any other state in the US – the result of a dramatic intensification of milk production per farm, enlargement of herd sizes, and consolidation of dairy farms. I hypothesize that transformations in the California dairy industry have occurred unevenly across different agricultural regions of the state. The following objectives guided this research:

(i) Understand the history and geography of California's dairy industry since the earliest dairies were established through the rise of California as the largest producer of milk in the country today.

(ii) Visualize change in the dairy industry using a series of maps to preserve spatial and temporal resolution.

(iii) Differentiate outcomes of dairy industry change across nine agricultural regions of the state, with context for the socio-environmental geographies surrounding each region.

Previous work on dairy in California has typically focused on policy, natural resources, environmental footprints, and other factors related to milk production for the state as a whole (Butler and Wolf 2000; Naranjo et al. 2020; Gilbert and Raymond 1988; Guthey, Gwin, and Fairfax 2003), though some work has been attentive to regional differences in production (Sumner 2020) and the typology of production systems found within the state (Guthey, Gwin, and Fairfax 2003). In 1896, Wickson wrote a report for the USDA titled "Dairying in California" which included a hand-drawn map of the dairying areas of California (Figure 2). So far, there has been no study of regional changes in dairy production over time in California. By mapping data

at the county level, this research reveals spatial patterns and regional variations in California's dairy industry obscured by typical state-level summaries of milk production.

I begin with an overview of the history and geography of milk production in California. Milk is produced and consumed around the world, and the United States is the 2nd largest producer of milk, with California producing more than any other state. The physical geography of the state creates diverse landscapes that fosters agricultural productivity. Dairy production in California began with European settlers, continued in line with population growth, was supported by research, development, and price stabilization, and was transformed by corral feeding which became a catalyst for rapid expansion and industrialization of milk production in Southern California. In a review of literature on the topic of dairy, I identify several themes related to the transformations occurring in dairy industries: intensification, mechanization, specialization, enlargement, consolidation, regional concentration, and alternatives. These effects are understood through the lens of agrarian political economy, including the capital penetration of the natural barriers of agriculture, productivism, and the treadmill of production. In the methodology section, I detail the steps taken to collect and process 41 years of county-level data on milk production and operations, and then analyzing the data using cartographic visualization and change calculations. The result is a series of maps that show the volume of milk, number of farms operations, and distribution of production across the state changing over time. The data is then summarized by nine distinct agricultural regions. Finally, I summarize the patterns of change seen in California's county-level milk production and operations and the types of change in large scale dairy production described in the literature review as three interdependent, multi-scalar transformations: intensification, consolidation, and regional concentration.

2. Background Context: The History and Geography of California Dairy

Dairy Production Basics

It is important to begin with an overview of dairy production, as is it practice in the US and Global North. Like all mammals, cows must be pregnant and give birth to induce lactation and produce milk. After birth, calves are removed from the mother. Most of the calves are destined for meat production, and about half the heifer calves (females) are raised as replacement heifers to enter the dairy herd in two years. Young heifers are often given growth hormones to help them reach maturity sooner. In the United States, a cow is typically milked for 2-4 lactation cycles before she is culled, either "voluntary culling" for her decline in productivity, or "involuntary culling" for health reasons like mastitis or lameness. The longevity of dairy cows has been declining (Dallago et al. 2021).

Worldwide, 81% of milk is derived from cattle, then buffaloes, goats, sheep, and camels (FAO 2023a). Almost all the milk in California is from two breeds of cattle Holsteins and Jerseys. Jersey cows are smaller, eat less, and produce less milk per cow, but their milk tends to have a higher proportion of milkfat and other milk solids compared to Holsteins. Cattle are ruminants meaning they eat forages for many hours a day and have multiple stomachs to digest their fibrous diet. Most dairy cows in California are fed rations of alfalfa hay, corn silage, small grain silage, corn, and oilseed meals as well a range of agricultural by-products, such as almond hulls. A very small share of milk in California, about 2%, is from organic dairies where cows are required to get a significant share of the forage component from pasture.

The United States is the second largest producer of milk in the world, after India, followed by China, Pakistan, Brazil, and Germany. New Zealand is the largest producer per capita and exporter of milk after a significant production boom in the 1980s. New Zealand, the

United States, Germany, France, Australia, and Ireland have the highest milk surpluses (FAO 2023b). Within the United States, California is the number one producer of milk, followed by Wisconsin, Idaho, Texas and New York (USDA 2022). The following section describes the geography of California and its relationship to agriculture and dairy production.

California Geography and Agriculture

California has a remarkable diversity of landscapes, climates, and agricultural activities. The state is home to the lowest and highest elevations in the contiguous United States, with the Sierra Nevada mountains and Death Valley National Park. Four mountain ranges encompass the Central Valley – the Sierra Nevada to the east, the Cascade Range to the north, the Coastal Range to the west and the Tehachapi Mountains to the south (USGS n.d.). The Sierra Nevada mountains accumulate many feet of snow during the winter and serve as the sole source of water for rivers and reservoirs in the Central Valley during the dry summers.

Major rivers of the Central Valley are the Sacramento from the north and the San Joaquin from the southeast; both originate from numerous forks in the mountains and converge at the California Delta before flowing into the San Francisco Bay (Figure 1). Tulare Lake Basin, a dry lake that rarely floods (except during rare years of massive rainfall like in 2023) makes up the lower third of the Central Valley as seen in Figure 1 (USGS n.d.). The Coast Ranges to the west form a topographic wall, shielding the valley of moist air from the Pacific Ocean. The 840-mile-long coastline collects all the moisture and fog, creating a variety of climates in different valleys and hillsides along the coast from the sunny beaches in San Diego, the towering cliffs of Big Sur, the hills and valleys of Napa and Sonoma, and the redwood forests in Humboldt.

The topography of the state with mountains to the north and east, desert to the south, and the vast ocean to the west originally created an insulated region of agricultural production, where

Figure 1. Map of the Central Valley's four major regions (USGS n.d.)

production, processing, and consumption all happened within the state. The warm and dry Mediterranean climate of the Central Valley offers a long growing season and fosters agricultural diversity. Without rain for nine months of the year, the Sacramento and San Joaquin Rivers are the lifeblood of agriculture in the Central Valley. As a result, California is a highly productive state for agriculture – growing hundreds of types of crops and many livestock products, and producing half of all US-grown fruits, nuts, and vegetables. A diverse list of livestock and crop commodities comprise the top farm revenue commodities: milk, grapes, almonds, cattle and calves, strawberries, pistachios, lettuce, tomatoes, walnuts, and rice (CDFA 2022). This list accounts for only 60% of the total farm revenue in California. For comparison, in Iowa, the second most important farm state, the top four commodities account for more than 90% of farm revenue (USDA ERS 2023).

Despite its agricultural diversity, milk is the number one commodity from California in terms of revenue, and despite the multiple other states with high rates of milk production like Wisconsin, California has been the number one producer of milk in the United States since 1993 (Sumner 2020). Although the California dairy industry has a long history, the expansion of the dairy industry in California and its global prominence is relatively recent.

Early History of Dairy in California

Dairy has been a part of the history of California since the land was first colonized by Europeans. In the late 1700s, Spanish settlers brought cattle with them from Mexico to the Catholic missions along the coast of Alta California. The cattle were primarily used for meat, hide, and tallow, but milk and cheese were an essential part of the mission diet (CA State Parks 2005). A Russian fur trapping settlement at Fort Bragg also raised dairy cows and exported butter and cheese to settlements in Alaska. John Sutter, the man known for gold discoveries on

his land, used part of his fortune to purchase farm equipment from Fort Bragg and kept dairy cows among other livestock along the Sacramento River. In 1849, settlers from the United States arrived in large numbers from the east in search of gold, bringing animals and milk cows with them. These cows provided milk but also physical labor to pull wagons or plows when oxen tired. In the gold rush settlements, women who sold fresh milk and butter within the community may have brought home more income than their miner husbands (CA State Parks 2005).

The first recorded commercial dairy was established on 10,000 acres by Clara Steele in the coastal region of Marin County, where coastal hills had long been grazed by tule elk and Mexican longhorns. The coastal fog maintained green pastures through the summer and the cows could live outside year-round thanks to the temperate winters. The Steele dairy shipped fresh milk and cheese by boat to the new city of San Francisco and their success prompted a 'dairy fever.' In the 1850s and 1860s, grassland in Marin County was divided into in ranches for dairy and beef production. Marin and Point Reyes became famous for their high-quality butter, humorously known as the "new gold rush," the excess of which was shipped back east via the recently constructed continental railroad (Hutchison 1946; Livingston 2013).

As the population of California grew, the dairy industry expanded. The urban populations of San Francisco and Los Angeles increased the demand for milk and dairy products, further establishing dairying regions in Marin and Sonoma counties, and within Los Angeles County in the late 1800s (Gilbert and Wehr 2003). Coastal dairies spread down to Monterey and San Luis Obispo and up to Sonoma and Humboldt counties, and grassland in the Central Valley was also converted for dairying. In the north-eastern part of the Sacramento Valley, some dairies mimicked the Alpine style of dairying where cows spent summers in the mountains and winters in the valley (Wickson 1896). In 1896, University of California Professor E.J. Wickson

Figure 2. Map by E.J. Wickson (1896) of dairy regions in California, labelled by region.

documented the extent and climate types of dairy regions in California (Figure 2). At the time, he identified Humboldt County as the leading dairy county of California for having the greatest amount of product, greatest number of establishments, and for constructing the first modern creamery.

By the end of the 19th century, milk production was widespread across the coast, valley, and Northeast mountains of the states. Over 50% of farms in California had milk cows, and all processing of milk, butter, and cheese was done on the farm (Hutchison 1946). The home-based model of milk and dairy production would soon be replaced.

Industrialization of Dairy in California

As with almost every other significant commodity industry in California, research, extension, and education provided by the University of California played a significant role in the expansion of the dairy industry in California. Research at the University involved breeding and genetic experimentation to increase the productivity of cows and milkfat content of the milk and the development of dairy-farm building plans that were structurally appropriate for California's warmer climate (Hutchison 1946). Sanitary concerns of milk became the foremost issue for the industry, as illness from spoiled milk in the summer became routine, and in 1908, the University established the College of Agriculture in Davis, CA with its inaugural course on sanitary butter manufacturing for a larger scale processor (Hutchison 1946).

Los Angeles was the first county to industrialize dairy production (Gilbert and Wehr 2003); the number and size of milk cow herds expanded to supply the rapidly expanding demand for dairy products. By 1925, Los Angeles County was the leading producer of milk in the state, driven by population growth after World War I. The high cost of hauling fresh milk long distances meant dairies were located near the demand for the milk. Scientific advancements in

breeding, urbanization squeezing available land for grazing, and the introduction of drylot feeding by Dutch immigrant dairymen also drove the industrialization. Drylot feeding, also known as corral feeding or zero-grazing –essentially the practice of concentrating cows into a small acreage and bringing their food to them – was revolutionary for California dairy production (Gilbert and Wehr 2003, 475). This practice succeeded in California because the abundance of local agricultural by-products like sugar beets and citrus and the availability of cheap hay made drylot feeding affordable, actually increasing milk production per cow compared to grazing (Gilbert and Wehr 2003). A quote from the 1946 book *California Agriculture* written by the University of California College of Agriculture faculty exemplifies this well.

> When the valleys of California were planted with field crops, fruits, and vegetables, so that fences had to be built, beef cattle and sheep were relegated to the hinterlands. Not so the dairy cow: she thrives under intensive agriculture, and a small area will accommodate her individual manufacturing plant. She does best when she need not search for her raw material. If given roughages and concentrates in large amounts, she can devote her energies to converting the nutrients into milk. (Hutchison 1946, 83)

The Great Depression almost sank the dairy industry in California; surplus production, price cuts, and unregulated competition between processors, retailers, and farmers became known as the Milk Wars of the 1930s. The government stepped in with a Federal Milk Marketing Order (MMO) to help regulate national milk prices, but Californians, both farmers and distributors, argued it was a local issue, pushing instead for state legislation. The Young Act of 1935 set minimum prices for fluid milk in California, stabilizing the industry and increasing profits for farmers (Gilbert and Wehr 2003). California would maintain its own price regulations under a state MMO, resulting in less aggregate milk produced (Butler and Wolf 2000), until

2018 when the dairy industry voted to move to the federal MMO (CDFA 2023).

The new stability from the state MMO allowed farmers to invest in new technologies. This included upgrading facilities to have stainless steel and tile for sanitary improvement and, more importantly, introducing machines that milked cows with a vacuum pump connected to a cooler for immediate processing. These upgrades reduced the labor required for milking and enabled herd sizes to grow significantly in number (Gilbert and Wehr 2003).

As urban expansion in Los Angeles increased land values, farmers were able to sell their dairies at high returns and move east towards the Valley, often choosing to buy more land, build new dairy structures, and expand their herds. This cycle of urban encroachment, farm relocation, and herd expansion reoccurred several times during the 1930s and 40s in Los Angeles County, until eventually most of the dairy had moved to San Bernardino (Gilbert and Wehr 2003). For the same reason 40 years later, dairy farmers in Marin established the first agricultural land trust to protect family farms from urban development pressures in the Bay Area (MALT 2023).

Between the 1970s and 2000s, California production rates accelerated, surpassing Wisconsin as the leading producer of milk in the 1990s with almost 20% of the U.S. total production (Sumner 2020). This acceleration is attributed to unique geographic features of California that created ideal conditions for growth, despite several setbacks related to land prices, water availability, and the relatively late start for the industry (Butler and Wolf 2000). The warm climate allowed for large herd sizes without the need to house them indoors during the winters; the nearby crop production of high quality alfalfa and fruit or vegetable by-products, especially almonds-hulls, that helped minimize costs of feed; the geographic isolation of the state requiring sufficient in-state processing facilities; the large and diverse population creating demand and

labor for the industry; and the early adoption, or rather invention, of dairy science technology, have all helped bolster and accelerate dairy industry expansion (Butler and Wolf 2000).

California Dairy in the 21st Century

Throughout the past two decades, California remained the leading dairy producer in the country and became known for its "megadairies" of more than a thousand cows in a herd (source). The technological developments and huge herds established a new mode of production for dairies, unlike anything attempted by the traditional dairying states in the Midwest and Northeast. Yet the industry in California is still heterogenous. Organic dairy production is heavily concentrated along the coasts, in Marin, Sonoma and Humboldt, while conventional dairies and concentrated animal feeding operations (CAFOs) dominate the Central Valley. Despite the large size of the farms, 99% of dairies are considered family farms[1] (Keough 2021).

The environmental impacts of dairy production are primarily methane emissions from enteric fermentation (gas from digestion) and manure storage, water quality impacts due to nitrogen and phosphorus excretion from manure lagoons, and water and land use for feed production (Naranjo et al. 2020). California has implemented mandates for reducing greenhouse gas emissions (GHG) to 40% below 1990 levels by 2030. While California's agriculture sector

[1] The USDA defines a family farm as "any farm in which the majority of the business is owned by an operator and any individuals related to them by blood, marriage, or adoption, including relatives who do not live in the operator's household" (USDA 2023).

makes up a smaller share of GHG emission compared to transportation and energy, its emissions have more than tripled since 1990 (Energy Information Administration 2018). There are currently efforts to reduce methane emissions in dairy production; with state programs that incentivize anaerobic digesters for manure, or alternative manure management practices like composting or separating solids; as well as increasing the productivity per cow to reduce the GHG footprint per unit of milk produced; and research into feeding seaweed supplements to reduce methane gas from digestion (Naranjo et al. 2020).

Water quality impacts are acutely felt in the San Joaquin Valley, as drinking water is contaminated with nitrates from agriculture, including manure from dairy concentrated animal feeding operations (CAFOs), which is associated with higher rates of disease and cancer (Community Water Center n.d.). In Marin County, Conflict over land use for grazing is exemplified by tensions between conservation efforts to re-establish free-ranging tule elk in Point Reyes National Seashore and the long-term beef and dairy producers in the designated pastoral zone (Black and Larson 2018).

The unique history and geography of California has both supported and challenged the expansion of the dairy industry into the modern day giant of milk production. The following literature review looks at structural changes in dairy production in California, the United States and globally through the lens of political economy.

3. Literature Review: Structural Change in Dairy Production

Fundamentally, agriculture is the production of living things, relying on plants, animals, and life sustaining ecological elements like water, soil, air, and sunlight to grow food, fiber, and fuel. For the entire history of humanity, and even in a modern capitalist society, agriculture and access to food has been, is, and will continue to be essential to the function of society. The expansion of agricultural production and the planned food system has enabled the development of all other sectors of the economy and society. With fewer people producing food as their occupation, producing more of it is both necessary and opportunistic.

The study of food and agriculture is undertaken by many disciplines; biologists, chemists, economists, historians, sociologists, anthropologists, and geographers – this long list exemplifying its complexity and importance. Within the discipline of Geography, and sometimes overlapping with other social sciences, there are several subdisciplines that attempt to capture and explain the relationships between environmental, economic, political, social, and cultural factors that converge in the production of food. These subdisciplines include political economy of agriculture, political agroecology, rural agrarian sociology, black food geographies, and sustainable agriculture and food systems, etc.

For understanding California's milk production, I am interested specifically in literature related to: *agricultural production*, rather than supply chains or consumption; *animal agriculture*, although CAFOs rely wholly on feed from corn, soy, and hay growers, and benefits from crop production by-products; and *industrialized operations*, although there remains a small amount of small-holder dairy operations in the state. For understanding the realm of industrialized animal agriculture, that which California milk production (mostly) lies within, the political economy of agriculture is the most appropriate subdiscipline to contextualize the structures that shape change in the dairy industry in recent history.

Political Economy of Agriculture

The political economy of agriculture is a cross-disciplinary concept that deals with the relationship between agricultural production and structural forces. “The political economy of agriculture (or agrarian political economy) investigates how “structural changes” (e.g., policies and markets) in agri-food systems shape the means of production, thereby constraining and/or enabling producers' decision-making (Buttel, 2001)”(Clay and Yurco 2020, 5). Political economy of agriculture is rooted in liberal and Marxian traditions and the belief that capitalism is the organizing force for agriculture in the U.S. The clearest difference between political economy of agriculture and political ecology of agriculture is that the former focuses more on structures, while the latter leans more toward individual agency and also tends to emphasize topics of environmental conflict and ethics. The following subsections describe three themes of agrarian political economy related to structural changes that shape dairy industries: capitalist penetration of agriculture, productivism, and the treadmill of production.

Capital Penetration of Agriculture

In the production of living things, agriculture presents natural barriers to capital penetration. The Mann-Dickson Thesis (1978) states that “[c]apitalist development appears to stop, as it were, at the farm gate” (qtd in Carolan 2022, 15) which is to say that the unique nature of agriculture and food production, such as the perishability of food or the long production time compared to labor time, hinder the accumulation of capital in agriculture. In the pursuit of surplus value, capitalism must transform and subvert these natural processes into a source of productivity, a process known as the *real subsumption of nature* (Cooper 2017; Boyd, Prudham, and Schurman 2001). In the United States, dairy operations have overcome natural barriers to capital such as perishability, long production time, and waste in the following ways. Fluid milk is

highly perishable, which presents many risks to the producer. “The more perishable the commodity is and the greater the absolute restriction of its time in circulation as a commodity on account of its physical properties, the less it is suited to be an object of capitalist production” (Marx qtd in Carolan 2022, 16). Standards for sanitation and food safety, and the interest of prolonging the shelf life of milk, led to the invention of pasteurization and refrigeration. Too little time on the shelf is coupled with too much time for production. A dairy cow takes two years to reach puberty with another nine months for gestation before she produces milk. The long production time of has been shortened with concentrated feeding to increase weight gain and shorten time until puberty, and the use of hormones to increase the imminence and volume of milk production. That said, unlike most other agricultural products, milk production requires daily ‘harvesting,’ increasing the labor time. Finally, the production of milk inevitably co-produces manure and methane as waste. This becomes problematic under intensified conditions, requiring removal and creating sources of pollution. The generation and concentration of manure produced in large dairy operations is dealt with using flush systems to waste lagoons, resulting in water pollution and methane emissions. These three examples of agriculture’s unique properties that hinder capitalist penetration, but are still overcome with certain interventions, or subsumptions of nature, set the stage for the other transformations that have occurred in the dairy industry, detailed below.

Productivism

The concept of productivism, or the emphasis on increasing agricultural production above all else, appears frequently in the literature about dairy production in the Global North. In 1993, Lowe et al. defined productivism as “a commitment to an intensive, industrially driven and expansionist agriculture with state support based primarily on output and increased productivity”

(qtd. in Jay 2007, 267). Jay describes how productivist sentiments shaped the New Zealand dairy industry to expand rapidly in the 1980s, resulting in dual pressures to maintain its economic efficiency while reducing its environmental impact. In their summary of three different narratives about the preferred trajectory of milk production in the Global North, Clay and Yurco (2020) situate the growth of the US dairy industry in the 20th century as the result of productivism after World War II, couched in language about growing a nation through growing strong bodies with "more milk". Attitudes of productivism manifesting as the intensification of milk production were, and continue to be, the catalysts for multiple other forms of transformation at the dairy farm and industry.

The Technological Treadmill

The treadmill of production is a concept coined by Cochrane (1958) to explain how economic pressures to lower prices and competition with other producers keeps agribusiness in a constant state of the pursuit of growth. Schnaiberg built on this concept in 1980 by applying the treadmill of production to explain the increasing demand for natural resources resulting in increasing environmental degradation (Kenneth A. Gould, Pellow, and Schnaiberg 2004). The use of new technology or resources by early adopters eventually brings a boost in production, which allows that producer to eventually lower their prices, making their product more competitive on the market. To compete, other producers must also adopt the new technology or increase in resource use, until eventually most producers have either invested in the technology or gone out of business because they could not produce enough compete. This results in fewer farms, producing more and more product, until the next technology comes along to perpetuate the cycle, hence the idea of the 'treadmill.'

Transformations in Dairy Production

The following is a summary of trends and themes documented in the literature about dairy production in the United States and Global North. Past and current geography research on dairy depicts an industry in flux, under the influence of capitalism, policy, and the environmental contexts of the region at hand. Here (Table 1), I define and describe the six themes of transformation occurring in the dairy industry, and a seventh theme, the alternatives that have arisen in reaction to these dominant transformations.

Table 1. Themes observed in literature on dairy production in the Global North

Theme	**Example from the literature**
Intensification	"increased milk output relative to inputs of feed, labour, land, or herd size." (Clay, Garnett, and Lorimer 2019, 35)
Mechanization	"Farm specialization and mechanization strategies emphasize increasing milk production through larger herds, breeding technologies, indoor housing/feeding, energy and protein-dense commercial feeds, antibiotics and growth hormones (in NA), specialized staff or machines." (Clay, Garnett, and Lorimer 2019, 36)
Enlargement	"growth in size, scale and productivity" (Willis 2004, 84)
Specialization	"milk production changed from being an activity, perhaps only a side-line, on a farm with milk cows to an activity on an operation where milk production was the sole or most important activity." (Blayney 2002, 1)
Consolidation	"The average farm size is increasing, the number of dairy farms is decreasing…" (B. Gould 2010, 2) "[T]he U.S. farm size distribution in agricultural production is highly skewed—there are many very small farms in the Nation, but most agricultural production is concentrated among a small number of much larger farms." (MacDonald, Hoppe, and Newton 2018, iv)

	"The pace of farm consolidation appears to have slowed after 2007. In livestock, only dairy shows continued rapid consolidation." (MacDonald, Hoppe, and Newton 2018, 1)
Regional Shifts	"[S]pecialization contributed to creation of identifiable dairy regions, a factor with important ramifications for dairy farmers and other members of society." (Blayney, 2002, p. 1)
	"[T]he location of production has shifted significantly to non-traditional production areas. The expansion of the dairy industry in such states as Idaho, Texas and New Mexico and concurrent reduction in production in traditional dairy states has resulted in the production by small farms in the historical producing areas being replaced by production originating from significantly larger operations (GAO, 2001)." (B. Gould 2010, 2)
Alternatives	"Rather than sell out entirely or relocate to expand their operations, [dairy farmers in Marin, CA] are transforming their farms. They are experimenting with organic milk and boutique cheeses, organic beef and produce, olives, and wine grapes. Some incorporate new ventures into traditional milk production. Others are developing new management styles or even purchasing more land for their dairies." (Guthey et al., 2003, p. 2)
	"Recognition of these negative impacts of intensification has led to efforts to envision and enact alternative dairy futures. These efforts can be categorized into three broad framings that shape research and ongoing policy and advocacy agendas on dairy production and consumption: (1) sustainable intensification, (2) multifunctional agriculture (including alternative food networks), and (3) agroecology." (Clay et al., 2019, p. 41)

Intensification

Intensification is a major buzzword in the world of agriculture, but it has varied definitions and applications. Fundamentally, intensification implies a change or transformation of the mode of production. In the original sense of the term, intensification is an increasing ratio between inputs and outputs; the variation in meaning exists in the consideration of different types

of inputs. While agricultural economists look at increasing production relative to inputs of feed, fertilizer or water, geographers consider land and capital to be inputs capable of intensification and use the term intensification to describe all manner of increased productivity or large-scale agricultural systems. Clay et al. (2019) define intensification in dairy as the increased milk output relative to inputs of feed, labor, land, or herd size, while Bojovic and McGregor (2022) describe the intensification of capital, land, and animals within the industry. The term is used to convey negative or increased impacts on the environment, because of the increased use of resources or pollution. The concept of "sustainable intensification" is commonly found in recent literature on agriculture, which is defined as increasing food production while minimizing the effects of production on the environment and not expanding the area of land used for agriculture (Cassman and Grassini 2020).

Mechanization

Mechanization is the replacement of production processes with a machine or technology. The use of technological innovations in agriculture, as described in the background section, has been a key transformation to enable intensification and allow for capital penetration. Many of these technological innovations come in the form of machines, or practices that require the use of machines, like concentrated animal feeding operations (CAFOs), automated milking machines, or anaerobic digesters. The technological fix is a concept in agriculture and technology studies that describes the act of inventing a new technology to solve every new problem, which is often criticized for creating new problems of their own, and perpetuating systems that should be abandoned (Scott 2011). Dairy technologies that may be subject to this line of criticism are anaerobic digesters or the recent research to use CRISPR to genetically modify the methane-producing microbes in the cows' stomachs (Sicard 2023). Mechanization contributes to

enlargement and specialization in dairies by reducing the space or labor needed to feed and milk cows, as is the case with CAFOs or automated milking machines, and by encouraging investment and specialization in that specific stage of production.

Enlargement

One of the hallmarks of change in industrial dairy production is the enlargement of herd sizes. The average number of cows per farm is increasing in the U.S., and dairy production increasingly comes from large farms, measured by farm income (MacDonald, Hoppe, and Newton 2018). Willis (2004) documents the dramatic enlargement of diaries that occurred in New Zealand between 1971 and 2001, where the number of cows increased 51%, the average herd size increased 128%. Enlargement is type of intensification – in which the input is the number of farms and the output is the herd size or amount of milk produced per farm. Enlargement both requires and allows for specialization and mechanization to occur by making the investment in technology and machines more affordable, thus encouraging more expansion thereafter.

Specialization

Specialization is the focus on fewer commodities or stages of production within each farm. In the case of dairy, operations specialize to only produce milk, purchasing their cows and feed from other sources, and selling milk to a processor. This involves enlarging herd sizes and investing in equipment that increases efficiency of milk production (Blayney 2002). Specialization is related to *horizontal integration*, in which operations expand their production of milk by increasing their herd size or acreage. The opposite model is *vertical integration*, in which a single farm may breed, raise, milk, and slaughter their own cows, grow their own feed,

manage their own pasture, or process their own milk, cheese, or butter. The process of specialization is stretching these stages of production across multiple operations, meaning that the raising, feed production, milk production and dairy processing each happens in a different location. As milk production, mechanization, herd sizes, and specialization all increase, the industry is consolidating.

Consolidation

The number of dairy farms has been rapidly declining everywhere in the United States. Consolidation is happening across all agriculture in the US but especially so in dairy. As MacDonald et al. report, "the pace of farm consolidation appears to have slowed after 2007. In livestock, only dairy shows continued rapid consolidation" (2018, 1). Consolidation has not occurred evenly across the livestock sector; dairy, chickens, turkeys, and hogs are highly consolidated, while beef and cattle operations are not, suggesting that consolidation has more to do with the confinement style of raising livestock or the frequent milkings required on a dairy farm, than the species of animal itself. This consolidation may be due to smaller farms going out of business, merging with larger farms, or moving to other regions. Gould (2010) documents consolidation in dairy farms, co-operatives and processing facilities and argues that this high level of consolidation differentiates dairy from other agricultural sub-sectors. Cross (2006) characterizes the restructuring of dairies as a shift toward megadairies in California, away from the traditional dairy belt in the Midwest and Northeast. He also points out that Amish farmers are the ones who continue to run dairy farms at a small scale, speaking to the technology-driven industrialization of large-scale farms.

Regional Shifts

The final trend observed in the literature about dairy is the discussion of regional shifts in where dairy is produced. The specialization of dairy production led to the creation of identifiable dairy regions in the United States, which have historically been in the Northeast and Midwest, also known as the 'dairy belt' (Blayney 2002; Cross 2006). Scholars observe the trend of regional shifts in production both within the United States and on a global scale. Cross (2006) describes the shift from the traditional dairy belt in the Midwest and Northeast states out west to California and Idaho. Harrington et al. (2010) describe the movement of large dairies into the plains of Southwestern Kansas. Gould (2010) names the expansion of dairies in Texas, Idaho, and New Mexico as concurrent with the reduction of dairies in traditional dairy states, such as Vermont, where organic dairy farmers resist pressures to expand or sell (Krieg 2014). Dairy production on a global scale is also expanding into the Global South as Western diets and higher rates of milk consumption are adopted in East Asian and African countries (Bojovic and McGregor 2022). All these observations of the regional shifts of milk production are described alongside processes of consolidation, specialization, enlargement, mechanization, and intensification.

Alternatives

Finally, although the topic is beyond the scope of my research, the many alternatives to the structural transformations that are observed in dairy literatures in the United States and beyond must be addressed. Alternative production trends include sustainable intensification, multifunctionality or vertical integration, and agroecology (Kremen, Iles, and Bacon 2012; Clay, Garnett, and Lorimer 2019), as well as regenerative and organic dairy production (Krieg 2014; Guthey, Gwin, and Fairfax 2003) and increasing disruption from the rise of plant-based non-

dairy milks (Bladow 2015; Clay et al. 2020; Bojovic and McGregor 2022). These all come in reaction to the negative environmental, human, and animal impacts of intensive dairy production and fall under the "better milk" or "less milk" narratives for the future trajectories of milk (Clay and Yurco 2020). In California, Marin and Sonoma Counties are the region with the strongest collective effort to produce milk alternatively to the industrial model of the rest of the state (Guthey, Gwin, and Fairfax 2003).

In summary, dairy industries in the United States and Global North have undergone, and continue to experience, significant transformation. Six dominant themes of transformation discussed in the literature are intensification, mechanization or technological innovation, enlargement, specialization, consolidation, and regional shifts. Evidence of these transformations are seen in the trends of milk production and number of operations derived from the following methodology and analysis.

4. Methodology: Visualizing Spatial-Temporal Change

To understand the changing geography of the dairy industry in the California, I used data from the USDA Census of Agriculture and California Crop Reports to map changes over time in milk production and number of dairy operations across California's 58 counties. Previous work on dairy in California has typically focused on policy, natural resources, environmental footprints, and other factors related to milk production for the state as a whole (Butler and Wolf 2000; Naranjo et al. 2020; Gilbert and Raymond 1988; Guthey, Gwin, and Fairfax 2003), though some work has been attentive to regional differences in production (Sumner 2020) and the typology of production systems found within the state (Guthey, Gwin, and Fairfax 2003). In 1896, Wickson wrote a report for the USDA titled "Dairying in California" which included a hand-drawn map of the dairying areas of California (Figure 2). So far, there has been no study of regional changes in dairy production over time in California. By mapping data at the county level, this research reveals spatial patterns and regional variations in California's dairy industry obscured by typical state-level summaries of milk production.

Data Sources

California County Ag Commissioner's Crop Reports, 1980-2020

The United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) publishes annual crop reports from the California County Agricultural Commissioners. These reports compile the total production, acres, yields, prices per unit and value of many agricultural commodities from each county in California. The data are available for every year from 1980 to 2020 for download from the USDA NASS website under the California County Ag Commissioners' Data Listing (USDA NASS 2022). The most recent year's report (2020) was partially incomplete at the time of this study. Some counties were absent from

the data and had to be interpolated using the average of the years before and after each missing year. Data collection and reporting is the responsibility of each individual county, and not standardized in either definitions, data collection, or reporting, so the way values are measured or aggregated may have differences across different counties and years. It is not possible to readily know the differences in method or definition. The crop reports also do not disclose any information about farm sizes or the number of farms, so production values are the sum of all operations' production at the county level, and prices are the average price. This obscures any nuance between different operations, but for a state-wide analysis like this one, these crop reports offer the best available data on agricultural production by county on an annual basis.

USDA Census of Agriculture, 1997-2017

The Census of Agriculture is the only source of uniform and comprehensive data about agricultural producers, acreage, activities, and sales in the United States. In recent decades conducted by the USDA, the Census of Agriculture is a national survey of all agricultural activities, operations, and producers, conducted every five years that attempts to collect information from every relevant farm operation. The most recent agricultural census, for 2022, was still being conducted at the time of this study, therefore 2017 was the most recent year available.

The Census Bureau began collecting data on household agricultural activity in 1820 as part of the national decennial census. From 1840 to 1950, a separate census of agriculture was collected the same year as the national census, until it was switched to a five-year interval in years ending in 4 and 9, and then again in 1982 to years ending in '2 and '7. In 1997, funding responsibility shifted to the USDA, but questionnaires and mailing are still carried out by the Census Bureau.

The census captures dairy in a few ways, including *Milk - Operations with Sales*, *Milk - Sales in US Dollars*, and *Milk Cows Inventory*, but it does not have a definitive count of active dairies. Operations with milk sales may differ from operations with milk cows in a given census year if the operation is going out of business and still has milk to sell but no longer has cows on site. Farms may also have a family milk cow, or a cow as part of a child's 4-H project. In these cases, the farm may have other activities but not be engaged in milk sales and therefore not be considered an active commercial dairy farm. For the purposes of this study, I chose to use operations with milk sales to capture most of the active dairies from each year. Using the USDA Quick Stats tool to find census data on *Milk - Operations with Sales* for California returns the years 1997, 2002, 2007, 2012 and 2017 and comes with the county name and the number of operations.

Data Processing

County Milk Production

All available years of the county crop reports were downloaded from the USDA NASS site as .CSV files and compiled using R Studio for processing and analysis. A total number of 442 crop types were reported. After merging the 41 years into a single data frame, I filtered the dataset to include only milk related commodities, of which there were three possible types: *Milk Market Fluid*, which refers to Grade A beverage milk (all fluid milk in the US has to be Grade A); *Milk Manufacturing*, which refers to milk that is used to make butter, cheeses or milk powder; and *Milk Cow's Unspecified*, which simply means that the county did not distinguish between fluid and manufacturing milks. While they are reported differently depending on the county, these three types of milk are the same in terms of form and units (hundredweights or Cwt). Milk is measured in hundredweights, notated as Cwt, which is equal to 100 pounds or

11.63 gallons of fluid milk. For the purpose of my analysis, I summed the different production values for the three categories of milk to allow for comparison across all counties.

Lastly, I pivoted the table to make the data compatible with a shapefile for mapping, so there was one row per county with a column for each year of production, 1980-2020. This pivot removes any associated data such as price per unit or value, which can be addressed in a separate data frame or re-joined if desired but was not included in this analysis. At this point, any holes in the data were identified where the original county reports were missing production quantities for certain counties and years. This may be due to errors in the compiled report, or that the county only reported the total monetary value of the commodity, without reporting the hundredweights of milk produced. Table 2 summarizes the counties and years that were missing data, and what steps I took to fill in the data.

I first searched directly in the County crop reports online and filled in blank data in an excel sheet. If the crop reports did not report milk production quantities that year, I used a simple average formula to interpolate the data from the previous and following year so as to not leave any blank cells, which would appear the same as zeros on the maps. For a few counties, the reports from 2018 onward were missing, so I extrapolated numbers from the most recent year. In the end, 41 out of 58 of California counties remained in the dataset, meaning 41 counties reported milk production at least once between 1980 and 2020. Of these 41 counties, 22 of them had milk production reported for the full time-period (after interpolation), while 18 counties stopped reporting milk production at some point between 1981-2014.

Table 2. Data points missing from the USDA CA Agricultural Commissioner's Data Listing

County	Years	Method or Source	Production quantity
Del Norte	2020	Extrapolated from 2019	*532,000
Humboldt	1993	(Humboldt County Department of Agricutlure 1993)	2,380,434
	1996-1997	Interpolated between 1995 and 1998	*2,497,901
	2020	Extrapolated from 2019	*2,353,000
Mendocino	1985	Interpolated between 1984 and 1986	*109,445
	1987-1991	Interpolated between 1986 and 1992	*138,092
	2018-2020	Extrapolated from 2017	*219,000
Santa Barbara	2001	(Santa Barbara County 2001)	597,512
Santa Clara	1985	(Santa Clara County 1986)	751,000
Santa Cruz	1983-1985	Interpolated between 1982 and 1986	*82,080
Sonoma	1984	(Sonoma County 1984; 2020)	533,800
	2019		4,790,312
Stanislaus	2004	(Stanislaus County Department of Agricutlure 2004)9/7/23 9:37:00 AM	37,616,000
Sutter	1988	Interpolated between 1987 and 1989	*100,669
Yuba	2018-2020	Extrapolated from 2017	*656,000

(* interpolated or extrapolated value)

Operations with Milk Sales

For the Census data, I downloaded all available years (1997, 2002, 2007, 2012 and 2017) from USDA Quick Stats as CSV files and brought them into R Studio. Following similar steps explained in the previous section, I filtered the dataset to keep only the relevant information (county, year, data item and production value) and then pivoted it to create one row per county and one column for each year. The data had no missing values. In the end, 55 out of 58 of California counties remained in the dataset, meaning 55 counties had at least one operation with milk sales reported in the Census between 1997 and 2017.

California Counties and Agricultural Districts

California has 58 counties; the smallest is San Francisco County and the largest is San Bernardino. These counties are grouped into eight agricultural districts by the CA County Agriculture Commissioner's Data Listing. The finest resolution of the production and operations data publicly available is at the county level. The initial analysis is presented at the county level for all the Census years and decades, after which the data is aggregated into regions, as shown in Figure 3, to show the broader patterns. Based on the history of California's dairy industry, and the current milk production rates, I distinguish Marin and Sonoma from the Central Coast counties as its own agricultural region in the context of dairy production, creating nine regions.

Data Visualization and Analysis

This research involves two sets of spatial-temporal data from 58 counties spanning 41 years. When visualizing changes over space and time, a static map or time-based chart will inevitably sacrifice nuances, obscuring changes through the years or spatial relationships between counties. I developed a methodology to map changes over time using a sequence of maps designed to be viewed in succession, either flipping through full pages or as an animation in a GIF file. The result is a unique visual of the data that captures the spatial relationship while maintaining the temporal resolution. To provide further detail, the maps are supplemented with data tables summarized by decade and with basic calculations like percent share and percent change to quantify the effect that the maps give visually.

Mapping Spatial and Temporal Data

To visualize the milk production and dairy operations data I had acquired, I created bubble maps, or maps using proportional symbols, to address the problem of using county-level

Figure 3. Map of California county borders, labelled with county names and colored by agricultural region. Cartography by the author. Data source: State of California (2023).

data in symbolizing quantities. A map with proportional symbols uses point sizes to represent the number of farms per county, or volume of milk produced. This is an alternative to maps where a color gradient fills the shape of the county, known as a choropleth map. While there are benefits and drawbacks to both types of symbology, I decided to use proportional symbols because the size of the counties in California is irregular, and the size of the counties would affect the visual weight of the color. I executed the same steps to create the maps of milk production and number of operations for all years, as follows.

There are at least two methods to create the maps of proportional symbols, and I used both – the first in R for creating a series of 41 maps automatically and the second in ArcGIS Pro for more detailed cartographic design. In R Studio, I created centroids of each county based on a shapefile of California County Boundaries (State of California 2023), and then joined the processed and interpolated data to the shapefile based on county name. I used the "tmap" package with the "tm_bubbles" function to create circles based on the quantity of milk production or operations within each county. I set the "size.max" as the maximum production quantity, or number of operations, for the full dataset to standardize symbology across all the years. I set the scale to 5, the style to "fixed," and set breaks to 2,500,000 for production. I used a function to iterate over each column of the dataset to create maps of production for all 41 years automatically. Finally, I exported the maps as images and brought them into Photoshop where I overlay and animated them into a short GIF that loops through all years. The GIFs can be viewed via Google Drive at https://bit.ly/CAdairyGIFS.

In ArcGIS Pro, the visualization was almost identical but the steps to create the maps were different. I symbolized the data from each year using proportional symbols and set the maximum point size for each year to a fraction of that year's maximum value to standardize the

sizes of the symbols across all years. For the production maps, this fraction was one over one million – for example in 1980 the maximum production value was 24,711,000 Cwt, and I set the maximum symbol size for the 1980 map to 24.7 points. The minimum symbol size for production was 1pt throughout all years because the minimum production values were always less than half a million. For the operations maps, the fraction was one fifth – so in 1997 the maximum number of operations in a county was 325, and I set the maximum symbol size to 65 points. The minimum symbol size was calculated the same way, but the minimum number was always less than 6 so the minimum point size was always one. Taking the same fraction of each year's minimum and maximum created a uniform scale of point sizes across the multiple years. If I were to leave the minimum and maximum the same for multiple years, the values would be stretched or compressed within that range, but the sizes would not correspond to the same values across different years. This did mean that each of the years had to be symbolized individually, which I did for five decades for the production maps and five years for the operations maps. Since the maps in ArcGIS were created to be static maps published in this thesis submission, or a journal submission, where a GIF animation will not work, I decided to average the 41 years of production data by decade, so as to not be forced to cherry-pick 5 singular years, thus losing 37 years of data, when creating a series of five maps. While averaging the decades does reduce the temporal resolution, the averages still represent the general annual production rate of each county. I calculated the average annual production in Excel for 1980-1989, 1990-1999, 2000-2009, and 2010-2019. I left 2020 on its own and symbolized its own map, since the data seemed dissimilar to the production rates even a few years before, and is the start of a new decade.

Measuring Change

The effect of the maps is that the actual change, percent change, and percent share are all represented visually by the changing sizes of the circles. In order to quantify the changes represented in the maps, I calculated each county's percent share of the state total of production (Table 4) and operations (Table 6) for all years available, and then the actual change and the percent change of each county's production (Table 5) and operations (Table 7) from the beginning of the dataset to the end, 1980-2020 and 1997-2017 respectively.

Percent share, meaning what part of the whole each county contributed, was calculated with the following formula, using production as an example:

Percent Share = County Production in 1980 ÷ State Total Production in 1980 × 100

Percent share gives a sense of where each county stands in relationship to the rest of the state, and is also useful for tracking across the period of time to show if the county gained or lost production and operations at a rate similar or different to the rest of the state. Any missing data will skew the percent shares of states that did report production. Actual change and percent change are calculated based on a start and end point; for production, I compared the 1980s average annual production to the 2010s and for operations I compared 1997 to 2017. They are calculated using the following formulas, using production as an example:

Actual Change = Production in 2010s – Production in 1980s

Percent Change = Actual Change ÷ Production in 1980s × 100

Both values will either be positive (meaning the variable increased), negative (meaning the variable decreased), or zero (meaning no change). This gives a sense of comparison within the county itself over time, and it is useful to compare the percent change in milk production next to operations within the same county.

Limitations

There are a few limitations to the data involving the quality and time-period and scale of the data that must be acknowledged. The data had 45 counties in the production dataset and 55 counties in the operations dataset. This points to potential flaws and differences in both the county crop reports and the Census of Agriculture data. The annual county crop reports are compiled from independent reports, they do not claim to cover all of agriculture or report everything. In the reports, counties aggregate the revenues of many commodities and may exclude small quantities. This may result in underestimates of production. Missing data will also increase errors in the percent share calculation of other counties. As described in the data processing subsection, missing data was addressed using interpolation (Table 2). The Census of Agriculture has the opposite problem where any operation with milk sales is included in the dataset regardless of size or actual commercial dairy status, possibly resulting in overestimates of the number of active dairy operations.

The data is also limited to the time-period of available data and that two datasets do not cover the same length of time. The county crop reports were available annually from 1980, while the Census of Agriculture was only available every 5 years beginning in 1997. This limits the capacity for comparison of production and number of operations by year, as the beginning dates are 17 years apart and the resolution of the data is so different. This also keeps our analysis in the contemporary period, whereas we know from our literature review that milk has been produced commercially in California since the late 1800s, about 150 years.

Finally there is the problem of resolution and geolocation. The finest scale data readily available is at the county level. The county sizes vary greatly and many of them overlap with mountain ranges or deserts that are not agriculturally productive, therefor diluting the actual area. When I use proportional symbols, they are plotted in the center of the county, or the centroid. For

large counties like San Bernardino and Tulare where more than half of the state is desert or mountains respectively, this can create a misleading effect in the maps. This problem persists, and possibly made worse, when I use graduated colors or dot density maps as well, as the full area is filled with color or dots, while actual milk production may occur only in a small corner of the county. This problem would be ameliorated with more information on the locations of the dairies, but without it, the maps should be interpreted with the understanding that the dots are not accurately located where milk production occurs in the county, and instead should be interpreted as a symbolic marker of the county's production rates.

5. Results and Analysis: Mapping Transformations in California's Dairy Industry

Production and Operations Maps

The following two sections contain maps visualizing the data collected on milk production and operations at the county-level, each followed by tables of the quantities and percent shares of production and operations that the maps were based on for more detail. The California Agricultural Commissioner's Annual Crop Reports provide data on individual county milk production rates from 1980-2020. Figures 4-8 are maps of the average milk production by decade. Table 3 shows the average annual volume of milk produced for each county by decade, and Table 4 shows each county's percent share of the total average annual production. Table 5 shows the actual change and percent change between the 1980s and 2010s of average annual production for each county. The Census of Agriculture provides data on the number of operations with milk sales for each county for the years 1997, 2002, 2007, 2012 and 2017. Figures 9-13 are maps showing the decreasing number of operations by county through all 5 of the Census years. Table 6 shows the quantities and percent share of operations for each county for all 5 years. Table 7 shows the actual change and percent change in number of operations between 1997 and 2017.

Milk Production, 1980-2020

From 1980-1989, the total average annual milk production was 159 million Cwt for the state (Figure 4). 40 counties reported milk production; the lead producing county from was San Bernardino with an average of 28.3 million Cwt, followed by Tulare (19.5 million Cwt), Riverside (17.6 million Cwt), Stanislaus (17.3 million Cwt), and Merced (17.1 million Cwt) are the top five producing counties, all from Southern California or the San Joaquin Valley. The minimum production reported was Inyo County in the Sierra Nevada Mountains with 400 Cwt.

From 1990-1999, California's total average annual milk production was 249 million Cwt. 36 counties reported milk production; Tulare swapped with San Bernardino for first, reporting an average of 49 million Cwt of milk produced annually, a significant jump from 19 million in the 1980s. San Bernardino (32 million Cwt), Merced (30 million Cwt), Stanislaus (26 million Cwt) and Riverside (23 million Cwt) came in the top five. All of these top producers increased actual production quantities but Riverside and San Bernardino decreased in percent share of total production (Table 4). The minimum production reported was Lassen County, in the Northeast Mountain region with 18,868 Cwt (Figure 5).

From 2000-2009, California's total average annual milk production was 368 million Cwt. 30 counties reported production after 2000. The lead producing county for the full decade was Tulare, averaging 96 million Cwt of milk per year, almost twice the 1990s level. Tulare was followed by Merced (51 million Cwt), Stanislaus (37 million Cwt), Kings (32 million Cwt) and Kern (27 million Cwt) as the top five producing counties. San Bernardino (26 million Cwt) and Riverside (15 million Cwt) fell out of the top five and decreased their averages and percent shares of total milk production. The minimum production reported was Colusa County in the Sacramento Valley with 12,578 Cwt (Figure 6).

From 2010-2019, California's total average annual milk production was 402 million Cwt. 23 counties reported production after 2010. Tulare County produced an average of 110,418,100 Cwt during this decade, which is over a quarter of the state's total. Merced (61 million Cwt), Kings (42 million Cwt), Stanislaus (41 million Cwt)and Kern (38 million Cwt) made up the rest of the top five. These five counties alone make up 73% of the reported milk production, and are all located in the San Joaquin Valley (table). The minimum amount produced was from Butte County in the Sacramento Valley with an average of 52,753 Cwt (Figure 7).

Finally, in 2020, California's total average milk production was 368 million Cwt, with 16 counties reporting . The lead producing county was Tulare (100 million Cwt), followed by Merced (56 million Cwt), Stanislaus (39 million Cwt), Kings (37 million Cwt), and Kern (million Cwt). San Bernardino ranked 11th for milk production with 5.9 million Cwt. The minimum produced was from Siskiyou County in the North Mountain region with 200,000 Cwt (Figure 8). The year 2020 saw an overall decline in milk production, possibly due to an error in reporting or the impact of COVID-19.

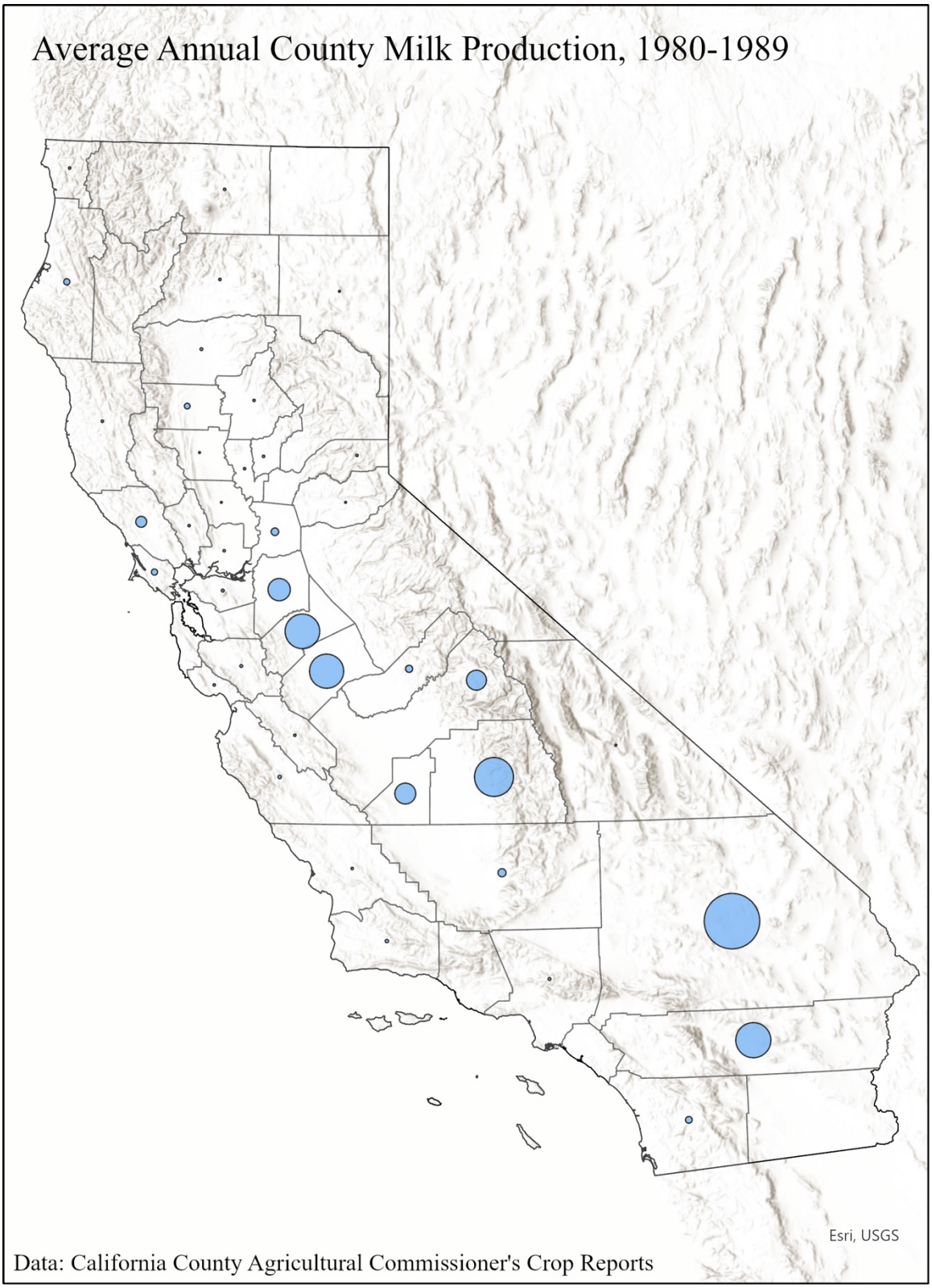

Figure 4. Map of proportional symbols representing the average annual county milk production the 1980s. Circles are centered on the county. Cartography by the author.

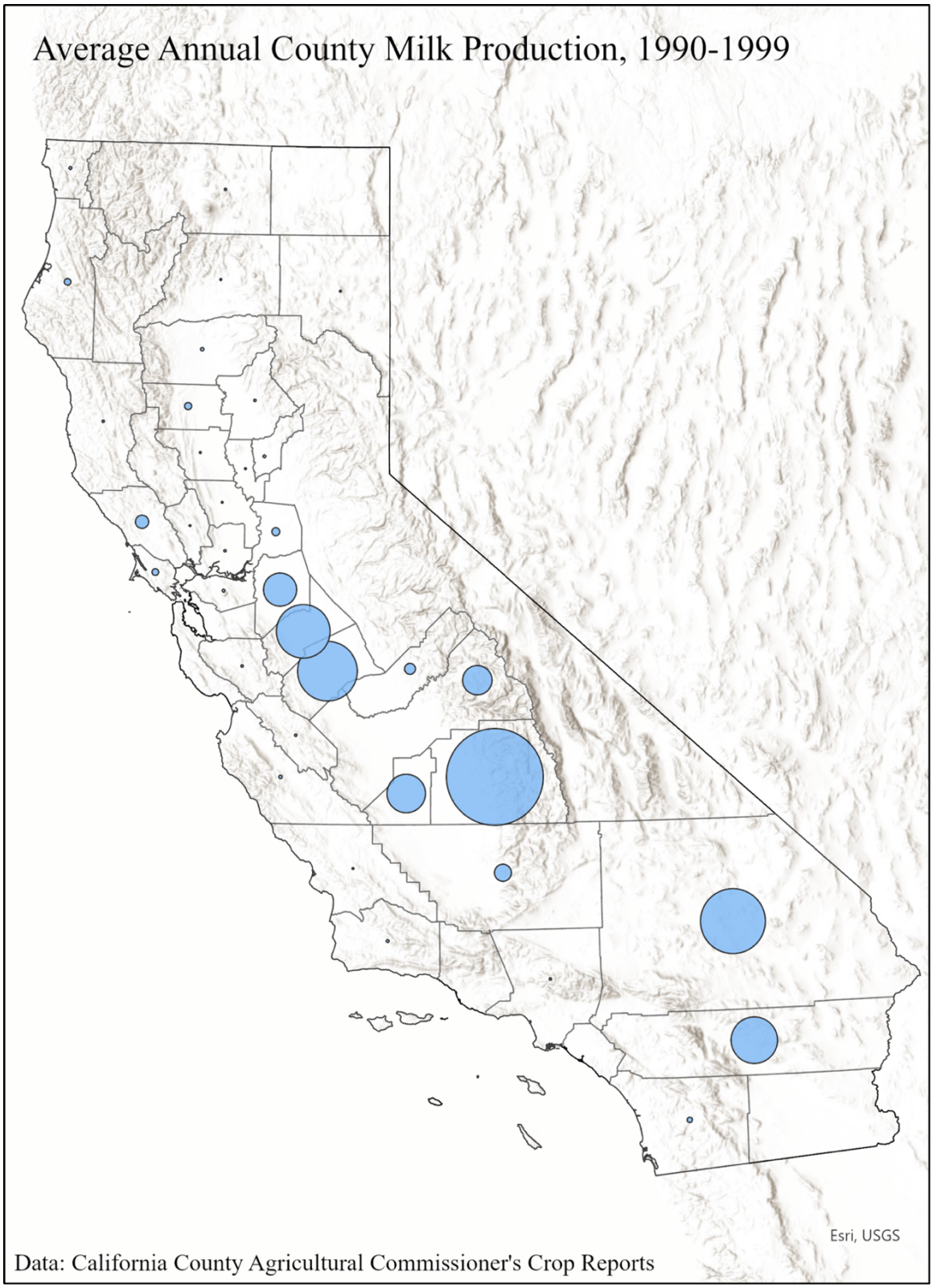

Figure 5. Map of proportional symbols representing the average annual county milk production the 1990s. Circles are centered on the county. Cartography by the author.

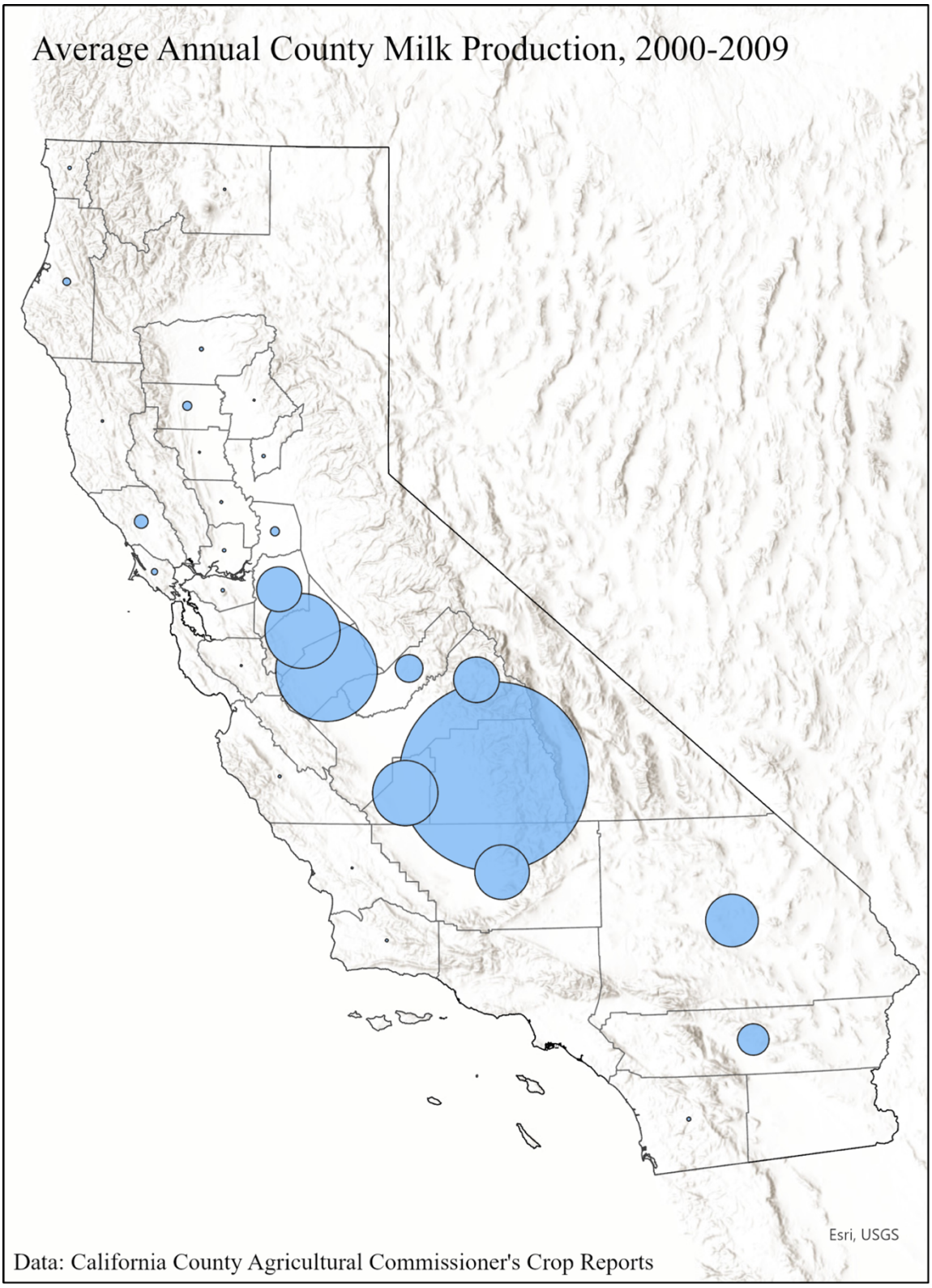

Figure 6. Map of proportional symbols representing the average annual county milk production the 2000s. Circles are centered on the county. Cartography by the author.

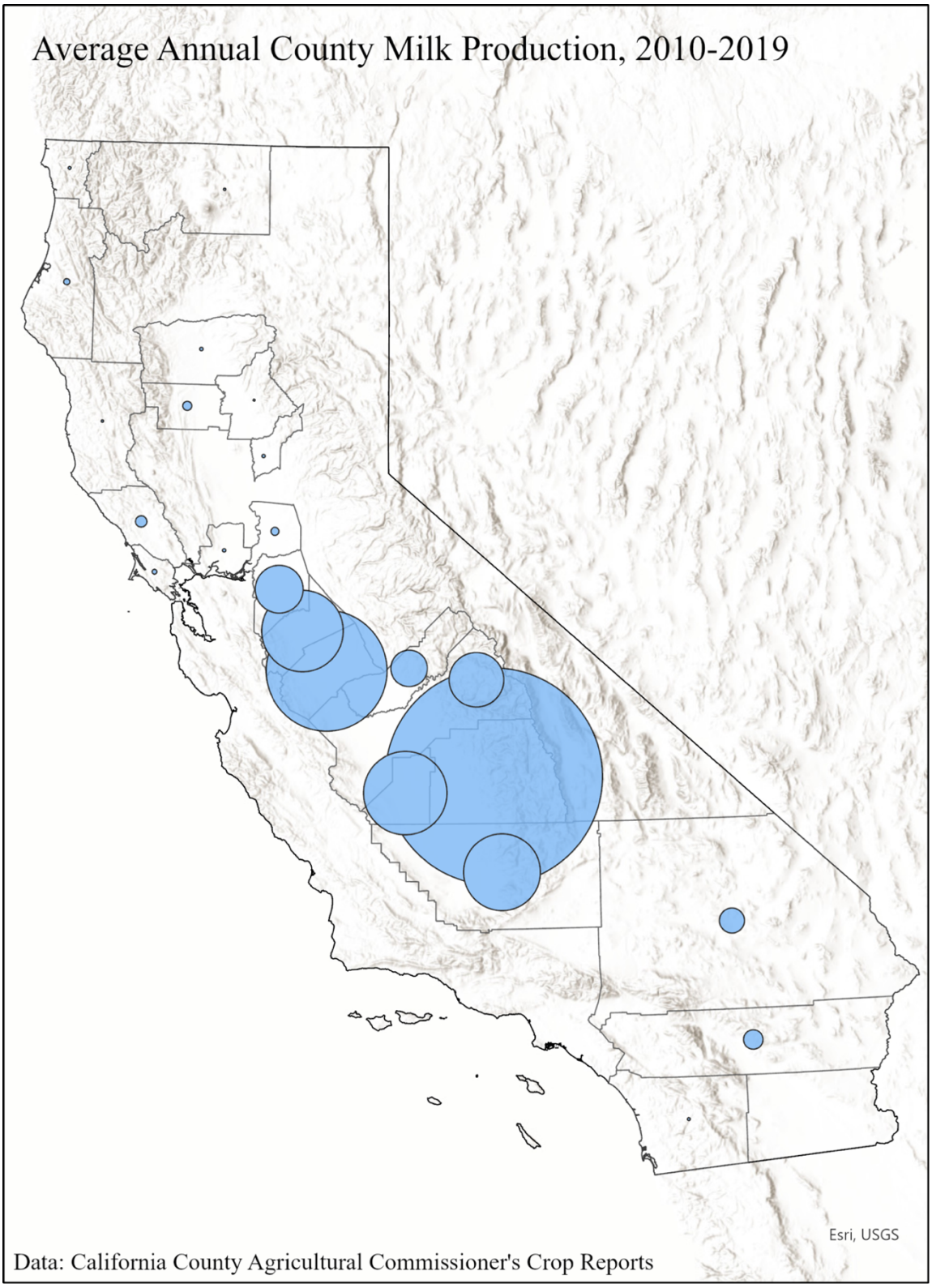

Figure 7. Map of proportional symbols representing the average annual county milk production the 2010s. Circles are centered on the county. Cartography by the author.

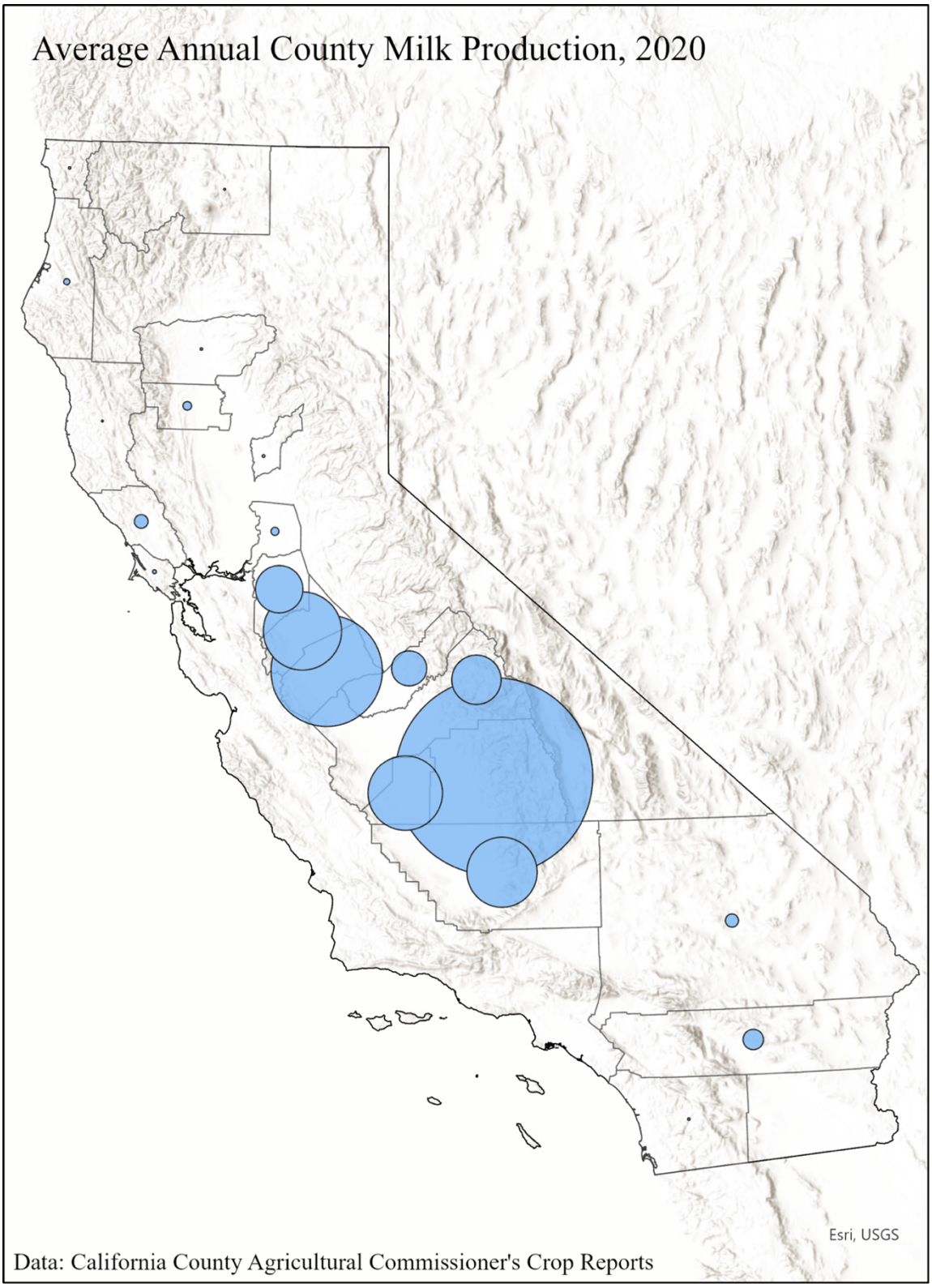

Figure 8. Map of proportional symbols representing the average annual county milk production in 2020. Circles are centered on the county. Cartography by the author.

Table 3. Average annual milk production by county and decade (Cwt).

County	1980-1989	1990-1999	2000-2009	2010-2019	2020
Tulare	19,523,600	49,442,500	96,227,100	110,418,100	100,360,000
Merced	17,112,900	30,120,043	51,140,490	60,937,815	56,200,000
Kings	10,045,948	19,057,427	32,516,149	41,926,980	37,330,000
Stanislaus	17,342,400	26,997,100	37,542,600	40,959,700	39,171,000
Kern	3,133,277	7,869,744	26,860,690	38,530,080	35,200,000
Fresno	9,432,950	14,381,040	22,426,590	26,955,600	24,541,000
San Joaquin	10,773,100	16,205,400	22,221,224	23,683,700	23,520,000
Madera	2,795,477	4,752,744	13,141,774	17,880,280	17,090,000
San Bernardino	28,325,170	32,932,452	25,993,678	11,995,058	5,897,570
Riverside	17,592,892	23,169,004	15,049,945	9,136,200	9,600,000
Sonoma	4,711,606	6,031,869	6,086,760	4,871,452	6,227,000
Glenn	2,011,339	2,761,939	3,713,143	3,640,480	3,540,000
Sacramento	3,030,050	3,219,000	3,525,164	3,275,890	3,430,000
Humboldt	2,149,722	2,495,964	2,825,528	2,297,500	2,353,000
Marin	2,287,254	2,541,701	2,090,589	1,408,473	1,193,000
Solano	206,248	292,390	699,394	867,000	
Tehama	431,363	649,152	1,024,672	697,603	390,000
Yuba	293,757	479,603	613,348	659,300	656,000
Del Norte	262,498	389,280	704,875	516,350	532,000
San Diego	2,423,504	1,628,534	990,873	458,900	430,000
Siskiyou	348,823	213,867	307,565	292,700	200,000
Mendocino	114,835	210,166	296,463	212,900	219,000
Butte	221,921	159,842	108,558	52,753	
Los Angeles	578,282	365,000			
Santa Barbara	647,373	567,705	475,864		
Santa Clara	544,763	223,144	103,821		
Monterey	704,346	663,469	363,464		
San Luis Obispo	282,163	70,205	39,444		
Contra Costa	443,127	520,767	628,000		
Napa	170,840	52,443			
Sutter	142,963	45,923			
Shasta	155,988	99,000			
Placer	113,420				
Santa Cruz	183,749				
Colusa	63,936	34,949	12,578		
Yolo	102,181	107,337	407,675		
Lassen	23,408	18,868			
El Dorado	9,709				
Inyo	400				
San Benito	169,600	166,702			
Total	158,906,878	248,936,247	368,138,016	401,674,814	368,079,570

Table 4. Percent share of total annual milk production by county and decade (%).

County	1980-1989	1990-1999	2000-2009	2010-2019	2020
Tulare	12.3	19.9	26.1	27.5	27.3
Merced	10.8	12.1	13.9	15.2	15.3
Kings	6.3	7.7	8.8	10.4	10.1
Stanislaus	10.9	10.8	10.2	10.2	10.6
Kern	2.0	3.2	7.3	9.6	9.6
Fresno	5.9	5.8	6.1	6.7	6.7
San Joaquin	6.8	6.5	6.0	5.9	6.4
Madera	1.8	1.9	3.6	4.5	4.6
San Bernardino	17.8	13.2	7.1	3.0	1.6
Riverside	11.1	9.3	4.1	2.3	2.6
Sonoma	3.0	2.4	1.7	1.2	1.7
Glenn	1.3	1.1	1.0	0.9	1.0
Sacramento	1.9	1.3	1.0	0.8	0.9
Humboldt	1.4	1.0	0.8	0.6	0.6
Marin	1.4	1.0	0.6	0.4	0.3
Solano	0.1	0.1	0.2	0.2	
Tehama	0.3	0.3	0.3	0.2	0.1
Yuba	0.2	0.2	0.2	0.2	0.2
Del Norte	0.2	0.2	0.2	0.1	0.1
San Diego	1.5	0.7	0.3	0.1	0.1
Siskiyou	0.2	0.1	0.1	0.1	0.1
Mendocino	0.1	0.1	0.1	0.1	0.1
Butte	0.1	0.1	0.0	0.0	
Los Angeles	0.4	0.1			
Santa Barbara	0.4	0.2	0.1		
Santa Clara	0.3	0.1	0.0		
Monterey	0.4	0.3	0.1		
San Luis Obispo	0.2	0.0	0.0		
Contra Costa	0.3	0.2	0.2		
Napa	0.1	0.0			
Sutter	0.1	0.0			
Shasta	0.1	0.0			
Placer	0.1				
Santa Cruz	0.1				
Colusa	0.0	0.0	0.0		
Yolo	0.1	0.0	0.1		
Lassen	0.0	0.0			
El Dorado	0.0				
Inyo	0.0				
San Benito	0.1	0.1			
Total	158,906,878	248,936,247	368,138,016	401,674,814	368,079,570

Table 5. Change in average annual milk production by county between the 1980s and 2010s. Counties without production reported after 2010 are omitted.

County	1980s	2010s	Actual Change	Percent Change
Kern	3,133,277	38,530,080	+35,396,803	*+1,130%*
Madera	2,795,477	17,880,280	+15,084,803	*+540%*
Tulare	19,523,600	110,418,100	+90,894,500	*+466%*
Solano	206,248	867,000	+660,752	*+320%*
Kings	10,045,948	41,926,980	+31,881,032	*+317%*
Merced	17,112,900	60,937,815	+43,824,915	*+256%*
Fresno	9,432,950	26,955,600	+17,522,650	*+186%*
Stanislaus	17,342,400	40,959,700	+23,617,300	*+136%*
Yuba	293,757	659,300	+365,543	*+124%*
San Joaquin	10,773,100	23,683,700	+12,910,600	*+120%*
Del Norte	262,498	516,350	+253,852	*+97%*
Mendocino	114,835	212,900	+98,065	*+85%*
Glenn	2,011,339	3,640,480	+1,629,141	*+81%*
Tehama	431,363	697,603	+266,240	*+62%*
Sacramento	3,030,050	3,275,890	+245,840	*+8%*
Humboldt	2,149,722	2,297,500	+147,778	*+7%*
Sonoma	4,711,606	4,871,452	+159,846	*+3%*
Siskiyou	348,823	292,700	-56,123	*-16%*
Marin	2,287,254	1,408,473	-878,781	*-38%*
Riverside	17,592,892	9,136,200	-8,456,692	*-48%*
San Bernardino	28,325,170	11,995,058	-16,330,112	*-58%*
Butte	221,921	52,753	-169,167	*-76%*
San Diego	2,423,504	458,900	-1,964,604	*-81%*
State Total	158,906,878	401,674,814	+242,767,936	*+153%*

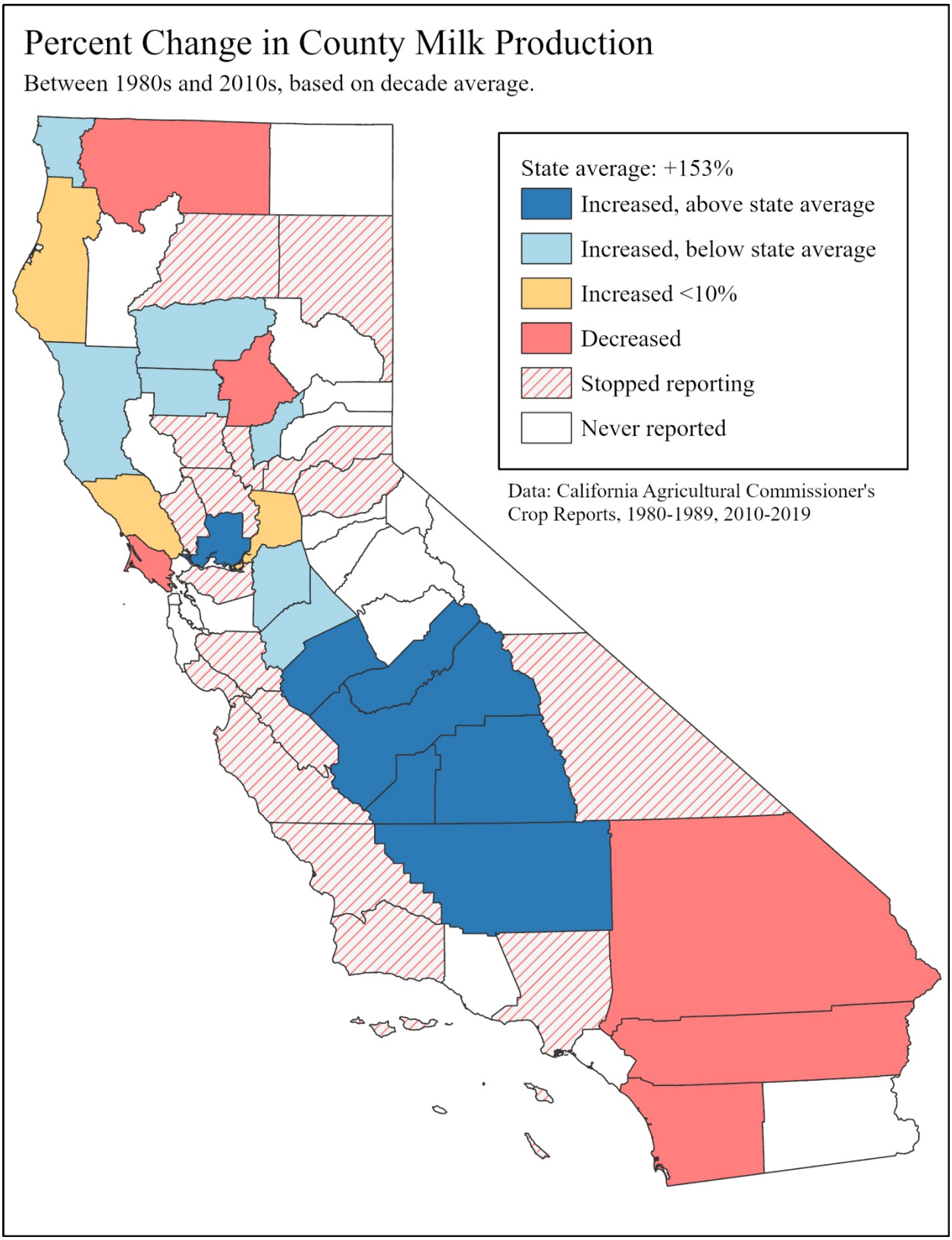

Figure 9. Percent change in annual average milk production by county, 1980s-2010s

There are several conclusions to be made based on the county milk production maps and tables. First, that Tulare County stands out as the largest producer of milk in the state, beginning with 12.5% in the 1980s, then rising to over a quarter (27.5%) of the total production and producing an average of 110 million Cwt of milk a year in the 2010s. Second, San Bernardino was once the leading producer of milk with 28 million Cwt in the 1980s, but experienced a 58% decreased in milk production between the 80s and 2010s and now produces less than 2% of the states total milk. Third, Kern County experienced an especially steep increase in milk production, going from an average annual production of 3.1 million Cwt to 38.5 million Cwt, or an increase of 1,130% or 11 times the original production rate (Table 5). The next highest percent change was Madera County with a 540% increase, then Tulare with a 466% increase.

Lastly, and perhaps most notably, there has been a wide range in outcomes of milk production for the dairy producing counties of California. There are distinct categories of rate of change that counties fall into; production increase above the state average like Kern and Tulare, production increased below state average like Stanislaus and Del Norte, production stayed about the same as 1980s like Sonoma and Humboldt, production decreased like San Bernardino, San Diego or Marin, and finally the counties that stopped reporting production like Solano or Monterey (Table 5, Figure 9). The proportional symbol maps (Figure 4-8) indicate the regional variation, and the choropleth map of percent change (Figure 9) make the regional variation, especially the growth of milk production in counties in the San Joaquin Valley, very clear. This led my research to analysis of production on a regional level in the section that follows, after I first examine and visualize the Census data on operations with milk sales by county.

Dairy Operations, 1997-2017

In 1997, the total number of operations with milk sales reported in the Census was 2,308 (Figure 10). 47 counties had operations with milk sales recorded in the Census, ten of which had more than 100 operations. Merced had the greatest share, with 325 operations (14.1%), closely followed by Stanislaus which had 323 (14.0%). Tulare was third with 259 operations (11.2%). San Bernardino was ranked 4th with 176 operations (7.6%).

In 2002, the total number of operations with milk sales reported in the Census increased to 2,422 (Figure 11). 47 counties had operations with milk sales in the Census, nine of which had more than 100 operations. Stanislaus had the greatest share, with 333 operations (13.7%), followed by Merced which had 317 (13.1%). Tulare was third with 309 operations (12.7%), and Kings and San Joaquin Counties were tied for fourth with 155 operations each (6.4%). San Bernardino operations had decreased to 132 (5.5%).

In 2007, the total number of operations with milk sales reported in the Census decreased to 1,953 (Figure 12). 47 counties had operations with milk sales in the Census, five of which had more than 100 operations. San Bernardino operations decreased to 92, leaving only counties in the San Joaquin Valley in the top five. Tulare moved up the ranks from 3rd to 1st with 288 operations (14.7%), followed by Merced (276 operations) Stanislaus (264), Kings (141) and San Joaquin (132).

In 2012, the total number of operations with milk sales reported in the Census decreased again to 1,554 (Figure 13). 40 counties had operations with milk sales in the Census, five of which had more than 100 operations. Tulare had the greatest number again, with 244 operations or 15.7%, followed by Merced (230), Stanislaus (222), Kings (122), and San Joaquin (105) counties.

In 2017, the total number of operations with milk sales reported in the Census decreased further to 1,287 (Figure 14). 41 counties had operations with milk sales in the Census, but only three counties had more than 100 operations, and 25 counties had less than 10 operations. Tulare still had the greatest number, with 224 operations (17.4%), followed by Merced which had 191 (14.8%). Stanislaus was third with 164 operations (12.7%). Kings had 98 (7.6%) and San Joaquin Counties had 95 operations (7.4%). 41 counties had operations with milk sales in the Census, but only three counties had more than 100 operations, and 25 counties had less than 10 operations.

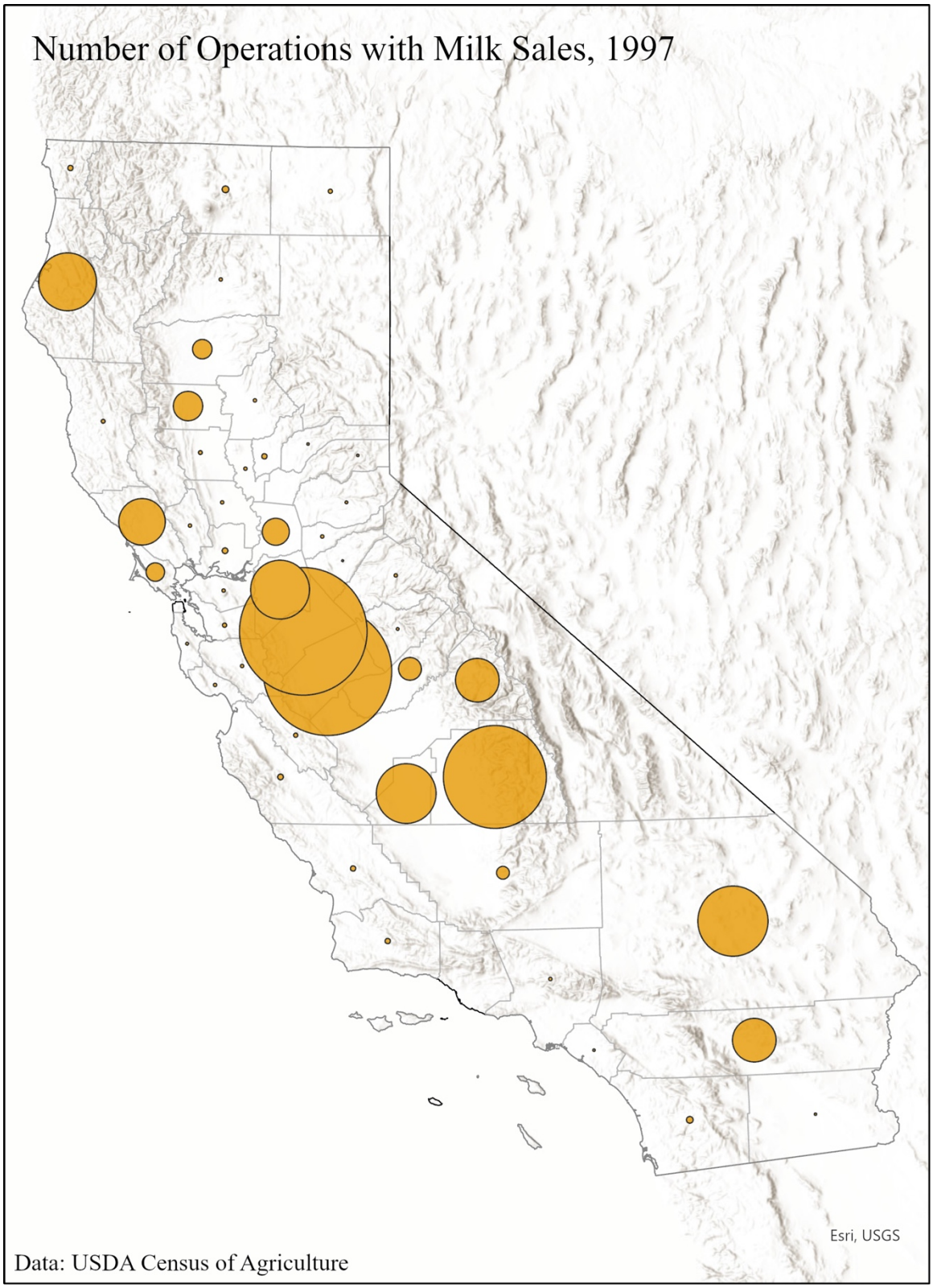

Figure 10. Map of proportional symbols representing the number of operations with milk sales by county in 1997. Circles are centered on the county. Cartography by the author.

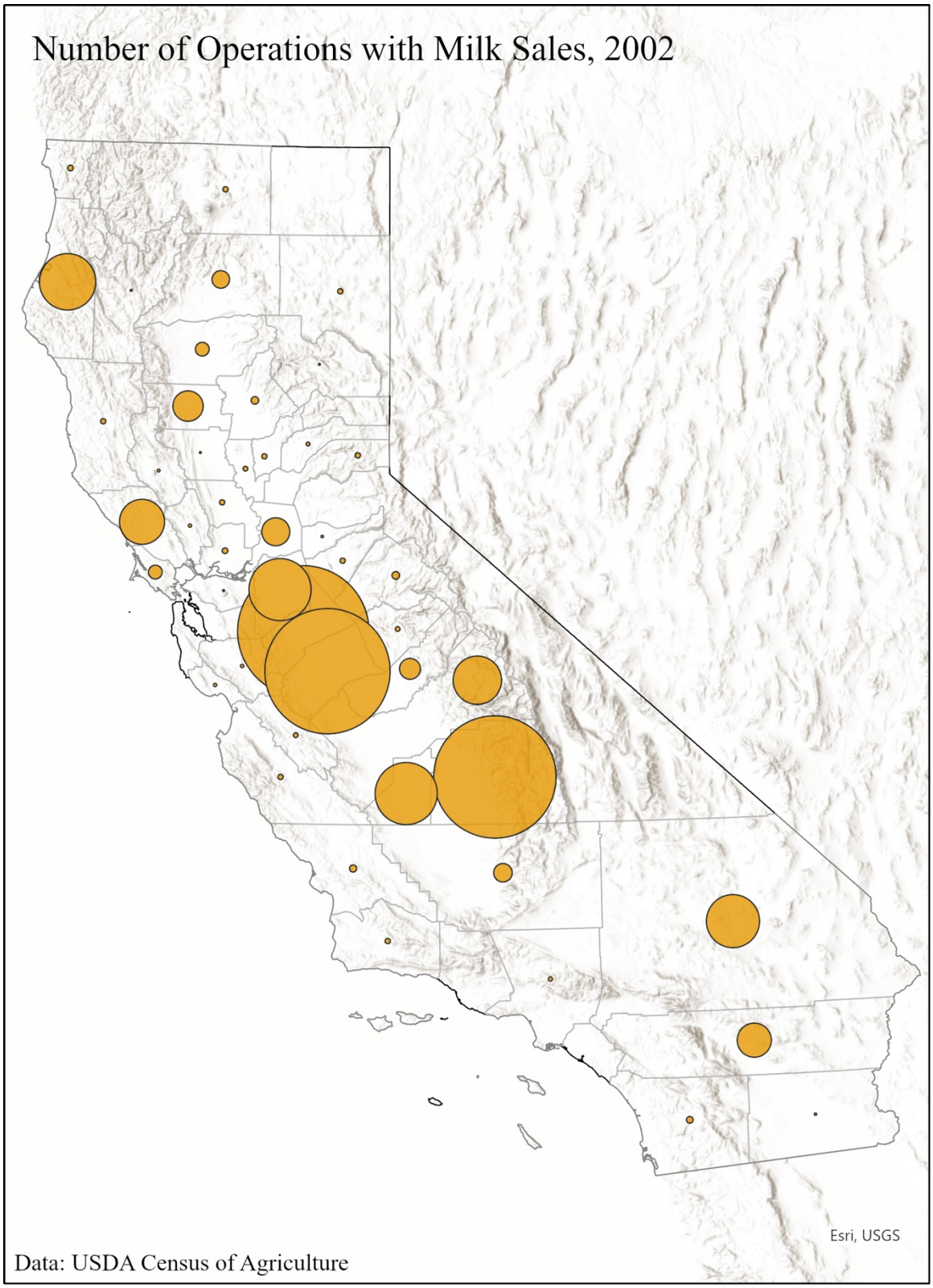

Figure 11. Map of proportional symbols representing the number of operations with milk sales by county in 2002. Circles are centered on the county. Cartography by the author.

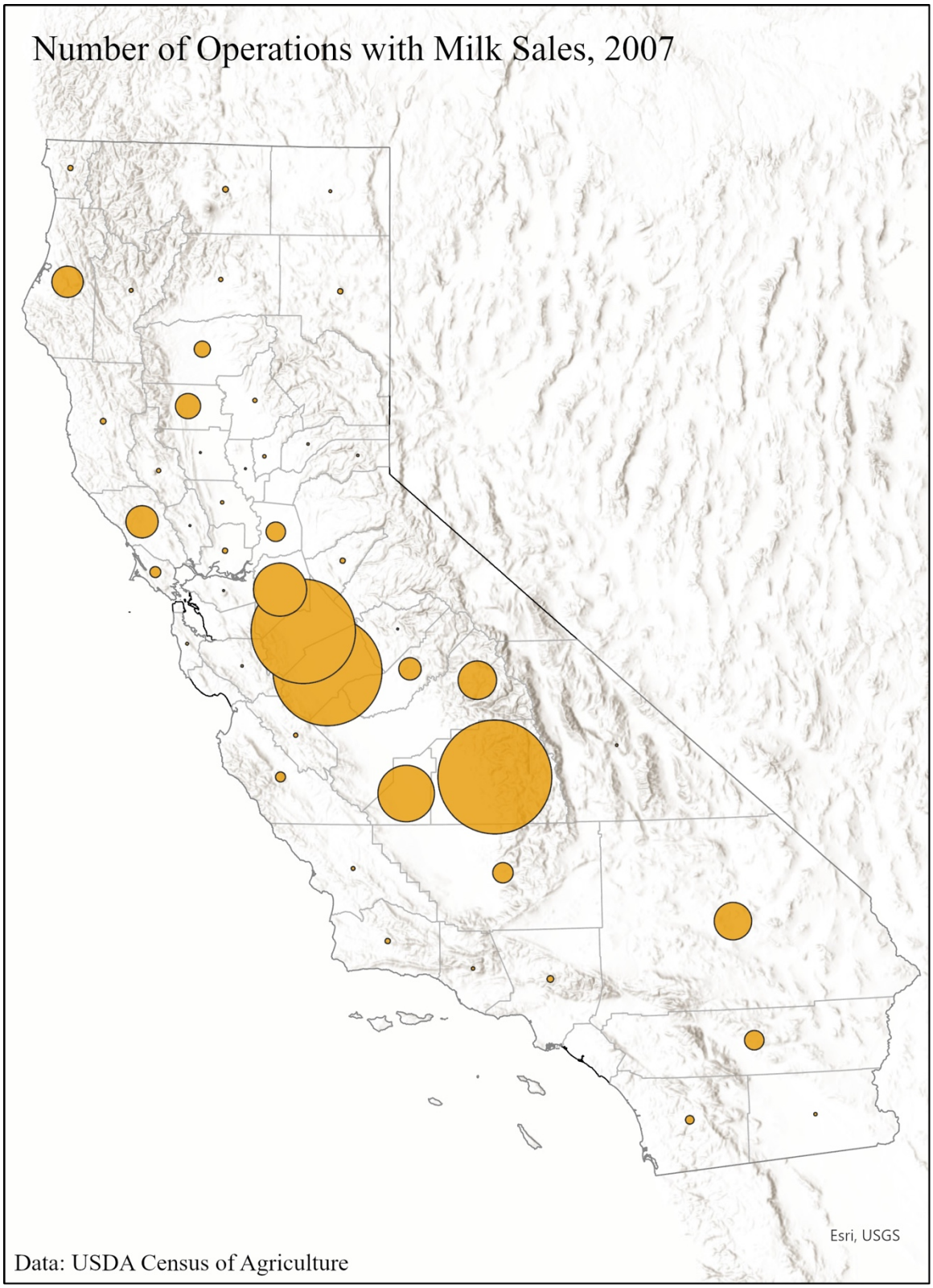

Figure 12. Map of proportional symbols representing the number of operations with milk sales by county in 2007. Circles are centered on the county. Cartography by the author.

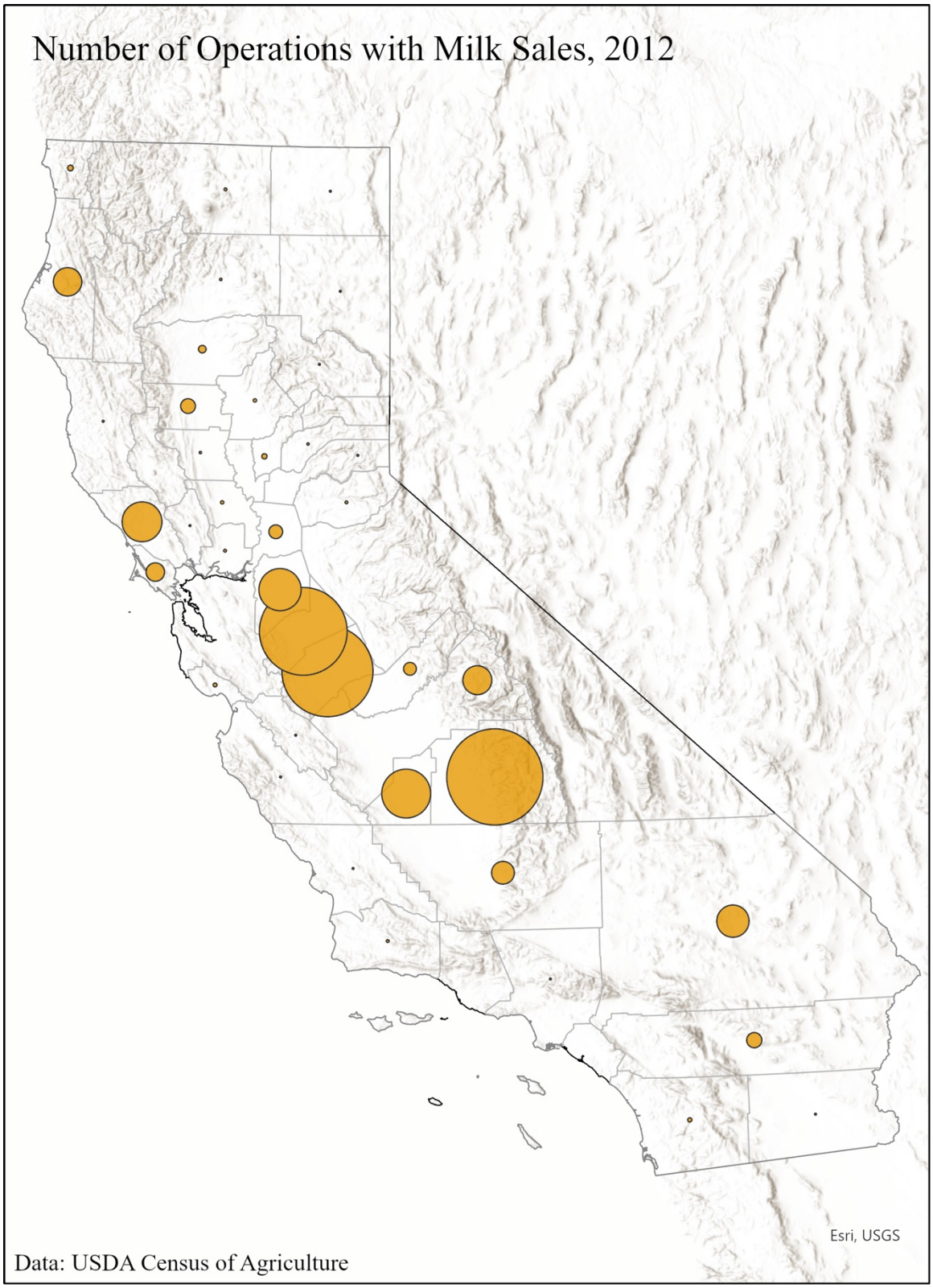

Figure 13. Map of proportional symbols representing the number of operations with milk sales by county in 2012. Circles are centered on the county. Cartography by the author.

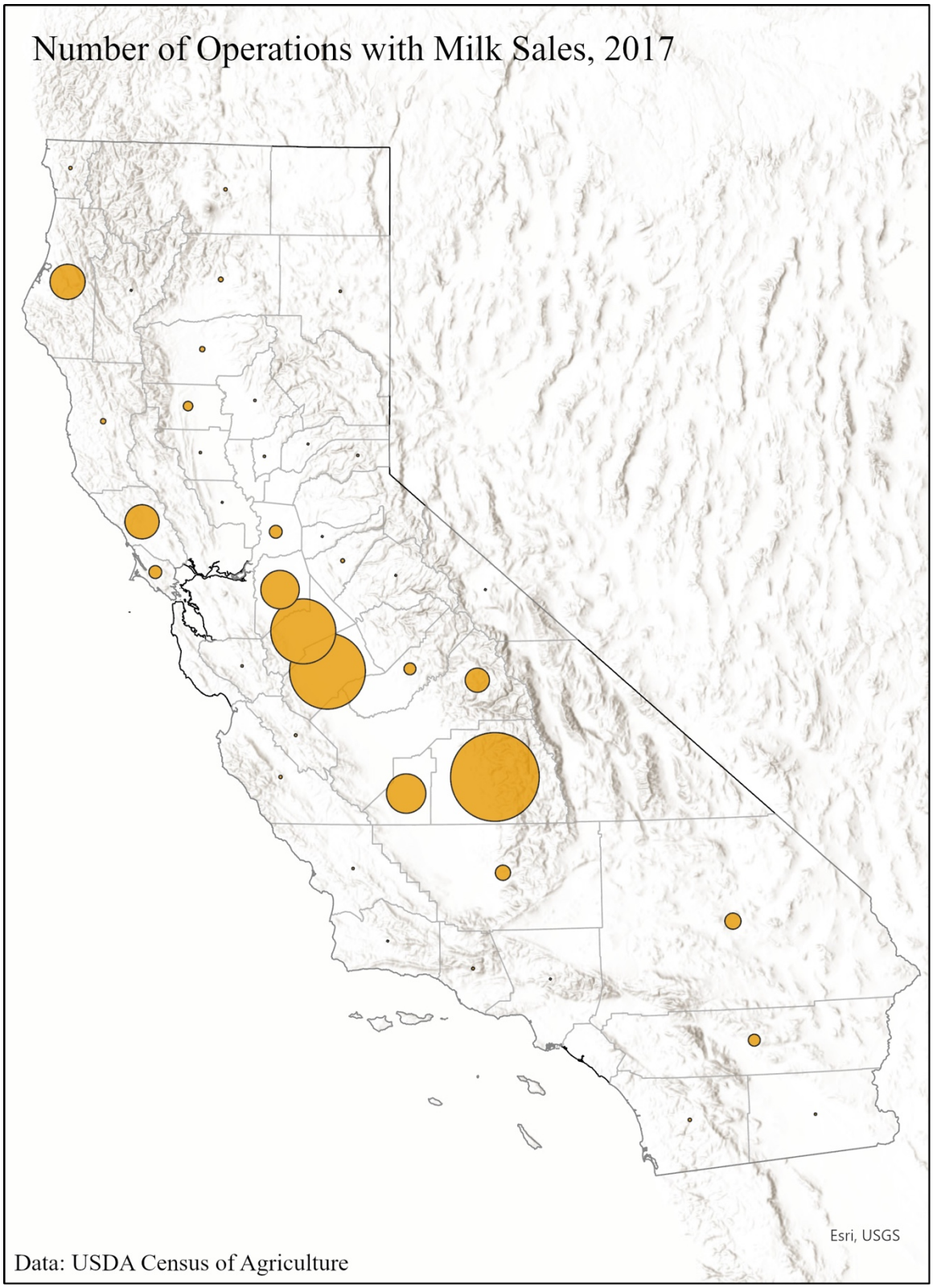

Figure 14. Map of proportional symbols representing the number of operations with milk sales by county in 2017. Circles are centered on the county. Cartography by the author.

Table 6. Number and percent share of operations with milk sales per county, Census years 1997-2017. 16 counties omitted for small quantities.

County	1997	%	2002	%	2007	%	2012	%	2017	%
Tulare	259	*11.2*	309	*12.8*	288	*14.7*	244	*15.7*	224	*17.4*
Merced	325	*14.1*	317	*13.1*	276	*14.1*	230	*14.8*	191	*14.8*
Stanislaus	323	*14.0*	333	*13.7*	264	*13.5*	222	*14.3*	164	*12.7*
Kings	148	*6.4*	155	*6.4*	141	*7.2*	122	*7.9*	98	*7.6*
San Joaquin	146	*6.3*	155	*6.4*	132	*6.8*	105	*6.8*	95	*7.4*
Humboldt	144	*6.2*	140	*5.8*	76	*3.9*	69	*4.4*	87	*6.8*
Sonoma	114	*4.9*	111	*4.6*	79	*4.0*	99	*6.4*	84	*6.5*
Fresno	107	*4.6*	120	*5.0*	94	*4.8*	70	*4.5*	58	*4.5*
San Bernardino	176	*7.6*	132	*5.5*	92	*4.7*	79	*5.1*	37	*2.9*
Kern	28	*1.2*	43	*1.8*	48	*2.5*	54	*3.5*	35	*2.7*
Marin	43	*1.9*	31	*1.3*	24	*1.2*	44	*2.8*	29	*2.3*
Sacramento	64	*2.8*	68	*2.8*	46	*2.4*	32	*2.1*	29	*2.3*
Madera	54	*2.3*	50	*2.1*	53	*2.7*	29	*1.9*	27	*2.1*
Riverside	107	*4.6*	84	*3.5*	46	*2.4*	35	*2.3*	26	*2.0*
Glenn	70	*3.0*	74	*3.1*	60	*3.1*	34	*2.2*	21	*1.6*
Tehama	45	*1.9*	31	*1.3*	38	*1.9*	15	*1.0*	10	*0.8*
Mendocino	5	*0.2*	9	*0.4*	11	*0.6*	1	*0.1*	9	*0.7*
Shasta	4	*0.2*	41	*1.7*	7	*0.4*	2	*0.1*	8	*0.6*
Calaveras	0		9	*0.4*	9	*0.5*	0		6	*0.5*
Monterey	10	*0.4*	9	*0.4*	21	*1.1*	1	*0.1*	5	*0.4*
Del Norte	8	*0.3*	11	*0.5*	9	*0.5*	11	*0.7*	5	*0.4*
San Diego	12	*0.5*	13	*0.5*	18	*0.9*	7	*0.5*	5	*0.4*
Siskiyou	12	*0.5*	10	*0.4*	11	*0.6*	3	*0.2*	4	*0.3*
San Benito	6	*0.3*	8	*0.3*	7	*0.4*	1	*0.1*	3	*0.2*
San Luis Obispo	9	*0.4*	14	*0.6*	6	*0.3*	1	*0.1*	2	*0.2*
Santa Clara	4	*0.2*	5	*0.2*	2	*0.1*	0		2	*0.2*
Lassen	0		10	*0.4*	9	*0.5*	1	*0.1*	2	*0.2*
Butte	4	*0.2*	16	*0.7*	7	*0.4*	5	*0.3*	2	*0.2*
Colusa	5	*0.2*	1	*0.0*	1	*0.1*	2	*0.1*	2	*0.2*
Yuba	8	*0.3*	10	*0.4*	4	*0.2*	9	*0.6*	2	*0.2*
Placer	1	*0.0*	9	*0.4*	2	*0.1*	1	*0.1*	2	*0.2*
Imperial	1	*0.0*	2	*0.1*	4	*0.2*	1	*0.1*	2	*0.2*
Yolo	3	*0.1*	9	*0.4*	4	*0.2*	4	*0.3*	1	*0.1*
Nevada	1	*0.0*	6	*0.2*	2	*0.1*	2	*0.1*	1	*0.1*
Los Angeles	3	*0.1*	7	*0.3*	13	*0.7*	1	*0.1*	1	*0.1*
Santa Barbara	8	*0.3*	10	*0.4*	10	*0.5*	3	*0.2*	1	*0.1*
Napa	3	*0.1*	5	*0.2*	1	*0.1*	1	*0.1*	0	
Solano	10	*0.4*	11	*0.5*	9	*0.5*	3	*0.2*	0	
Sutter	4	*0.2*	8	*0.3*	1	*0.1*	0		0	
Total	2308		2422		1953		1554		1287	

Table 7. Change in number of operations with milk sales between 1997 and 2017 for counties with more than 10 operations in 1997.

County	Operations 1997	Operations 2017	Actual Change	Percent Change
Kern	28	35	+7	*+25%*
Tulare	259	224	-35	*-13%*
Sonoma	114	84	-30	*-26%*
Marin	43	29	-14	*-33%*
Kings	148	98	-50	*-34%*
San Joaquin	146	95	-51	*-35%*
Humboldt	144	87	-57	*-40%*
Merced	325	191	-134	*-41%*
Fresno	107	58	-49	*-46%*
Stanislaus	323	164	-159	*-49%*
Madera	54	27	-27	*-50%*
Monterey	10	5	-5	*-50%*
Sacramento	64	29	-35	*-55%*
San Diego	12	5	-7	*-58%*
Siskiyou	12	4	-8	*-67%*
Glenn	70	21	-49	*-70%*
Riverside	107	26	-81	*-76%*
Tehama	45	10	-35	*-78%*
San Bernardino	176	37	-139	*-79%*
Solano	10	0	-10	*-100%*
Total	2308	1287	-1021	*-44.2%*

All counties experienced a decrease in the number of operations with milk sales, except one – Kern County. Tulare County had the greatest number of operations after 2007 and gained in percent share of operations, going from 11% to 17.1% of the total. Very few others gained significantly in percent share, Sonoma went from a 4.9 to a 6.5% share, Kern went from a 1.2 to a 2.7 % share but other increases were less than 1 percentage point. San Bernardino experienced the greatest percent change in number of operations, with a decline of 78% losing 139 operations, and going from 7.6% in 1997 share to 2.9% share in 2017. After Tulare, Sonoma and

Marin were the second and third for least percent decrease in operations between the 1980s and 2010s (Table 7).

The maps of production and operations data show spatial patterns and changes in the distribution of dairying within California. Broadly, milk production has dramatically increased, while the number of operations has declined for the whole state. This research makes clear the varied outcomes of change in milk production across counties and agricultural regions within California. The following analysis aggregates the county-level data by agricultural region (Figure 3) to better understand the regional variations in milk production in context with the varied geographies of those regions.

Regional Analysis of Milk Production and Operations

There are eight agricultural districts defined by the CA Crop Reports. I have distinguished Marin and Sonoma Counties as a distinct dairy producing region from the Central Coast based on other studies (Guthey, Gwin, and Fairfax 2003; Black and Larson 2018), the unique history, and the continued production rates. Nine agricultural regions are considered here: (from North to South) North Coast, North Mountain, Northeast Mountain, Sacramento Valley, Sierra Nevada Mountain, Marin & Sonoma, Central Coast, San Joaquin Valley, and Southern California (Figure 3). Table 8 summarizes production by region and Table 9 summarizes operations by region. Table 10 and Table 11 show the actual and percent change in production and operations respectively. The outcomes and contexts of each region are discussed in detail below, in order of average annual milk production in 2020.

Table 8. Average annual production (Cwt) and percent share by region and decade.

Region	1980-1989	1990-1999	2000-2009	2010-2019	2020
San Joaquin Valley	90,159,652	173,170,918	302,076,617	361,292,255	333,412,000
	56.8%	*68.4%*	*82.3%*	*90.1%*	*90.6%*
Southern California	49,567,221	58,521,736	42,320,014	21,590,158	15,927,570
	31.2%	*23.1%*	*11.5%*	*5.4%*	*4.3%*
Sacramento Valley	6,503,757	7,787,804	10,094,468	8,473,050	8,016,000
	4.1%	*3.1%*	*2.7%*	*2.1%*	*2.2%*
Marin & Sonoma	6,998,860	8,604,027	8,177,350	6,279,925	7,420,000
	4.4%	*3.4%*	*2.2%*	*1.6%*	*2.0%*
North Coast	2,527,055	3,142,230	3,826,866	3,026,750	3,104,000
	1.6%	*1.2%*	*1.0%*	*0.8%*	*0.8%*
North Mountain	504,811	203,748	307,565	292,700	200,000
	0.3%	*0.1%*	*0.1%*	*0.1%*	*0.1%*
Central Coast	2,446,292	1,654,397	442,023	*	*
	1.5%	*0.7%*	*0.1%*		
Northeast Mountain	23,408	5,868	*	*	*
	0.0%	*0.05*			
Sierra Nevada Mountain	88,172	*	*	*	*
	0.1%				
Total	158,819,227	253,090,728	367,244,903	400,954,837	368,079,570

(* no data)

Table 9. Number and percent share of operations with milk sales by region, 1997-2017.

Region	1997	2002	2007	2012	2017
San Joaquin Valley	1,390	1,482	1,296	1,076	892
	60%	*61%*	*66%*	*69%*	*69%*
Marin & Sonoma	157	142	103	143	113
	6.8%	*5.9%*	*5.3%*	*9.2%*	*8.8%*
North Coast	157	160	96	81	101
	6.8%	*6.6%*	*4.9%*	*5.2%*	*7.8%*
Southern California	308	248	188	126	75
	13%	*10%*	*9.6%*	*8.1%*	*5.8%*
Sacramento Valley	213	228	170	104	67
	9.2%	*9.4%*	*8.7%*	*6.7%*	*5.2%*
North Mountain	16	52	24	5	13
	0.7%	*2.1%*	*1.2%*	*0.3%*	*1.0%*
Central Coast	48	49	48	10	12
	2.1%	*2.0%*	*2.5%*	*0.6%*	*0.9%*
Sierra Nevada Mountain	13	50	16	6	12
	0.6%	*2.1%*	*0.8%*	*0.4%*	*0.9%*
North East Mountain	6	11	12	3	2
	0.3%	*0.5%*	*0.6%*	*0.2%*	*0.2%*
Total	2308	2422	1953	1554	1287

Table 10. Change in average annual production by region between the 1980s and 2010s.

Region	1980-1989	2010-2019	Actual Change	Percent Change
San Joaquin Valley	90,159,652	361,292,255	+271,132,603	*+300.7%*
Sacramento Valley	6,503,757	8,473,049.9	+1,969,293	*+30.3%*
North Coast	2,527,055	3,026,750	+499,695	*+19.8%*
Marin Sonoma	6,998,860	6,279,924.8	-718,935	*-10.3%*
North Mountain	504,811	292,700	-212,112	*-42.0%*
Southern California	49,567,221	21,590,158	-27,977,063	*-56.4%*
Central Coast	2,446,292	*		
Northeast Mountain	23,408	*		
Sierra Nevada Mountain	88,172	*		
Total	158,819,227	400,954,837	242,135,610.7	*+152.5%*

(*no data)

Table 11. Change in number of operations by region between the 1980s and 2010s.

Region	1997	2017	Actual Change	Percent Change
San Joaquin Valley	1390	892	-498	*-36%*
Sacramento Valley	213	67	-146	*-69%*
North Coast	157	101	-56	*-36%*
Marin & Sonoma	157	113	-44	*-28%*
North Mountain	16	13	-3	*-19%*
Southern California	308	75	-233	*-76%*
Central Coast	48	12	-36	*-75%*
North East Mountain	6	2	-4	*-67%*
Sierra Nevada Mountain	13	12	-1	*-7.7%*
Total	2343	1314	-1029	*-44%*

San Joaquin Valley

The San Joaquin Valley stands out because it contains the top five milk producing counties since the 2000s. This is a large region, containing the San Joaquin River Basin and the Tulare Basin; the climate is the driest and warmest of the five other regions of interest. Dairy production here has increased by 300% since 1980, the most of all the regions by far, and the percent share of total production in California went from 58% in the 1980s to 90% in the 2010s. Although the number of operations with milk sales decreased by almost 500, the region's share of total operations increased by 9%. Tulare County especially grew in milk production as the lead producing county of the state every year since 1990. Production increased by 570% from 1980 to 2014 and share of operations here increased by 7%. Kern County had the highest intensity of production to operations ratio (milk per farm) of all counties in 2017.

Southern California

Southern California, including Los Angeles, San Bernardino, and Riverside Counties, experienced a very different outcome from the rest of the state, with a steady decline in both production and operations. If the data had gone back to the 1930s, we likely would have seen an even larger decrease in percent share of production and operations; Los Angeles County was the biggest producer of milk in the 1930s (Gilbert and Wehr 2003), until San Bernardino County took the lead from the 1950s until 1990. Southern California's milk production decreased by 55% from the 1980s to the 2010s. The percent share decreased from a striking 30% in the 1980s to 5% in the 2010s. Southern California also lost the biggest share of operations, going from a 13% share in 1997 to 6% in 2017, and losing 233 farms. Despite the dramatic decrease in production and number of operations, the region is still the second largest producer of milk

behind the San Joaquin Valley in 2020, with 4.3% of the total production share in 2020 and 6% of the operations.

Sacramento Valley

The Sacramento Valley offers an interesting comparison to the San Joaquin Valley. It makes up the top third of the Central Valley and has a similar topography and climate to the lower two-thirds, but is slightly cooler due to the higher latitude, and is slightly narrower as three mountain ranges converge north of Redding. The region is made up of nine counties, all of which reported milk production through the 1980s, but by the 2010s, only Glenn, Sacramento, Temaha and Yuba Counties reported milk production.

Average annual milk production in the Sacramento Valley increased by 55% between the 1980s and 2000s, starting at 6.5 million cwt and increasing to 10.1 million Cwt (notably the same rate of change as the North Coast). However, this increase in production was still a decline in percent share of state total production, from 4.1% to 2.7%. This decline continued in the 2010s as both the volume of milk produced and percent share of production decreased, down to 8.4 million representing a 2.1% share.

Marin and Sonoma

Marin County and Sonoma County, also known as the North Bay in some studies, are a distinct region from the North Coast and Central Coast regions because they produce more organic milk, have smaller herds, and the price per unit of their milk is consistently above other regions in the state. Both counties are close to the San Francisco Bay area, and visitors to the Point Reyes National Seashore are attracted to the historic dairy region to enjoy local artisanal cheeses. The Marin Agricultural Land Trust has reduced the opportunities for landowners to shift

land to development uses, effectively keeping pasture available for dairy farms and ranches in Marin County despite development pressures. Production rose little compared to regions like the San Joaquin Valley, but the relative milk price for the region grew over time, which allowed farms with relatively low production of milk per farm to remain financially viable. These factors may explain why production and operation rates remained relatively stable compared to other regions.

Production in these two counties decreased by 10% between the 1980s and 2010s but rose back above its 1980 level of production in 2020. The percent share of production was small across all decades in the dataset and decreased from 4.5% to 2% between the 1980s and 2020. The number of operations decreased by 44 farms, from 157 to 113, a decrease of 28%. The percent share of operations was varied over time, starting at 7% in 1997, decreasing to 5% and then rising back to 9% of total operations in 2017. This region uniquely shows signs of decline and resurgence, with relatively stable numbers between the 1980s and 2010s.

The North Coast

Like Marin and Sonoma, production and operations in the North Coast region also stayed relatively stable. This region includes Del Norte, Humboldt, and Mendocino Counties. At the turn of the 20th century, Humboldt was the largest producer of dairy in the state (Wickson 1896). This is a remote region in the northwest corner of the state, contained by mountains and ocean and accessible via a 4-6 hour drive up the coast from San Francisco or through a mountain pass in the Cascade Range.

In the 1980s, the North Coast had a 1.6% share of total milk production. During the 90s and 2000s, average annual production increased by 55%, from 2.5 million cwt in the 80s to 3.8 million in the 2000s, but the percent share of production decreased to 1%, indicating that the

growth of milk production here was slower than the state average. Average annual production declined in the 2010s to 2.9 million cwt, or 0.7% share of state totals, and zero production was recorded in 2020, which is likely due to a delay in reporting. Operations began with 157 in 1997, 7% of the total. That number and the percent share of the total fluctuated in the census years 2002, 2007 and 2012. In 2017 there were 101 operations recorded which accounts for 8% of the state total.

The Central Coast and North, Northeast, and Sierra Nevada Mountains

These four regions, although on opposite sides of the state with vastly different topographies and climates, all had similar declines in dairying. The Central Coast, which extends from San Francisco south to San Luis Obispo County, was a popular dairy producing region for the same reasons that Marin and Sonoma were successful in dairy production back in the late 1800s. This region is still a highly active agricultural region, known for fruit and vegetable crops like strawberries, artichokes, and garlic. The mountainous regions in the northeast part of the state also used to have some dairy production, either in the foothills of the mountains or as summer grazing for the early Sacramento Valley dairies.

For both regions, their production and number of operations were minimal to begin with, and commercial milk production has almost completely disappeared from these regions. The Central Coast had only 1.5% of total production in 1980. Monterey, Santa Cruz, and San Luis Obispo Counties reported small amounts of milk production through the 1980s but stopped reporting milk production in 1990, 2006, and 2008 respectively, so the data show a 0% share of milk production. A small share of operations is still reported in the Census; the region had a 2% share in 1997, 2002 and 2007 with 48 operations, until 2012 and 2017, when the number of operations dropped to 10 and 12, less than 1%.

The North (N) Mountain, Northeast (NE) Mountain and Sierra Nevada (SN) Mountain regions had even less production and fewer operations and were combined for numerical significance. These three regions combined had 0.4% of total milk production in the 1980s and 35 and 2% of operations in 1997. The Sierra Nevada Mountain region was the first to stop reporting milk production in the crop reports after 1988, then the Northeast Mountain after 1993, and the North Mountain region continued to report milk production through 2020, with 200,000Cwt of milk, all from Siskiyou County which shares a border with southern Oregon.

Table 12. Bivariate table of change in percent share of production and operations.

Percent Share of Operations			
	Increased	Marin & Sonoma North Coast	San Joaquin Valley
	Decreased	Southern California Sacramento Valley Central Coast North/Northeast/ Sierra Nevada Mountains	
		Decreased	Increased
		Percent Share of Production	

To varying degrees, every region of California decreased in percent share of the state's total production, except for the San Joaquin Valley. Even if these other regions did increase their actual production rates, they still fell in percent share of the total because the large increase in milk production in the San Joaquin Valley outweighed every other region. The Central Coast, Northeast Mountain, and Sierra Nevada Mountain stopped reporting milk production, but did continue to report very small numbers of operations. Every region of California decreased in

absolute number of operations, representing consolidation across the whole industry, however Marin & Sonoma, the North Coast, and San Joaquin Valley increased their percent share of operations, suggesting they are declining slower than the rest of the state and retaining more operations.

6. Discussion: Intensification, Consolidation and Regional Concentration in Dairy Production

A Framework for Transformation in California Dairy

Based on the maps and regional analysis of dairy production change in California in the last 4 decades, and the literature on transformations in dairy industries, I propose the following framework (Figure 15) for understanding the multi-scalar and interdependent patterns of transformation, as they pertain to the California dairy industry.

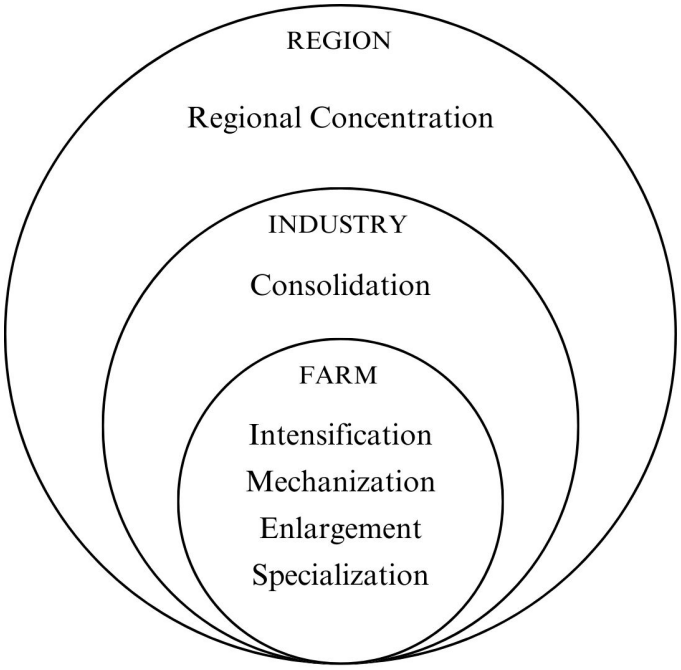

Figure 15. Diagram representing nested transformations occurring in California's dairy industry.

First there is the intensification of production at the farm-level, or the increase output of milk relative to the inputs of land and number of operations. Intensification is associated with three other transformations that may take place within the farm: enlargement or increasing herd sizes; mechanization and technological innovations, for example breeding cows to select for high

milk producing genes, using hormones to shorten the time to maturity and to increase lactation, and using milking machines to save labor and increase milking frequency; and finally *specialization* or the reduction of agricultural activities to focus solely on milk production. The increasing production in some regions alongside the decreasing number of operations in all regions suggests that intensification is taking place in some places like the San Joaquin Valley more than others.

Next, there is a marked trend of *consolidation* occurring across the industry. There are fewer farms today in all sectors of agriculture, but livestock consolidation has occurred unevenly, and dairy is highlighted as the only type of agriculture continuing to rapidly consolidate (MacDonald, Hoppe, and Newton 2018). The decline in number of operations across the board is evidence of consolidation occurring within the California dairy industry. Even in counties where milk production is multiplying 2-5 times the 1980s rate, the number of operations has been consistently declining since 2002. Several hypotheses have been forwarded to account for farm consolidation. These include theories such as the treadmill of production where pressures to keep up with new technologies to increase production require farms to invest and expand, resulting in fewer, larger farms (Kenneth Alan Gould, Pellow, and Schnaiberg 2008; Carolan 2022).

Finally, at the state level, I have observed a *regional concentration* of dairy production, or a shift in where milk is being produced. In California, dairies are moving into, or at least expanding within, the San Joaquin Valley, a region with a warmer climate, more open space, and that is close to other forms of agriculture for easier access to feed, processing, and distribution. In contrast, Southern California has been steadily decreasing in volume of milk produced and number of operations, likely due to development pressures from Los Angeles. While Southern

California lost 7.2 points of percent share in number of operations (13% to 5.8%), the San Joaquin Valley gained 9 points (60% to 69%) between 1997 and 2017. A similar pattern has been documented in other states and countries, and the new concentration seems to be associated with non-traditional dairying regions and climates.

These three scales of transformation can be seen in the increased milk production over the last 40 years, the decreased number of operations over the past 20 years, and the fact that the San Joaquin Valley, especially Tulare, is the only County where the percent share of production and operations both increased. Marin & Sonoma and the North Coast stand out in the regional analysis as the only regions where the percent share of production decreased but the percent share of operations increased. This suggests that producers here are not keeping up with the San Joaquin Valley's rates of production, but these two counties are retaining more of their dairy operations than the Southern California or Sacramento Valley regions are. This is likely due to "alternatives" or the non-conventional modes of production that farmers rely on to maintain economic viability. Organic milk production, vertical integration, and value-added products like cheese-making are some of the creative preservations that farmers in Marin Sonoma and Humboldt may use to stay in production (Guthey, Gwin, and Fairfax 2003). Finally, the apparent disappearance of production from the Central Coast, Northeast Mountain and Sierra Nevada Mountain regions are explained by the patterns of consolidation and regional concentration into a few regions – which implies the decline of production and operations in the peripheral regions.

The pattern of intensification, consolidation, and regional concentration that I have described is based on the experience of California but is not exclusive to this state; many of the same contexts exist to an extent in "new dairy states" like Idaho, Texas, and Kansas, which are rising in national ranks for milk production, and in the expanding dairy farms in traditional dairy

states like Wisconsin and New York, all of which are increasing herd sizes and decreasing in number of commercial dairies (Fraysse 2022).

Implications for Dairy in the San Joaquin Valley

Concentrated feeding operations, or "mega-dairies," produce immense amounts milk per farm with herd sizes of over 2,000 cows per operation, demand immense amounts of water and feed, and in turn produce immense amounts of milk and manure in highly concentrated area. This scale of feeding and milk production is possible because of the consolidation, mechanization, specialization, etc. but also because of California's unique geographic contexts. The Central Valley, although vulnerable and arid, provides expansive flat land and a warm climate that allows for large herds to be kept outdoors year-round. The local almond, fruit, and silage production also provides relatively inexpensive feed to supplement the grain, oilseed, and hay that is brought in from outside of California. The San Joaquin Valley, the lower half of the Central Valley, has increased its milk production threefold over three decades, now contributing 90% of total milk production with only 69% of the total operations in 2020. This is a remarkable transformation for one region, and there are costs to such concentrated production. The San Joaquin Valley is vulnerable to extreme climatic conditions like drought and flood, and environmental impacts like ground water pollution, land subsidence, local air pollution, and extreme dust with accompanying asthma and other respiratory diseases. Concentrated feeding operations have been linked to impaired streams in California (Alford and Perez 2019). The 1,750,329 milk cows in California (Census of Agriculture 2017) also contribute to greenhouse gas emissions, through both intensive anaerobic processing of manure and emission of enteric methane from the rumen. The more than 2,000-cow herd sizes, 110 million hundredweights of milk annually, and hundreds of concentrated animal feeding operations in the middle of the dry

and hot Central Valley is a dramatic change from the pasture-based dairy cows that originally provided milk to those who arrived in Northern California less than 200 years ago.

Based on these patterns of change observed over the last several decades, I see three potential trajectories for the San Joaquin Valley's dairy industry: (1) production continues to increase slowly, dairies continue to consolidate, herd sizes continue to grow, and production concentrates further into the San Joaquin Valley, leaving Southern California and Sacramento Valley with fewer cows and farms, (2) production growth ends, the number of dairies continues to decline, specialization is maintained as water pressures mean less hay and silage is produced near the cows, and regional concentration in the San Joaquin Valley slows, (3) environmental impacts on water quality and air pollution, methane mandates, and higher feed costs decrease California milk production and herd sizes growth slows. The trajectory of the dairy industry remains to be seen, and will be influenced by multiple factors, including consumer demand, state policy, climate change and environmental pressures, and production in other states.

7. Conclusion

The visualizations and supporting tables show how quickly and drastically intensive feeding transformed the dairy industry in California. There have been distinct varied outcomes in production across different regions and a universal decline in operations with some variation in which regions retained the most diaries. There is strong evidence of a concentration of production and share of operations into the San Joaquin Valley; minor increases in the Sacramento Valley, Marin and Sonoma, and the North Coast; a significant decline in Southern California; and a halt of production reporting in the Central Coast and mountain regions. Whether these declines and increases are the result of the movement of dairies from one region to another cannot be discerned directly from the data. However, these data do reveal patterns of intensification, consolidation, and regional concentration taking place in California. These three forms of transformation are interdependent; the various forms of enlargement and intensification of production at the farm level are both a catalyst for, and the result of, industry consolidation, with operations becoming larger and fewer, therefore requiring more space and encouraging expansion into non-traditional dairy regions and causing declines in coastal and mountainous regions.

The phenomena of intensification, consolidation, and regional concentration are not exclusive to California. Similar contexts exist in new dairy regions like Idaho, West Texas, and more recently Kansas and South Dakota, which are rising in national ranks for milk production, and even in traditional dairy states like Wisconsin and New York, all of which are increasing herd sizes and decreasing in number of commercial dairies (Fraysse 2022). California offers an interesting and important case study for the potential futures of dairy industries in other states, and for the US dairy industry as a whole. The diversity of agricultural regions and geographic contexts in California creates a microcosm for the rest of the US, with traditional dairying

regions represented in organic and alternative dairies in Marin and Sonoma, rapidly urbanizing agricultural regions represented by Southern California, and the increasingly concentrated and isolated dairy production in warmer climates represented in the San Joaquin Valley. That said, there are many aspects of California's geography that set it apart from other states, such as the population density, the Mediterranean climate, and the general agricultural productivity, making it difficult to compare it entirely to other dairy producing regions in the US.

There is ample room for future research in the topic of California's dairy industry that may serve to deepen understanding of the nuances in this case study. The opportunities for further analysis and visualization comparing county-level change in operations and production with the data presented here are extensive, although beyond the scope of this thesis. There is also the possibility of acquiring past data from more years of the Census dating back to the beginning of recorded milk production in California in the mid 1800s. More precise locations and sizes of current individual dairy operations would provide data for a spatial analysis of clustering or proximity to urban areas, agricultural areas, and other dairies, which would help to bolster my findings of a regional concentration into the San Joaquin Valley. To supplement the quantitative data analysis, interviews or surveys with dairy producers across the state, both active and former, would add to the narrative on the causes and impacts of the changes taking place in California. Finally, these findings could be compared to environmental or economic data to assess the impacts of the dairy industry in different regions of California. Beyond California, a similar analysis could be conducted using county-level data from the US as a whole to assess how the dairy industry is changing considering all dairy producing regions.

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