An Environmental Justice and Proximity Assessment of Bovine Concentrated Animal Feeding Operations (CAFOs) in the Central Valley, California

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ABSTRACT

The concentration of concentrated animal feeding operations (CAFOs) within the Central Valley has raised concerns of the disproportionate impact of pollution and odor on surrounding communities. Using GIS and the environmental justice (EJ) framework, this study investigates racial and socioeconomic disparities in the distribution of bovine CAFOs in the Central Valley. I hypothesized that the odds of people of color and lower income individuals living within one mile (<1.0 mile) of a CAFO was greater than that outside (>1.0 mile). To provide insight into intersectional issues, I assessed other sociological variables, including: educational attainment, householder gender, and employment in the agriculture/mining sector. Using odds ratios, I found that people of color were more likely to live within one mile (>1.0 mile) of a CAFO facility than Non-Latinx Whites with Latinx, Native, and Pacific Islanders having the greatest odds. Individuals belonging to census block groups with lower annual household incomes as well having lower levels of educational attainment similarly showed increased odds of living <1.0 mile of a CAFO. This study represents a point of reference for future environmental health and justice research by opening up further opportunities to collaborate with communities, assess CAFO-related health and environmental impact, and to understand the role of CAFOs in the environmental riskscape of California.

KEYWORDS

GIS, animal agriculture, U.S. Census, American Community Survey (ACS), buffer analysis

INTRODUCTION

One major result of the industrialization of animal agriculture in the United States is that consumers have come to rely on concentrated animal feeding operations (CAFOs) to produce the majority of their egg, meat, and dairy products (MacDonald and McBride 2009, Osterburg and Wallinga 2004). CAFOs are defined by the U.S. Environmental Protection Agency (EPA) in accordance with size and discharge criteria. A large CAFO is defined as any animal feeding operation (AFO) with more than 1000 animal units housed more than 45 days in a given 12 month period (EPA 2012). These facilities, when properly managed, can be low-cost sources of animal products due to more efficient feeding and animal housing practices (Hribar 2010). Although more economically efficient, CAFOs are notorious point sources of air and water pollution at the detriment of local communities and the environment. Studies have identified specific airborne pollutants of concern from CAFO facilities, which include $PM_{2.5}$, ammonia (NH_3), hydrogen sulfide (H_2S), malodorous vapors, greenhouse gasses (GHGs), and a variety of microorganisms (Heederik et al. 2007, Hribar 2010). In addition, animal waste from these operations has also created concerns for environmental and public health in the form of nutrient pollution and the presence of other contaminants (e.g., antibiotics, veterinary drugs) which impact surface and drinking water quality (Burkholder et al. 2007, Copeland 2010). Due to the concentration and colocation of animals at these facilities, CAFOs have intensified the risk of more virulent strains of microorganisms and zoonoses, which additionally impact traditional measures of water quality (Gilchrist et al. 2007, West et al. 2011). Regulating air and water contamination from these facilities has also posed a challenge to lawmakers (Jones et al. 2017, Copeland 2010). Namely, EPA regulation of ambient air emissions from CAFOs has changed very little in the past two decades as the administration has grappled to develop reliable methods of analysis for federal compliance assessments. The lack of consensus for how ambient air emissions should be measured and regulated has carried serious implications for environmental and public health (Jones et al. 2017).

Research in the area of environmental health has correlated CAFO proximity to poor health outcomes in children and adults, including: asthma, allergies, and impaired lung function (Kilburn 2012, Loftus et al. 2020, Pavilonis et al. 2013, Schultz et al. 2019, Sigurdarson and Kline 2006). Other studies have correlated CAFO proximity to lapses in mental and social health, including anxiety, depression, and the disruption of measures of quality of life (Donham et al. 2007). Despite numerous studies that have been performed on this topic in the field of environmental health, little to no research has been performed within California to assess community health outcomes associated with these facilities.

Under the environmental justice (EJ) framework, researchers are encouraged to ask questions about the distribution of environmental costs and benefits within communities (Bullard 2015). With the potential to impact health and quality of life, the disproportionate location of CAFO facilities may be considered a form of environmental injustice (Donham et al. 2007). Previous studies in other states have suggested that CAFOs are located in areas with greater percentages of people of color and lower income populations (Lenhardt and Ogneva-Himmelberger 2013, Loftus et al. 2020, Nicole 2013, Mirabelli et al 2006, Wing et al. 2000). However, the majority of these studies were performed in North Carolina due to the availability of CAFO location data provided by the state. As a site of intense agricultural production, the Central Valley contains many CAFO locations as well as other agricultural operations. Due to the lack of research on CAFOs within California, I conducted a GIS proximity assessment of bovine CAFOs in the Central Valley using block group level Census and American Community Survey (ACS) data in order to assess racial and socioeconomic disparities of neighborhoods that face the greatest risk of environmental burden from CAFOs. Multi-species CAFOs were excluded from my analysis due to lack of information on species counts or adequate animal unit conversion. Although proximity to CAFO facilities is not a direct determinant of environmental health outcomes, proximity assessments are widely performed within EJ literature to estimate risk in lieu of data on contaminants and public health (Mohai et al. 2009). I will study how neighborhood-level demographics from communities that surround CAFOs differ from the rest of California to understand the role of CAFOs in the environmental riskscape of the state. I will use odds ratios to assess whether the differences between CAFO neighborhoods and the state are significant as well as how racial and sociological factors compare to one another.

BACKGROUND

The California Central Valley

According to the United States Geological Survey (USGS), the California Central Valley is a vast agricultural region that encompasses an area of about 20,000 square miles roughly in the center of California. The region is incredibly agriculturally productive and generates approximately one quarter of the food supply of the United States, despite containing less than 1% of the farmland (USGS 2009). The high-value, large-scale agricultural production of the region places the Central Valley as one of the most important agricultural centers in the U.S. which produces billions of dollars in agricultural product cash receipts each year (USGS 2009, CDFA 2021).

At the same time, the Central Valley has a dynamic history of environmental issues and conflict. In contrast to the weath produced by agricultural industry, the Central Valley is defined by higher rates of rural poverty, environmental health risks, and racial discrimination (Edward and Martin 2000, Pannu 2012). Many residents in unincorporated communities lack access to basic infrastructure such as paved roads, sewage, and emergency health services (Anderson 2008). Air quality in the region has been historically poor as adjoining areas such as the San Joaquin Valley (SJV) continue to display some of the poorest air quality ratings in the nation along with high rates of cardiovascular and respiratory disease (Cisneros et al. 2017, Veloz et al. 2020). Water as an increasingly scarce resource in California and the depletion of groundwater resources in areas such as the Central Valley is coupled with water quality degradation arising from urban, household, and agricultural (e.g., CAFOs) sources (Harter 2015). A number of studies found significant nitrate contamination that exceeded national standards in Central Valley drinking water (Harter et al. 2012, Lockhart et al. 2013). Lockhart et al. 2013 associated degraded water quality in the SJV with the concentration of CAFO facilities as well as other agricultural operations (e.g., citrus, nut, and vegetable operations) which both carry the potential to increase nitrate pollution. Conflicts over drinking water in the Central Valley have manifested in community activism and EJ organizations such as the Community Water Center (CWC) have fought for clean water rights in the region for years (Alkon et al. 2012).

Within the Central Valley, CAFOs are located with greater density than anywhere else in the state (Figure 1). As sites of higher efficiency animal production, CAFOs have allowed producers to reduce costs and earn more profits from less land and capital; further encouraging the emergence of larger farms (Hribar 2010). The industrialization of the animal agriculture industry in the United States has resulted in the majority of dairy and meat products to be produced through CAFO facilities (MacDonald and McBride 2009). In California, the success of the dairy industry has been attributed to the dominance of CAFO-based models of production (Macmullen 2007). In fact, milk is California's largest food commodity and totalled $7.47 billion U.S. dollars in cash receipts in 2020 alone according to the California Department of Food and Agriculture (CDFA) 2019-2020 California Agricultural Statistics Review (Macmullen 2007, CDFA 2021).

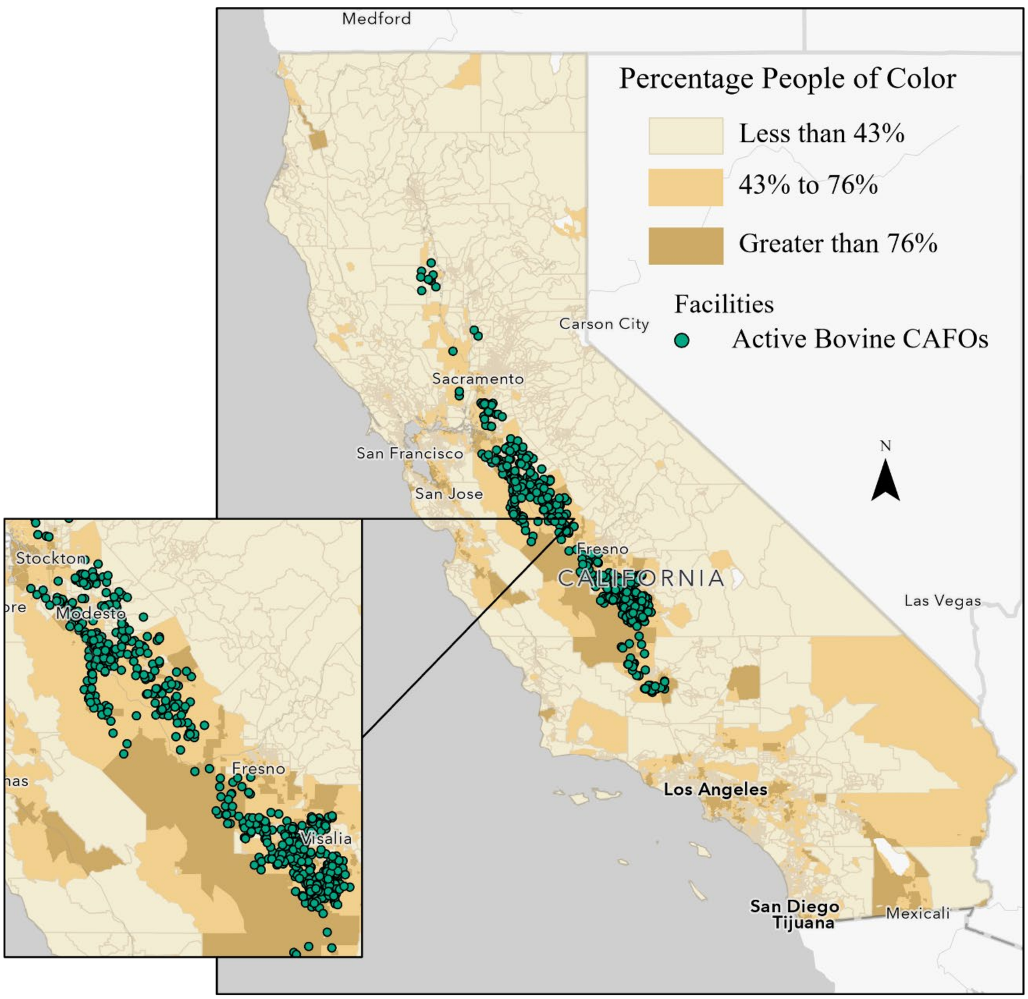

Figure 1. Map of all CAFO locations in the Central Valley (n = 777) and census block groups by percentage of people of color. Depicted CAFOs are excluded to active, medium to large-sized bovine-only operations. census block groups are from the 2010 Census.

The Environmental Justice (EJ) Framework

Environmental Justice (EJ) Movement was born out of the legacy of the Civil Rights Movement and emerged in part as a reaction to the myopic scope of traditional environmental movements, which were centered upon the preservation, conservation, and defense of nonhuman nature (Bullard 2015, Kojola and Pellow 2021). From this movement came the EJ framework, which offers a theoretical explanation of and methods to understand the ways in which social inequality, discrimination, and oppression shaped observable disparities in environmental risk (Bullard 2015, Kojola and Pellow 2021). A framework is a "'schemata of interpretation' that enables individuals 'to locate, perceive, identify, and label' occurrences within their life space and the world at large'" (Čapek 2015). Under the EJ framework, individuals may put a name to existing patterns of environmental injustices which disproportionately affect low-income communities and communities of color (Čapek 2015). In total, the EJ framework allows us to frame the ethical, moral, and political questions of environmental cost and benefit distribution in reference to historical paradigms of power (Bullard 2015).

Continuing environmental injustices within marginalized communities have expanded the EJ frame to encompass a variety of globalized and local issues. For example, indigenous EJ activism reflected in the Standing Rock Sioux protests against the Dakota Access Pipeline (DAPL) focused on toxic pollution but also affirmed indigenous cultural values and sovereignty. The growing list of EJ issues has expanded in recent years, allowing the consideration of more communities than ever before (Čapek 2015). In light of these changes, EJ researchers have sought to include other intersectional categories into EJ and social determinants of health, allowing research to expand past previous focuses on race and class (i.e., the "race vs. class debate) (Alvarez and Evans 2021, Mascarenhas et al. 2021). Within my study, I hope to take into account intersectional considerations of EJ and include variables recommended by Alvarez and Evans 2021 such as occupation, householder gender, and educational attainment in addition to race and household income.

The now long pedigree of EJ research has solidified its position in the sociological and environmental arena (Pastor et al. 2005). Since the breakthrough EJ studies in the 1980s, such as the United Church of Christ's "Toxic Waste and Race," EJ methodology has adopted increasingly sophisticated techniques along with enhanced data selection and analysis (United

Church of Christ 1987, Pastor et al. 2005). The earliest EJ studies debated the use of census tracts and zip codes (Mohai 2015). For the purposes of this study, I will be using census block groups. Block groups are the smallest geographic area in which the Bureau of Census collected data and are formed "by streets, roads, railroads, streams and other bodies of water, other visible physical and cultural features, and the legal boundaries shown on Census Bureau maps" (U.S. Department of Commerce 1994). Block groups contain more geographical detail than census tracts and are drawn to represent populations with fairly even demographic and economic statuses (Pastor et al. 2013). In this sense, block groups are valuable sources of information for fine-spatial resolution research and are noted by environmental justice researchers for their usefulness in modeling neighborhood-level population characteristics (U.S. Department of Commerce 1994, Pastor et al. 2013).

METHODS

Data sources

To perform an assessment of neighborhood demographics relating to CAFO locations, I relied on three data sources: the 2010 Census, the American Community Survey (ACS), and the California Integrated Water Quality System (CIWQS). First, I obtained a list of animal operations from CIWQS, and made available by the California Environmental Protection Agency. The CIWQS dataset which contained records of all facilities permitted within the animal waste water quality program in California dating back to November 1981 (https://ciwqs.waterboards.ca.gov/ciwqs/readOnly/CiwqsReportServlet?inCommand=reset&reportName=RegulatedFacility). The dataset contained the facility name, address, coordinates, registration date, and livestock population of all registered animal feeding operations within California as reported by facility operators (n = 1,936). Of the 1,936 facilities within the database as of October 2021, 1,411 were cattle operations and 524 identified themselves as operations with mixed animal type (e.g., swine, poultry, etc.). Multi-species CAFOs were excluded from my analysis due to lack of information on species counts needed to fit the EPA definition of a medium to large CAFO (EPA 2012). I filtered the CIWQS dataset down according to Figure 2 within Excel. First, I confined the location of CAFOs within the Central Valley using approximate coordinate location of the region (40°55'50.7"N, 134°54'51.0"N, 18°24'28.2"W, 22°29'25.2"W) and then removed any remaining facilities that were not located in the Central Valley. Then, I filtered these data to active CAFO locations to ensure that historical facilities were not included in my analysis. Facilities with livestock populations < 500 were excluded from these data so that only medium and large CAFOs were included within my analysis, such that I satisfied the EPA definition of medium and large CAFOs (EPA 2012). In total, the filtered dataset amounted to 777 facilities in the Central Valley that were active, bovine CAFOs of medium and large size.

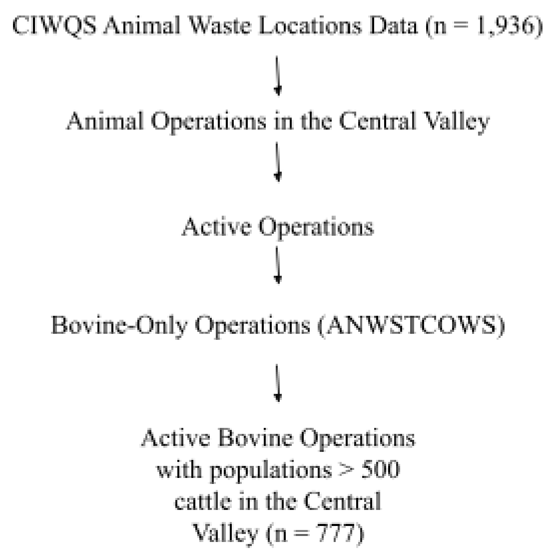

Figure 2. The identification of bovine CAFOs from CIWQS data. CIWQS data downloaded October 2021.

Shapefiles for block groups were obtained from the 2010 Census and accessed through a feature layer posted within ESRI's LivingAtlas, an online database for GIS data (https://www.arcgis.com/home/item.html?id=2158ce05955d4c529636b9fa0943193f). I decided to use block groups since they are the smallest geographical unit of the Census, and are often used within environmental health and justice literature to approximate neighborhood-level exposures to environmental pollutants (Pastor et al. 2013). In addition to block group boundaries, the data layer obtained from ESRI included data on the number of individuals per racial group, population size, as well as population density which I used in my analysis.

Block group level data on income, householder gender, educational attainment (for adults 25 years and older), and employment within the agricultural/mining sector was obtained from the American Community Survey (ACS) (https://www.census.gov/programs-surveys/acs). Since 1-year estimates for certain demographic variables were not available for block groups, I relied on 2013 5-year estimates for all my variables for data that were most comparable with the 2010 Census. I then condensed the data for income, poverty, householder gender, educational attainment (for adults 25 years and older), and employment within the agricultural/mining sector into a single table by joining the variable data by census block group ID number within Excel. To make the data available in a two-dimensional format, I joined a 2013 TIGER/Line shapefile for block groups in California (https://www2.census.gov/geo/tiger/TIGER2013/) with the ACS data.

To process the CIWQS, Census, and ACS data, I downloaded each dataset as a data layer within ArcGIS Pro 2.9.1. To ensure both datasets were within a geospatial projection which most accurately reflected the geospatial layout of California, I changed the projection of all data layers to the NAD 1983 (2011) California (Teale) Albers (Meters) Projection. I generated a series of buffers (>1.0,< 1.0, < 2.5, < 5.0, < 6.0, and > 6.0 mile) to assess the relationship between proximity and neighborhood demographics.

The 50 percent areal containment method

I employed the 50 percent areal containment method as described by Mohai and Saha (2006) to combine the Census, ACS, and CIWQS data I obtained. In this method, circular buffers are drawn around a point of environmental hazard and then intersected with census unit data. Any census unit whose area is 50 percent or more contained within the buffer is included in the analysis, while all other census units are excluded. The 50 percent areal containment method was especially useful because it allowed me to combine point data (e.g., CAFO locations) with two-dimensional data in predefined units (e.g., block groups). In addition, the 50 percent areal containment method allowed me to establish a guideline for including census units to assess areas of environmental exposure, while excluding expansive census units where spatial proximity cannot be established (Mohai and Saha 2006). Buffer and intersect functions were performed in ArcGIS and then exported to Excel for further analysis.

Statistical analysis

My main goal for the analysis was to examine racial and socioeconomic disparities in proximity to CAFO facilities and to investigate which disparities were the best predictors of CAFO proximity. To substantiate my analysis, I employed odds ratios (ORs) to assess the significance of such disparities between neighborhoods > 1.0 mile away from a CAFO facility and neighborhoods beyond the 1.0 mile mark. I treated populations that lived within 1.0 mile of an operation as my odds ratio exposure variable and calculated odds ratios as listed in Figure 3. I used Altman 1991 as reference to derive standard error and confidence intervals for each odds ratio, as well as Sheskin 2004 for each P-value. To create points of comparison, I generated dichotomous measures of race (Non-Latinx White vs. Latinx, Black, Asian, Native, Pacific Islander), 3-category measures of education (some high school or less, high school or some college, and bachelor's or graduate degree), 2-category measures of 2013 income (< $60,000 and > $60,000, with $60,000 being the approximate median household income in California), householder gender (male vs. female householder, and employment (male agricultural/mining workers vs. male workers in other sectors, female agricultural/mining workers vs. female workers in other sectors). For the median household income variable, I derived a rough estimate for the number of income earners by assuming that the value of the median annual household income was the same for all individuals within a given block group. My analysis did not control for potential confounding variables such as age, gender, and marital status because they were not expected to have significant effects given my large sample size of facilities and proximal populations.

	$< 1.0\ mi$	$> 1.0\ mi$
Population 1	A	B
Population 2	C	D

$$\text{OR} = \frac{\text{Odds that those in <1.0 mi belong to Population 1}}{\text{Odds that those in <1.0 mi belong to Population 2}} = \frac{A/C}{B/D}$$

Figure 3. The determination of odds ratios from study populations < 1.0 mile vs. > 1.0 mile from a CAFO.

RESULTS

Demographic survey of study area

I plotted the locations of 777 active medium and large-sized bovine CAFOs within the Central Valley and assessed the demographics of neighborhoods within < 1.0, < 2.5, < 5.0, < 6.0, and > 6.0 mile buffers. Table 1 offers a breakdown of the racial composition of the neighborhoods within each of the distance buffers. The table shows that racial characteristics generally vary across buffers, but buffered (< 6.0 mi) and non-buffered (> 6.0 mi) neighborhoods overall do not appear to display as significant differences as Pastor et al. 2013.

Table 1. **Average racial characteristics by buffer radius (mi) using CAFOs as center point**. 2010 Census data was downloaded from ESRI's Living Atlas. CAFO locations data downloaded from the California Integrated Water Quality System (CIWQS).

Buffer radius (mi)	**< 1.0**	**< 2.5**	**< 5.0**	**< 6.0**	**> 6.0**
Total Population	47,962	894,048	2,274,087	2,795,807	34,804,657
California Population (%)	0.1	2.4	6.1	7.5	93.4
Non-Latinx White (%)	36.9	39.7	37.5	36.3	40.4
People of Color (%)	62.2	59.3	67.5	62.7	57.0
Latinx (%)	53.5	48.4	47.8	48.0	36.8
Black/African American (%)	2.3	3.4	4.5	4.8	6.3
Asian (%)	4.8	5.9	7.4	8.2	13.4
Indigenous/Native American (%)	1.3	1.2	1.3	1.3	0.9
Pacific Islander (%)	0.4	0.3	0.4	0.3	0.4

Latinx and Native communities experience the most disproportionate burden: their share of the population living less than one mile away from a facility is about 1.5 times greater than outside the six mile range. It is also noteworthy to mention that individuals that were located within six miles of a CAFO facility constituted about 7.5 percent of the entire population of California, which signifies that the study area was more sparsely populated and predominantly rural compared to other urbanized centers in California. By contrast, Table 2 offers a first view at the sociological characteristics of the neighborhoods within the study area using ACS data.

Table 2. **Average sociological characteristics by buffer radius (mi) using CAFOs as center point**. American Community Survey (ACS) 2013 5-year estimates were downloaded from census.gov. CAFO locations data downloaded from the California Integrated Water Quality System (CIWQS).

Buffer radius (mi)	**<1.0**	**<2.5**	**<5.0**	**<6.0**	**>6.0**
Median Income (2013 Inflation-Adjusted $USD)	50,213	48,807	49,158	49,053	68,523
Education (Adults ≥ 25 years old)					
Less than High School (%)	23.4	18.5	16.9	17.1	18.2
High School Diploma or equivalent (%)	23.4	18.5	16.9	17.1	20.4
Some College or Bachelor's Degree (%)	35.1	38.1	40.3	40.4	49.8
Graduate Degree (Masters, Doctorate) (%)	3.3	4.0	4.5	4.7	11.7
Female Householder (%)	40.6	43.3	44.9	45.4	43.5
Agricultural and Mining Employed (% of working population)					
Men	28.9	18.8	15.6	15.4	2.2
Women	7.4	6.9	6.4	6.3	1.0

As depicted in Table 2, median annual household income was lower within six miles of a CAFO facility than outside the six mile mark. While the predominant level of education for adults over the age of 25 was some college or a bachelor's degree across all buffers, neighborhoods within six miles of a CAFO facility generally exhibited lower levels of educational attainment. For instance, the percent of individuals receiving a graduate degree was 3.5 times greater outside the six mile mark than at the one mile mark. Agricultural occupation was greatest for male and female workers at the one mile mark and showed heightened differences from the rest of California. The percentage of male workers in the agricultural/mining sector was 13.1 times greater in neighborhoods less than one mile from a CAFO than the six mile mark; for female workers the value was 7.4 times greater. Female householding within six miles of a CAFO was slightly lower than outside the six mile mark, but this difference was small in comparison to the other values exhibited in Table 2.

Comparing communities within one mile of a CAFO with odds ratios

Table 3 breaks down the demographics of neighborhoods less than one mile from a CAFO using unweighted quantities and percentages. The composition of selected census block groups that lay 50 percent or more within the 1.0 mile buffer are listed in order of race, income, education, householder gender, and employment in the agricultural/mining sector. Areas within one mile of a CAFO facility were predominantly Latinx (53.5%) and Non-Latinx White (36.9%). There were more census block groups with a median annual household income of less than $60,000 (73.9%) than above $60,000 (26.0%) (i.e., the approximate median income for the Central Valley). For education, 54.4% of adults over the age of 25 had completed high school or completed some college, compared with the 34.1% of adults that had completed some high school or received less education and the 11.4% of adults that had received a bachelor's degree or graduate degree. Male householders (58.3%) held the majority over female householders (40.6%). Lastly, males in the agricultural/mining sectors constituted 28.9% of the male working population, while females in the agricultural/mining sector constituted 7.4% of the female working population.

Table 3. **Sociological characteristics within one mile (<1.0 mi) of a CAFO.** 2010 Census data was downloaded from ESRI's Living Atlas. American Community Survey (ACS) 2013 5-year estimates were downloaded from census.gov. CAFO locations data downloaded from the California Integrated Water Quality System (CIWQS).

Attribute	Unweighted Quantity	Percent (%)
Non-Latinx White	17,682	36.9
Latinx	25,657	53.5
Black/African-American	1,087	2.3
Asian	2,322	4.8
Indigenous/Native American	603	1.3
Pacific Islander	176	0.4
Median Household Annual Income (2013 inflation-adjusted $USD)		
< $60,000	79,835	73.9
> $60,000	28,751	26.0
Education (Adults ≥ 25 years old)		
Some High School or Less	22,046	34.1
High School or Some College	35,226	54.4
Bachelor's or Graduate Degree	7,401	11.4
Householders		
Male	15,060	58.3
Female	10,743	40.6
Labor in Agriculture/Mining		
Male	6,859	28.9
Female	1,069	7.4

Table 4 shows the odds ratios from my comparison of neighborhoods within one mile of a CAFO versus outside the one mile mark. I found significant disparities associated with all my variables (i.e., $p < 0.0001$). Notably, Latinx individuals were more likely than Non-Latinx Whites to live within one mile of a CAFO facility (OR = 1.55, 95% confidence interval [CI] =

1.52, 1.58). Native and Pacific Islanders were additionally more likely to live within one mile of a CAFO than Non-Latinx Whites (OR = 1.41, 1.03; 95% confidence interval [CI] = 1.30, 1.53; 0.89, 1.19, *respectively*). Asian and Black individuals had a negative association in comparison to Non-Latinx White individuals (OR = 0.40, 0.41; 95% confidence interval [CI] = 0.39, 0.42; 0.38, 0.43, *respectively*). However, when considered as a group, people of color were more likely than Non-Latinx Whites to live within one mile of a CAFO (OR = 1.17, 95% confidence interval [CI] = 1.15, 1.19). Racial variables were not controlled for sociological variables such as gender and socioeconomic status.

Additionally, Table 4 shows the odds ratios for the additional sociological variables within my analysis. The odds ratios for these variables were all statistically significant at $p < 0.0001$. I found a greater likelihood of living within one mile of a CAFO for census block groups whose median annual household income was less than $60,000, than block groups whose median household income was greater than $60,000 (OR = 2.86, 95% confidence level [CI] = 2.82, 2.90). Those without a high school diploma (i.e., "some high school or less") were more likely to live near such a facility against those that received more education (OR = 2.25, 95% confidence level [CI] = 2.21, 2.28). Similarly, those who had received a high school diploma or completed some college had an even more increased odds of living near a CAFO than those who had received a bachelor's or graduate degree (OR = 2.87, 95% confidence level [CI] = 2.82, 2.97). Householders were less likely to be female with an odds ratio of 0.92 and a 95% confidence interval of 0.90 - 0.95. Lastly, both men and women laborers in the agricultural/mining sectors had very high odds of living within one mile of a CAFO facility than workers outside of those sectors (OR = 12.62, 5.76; 95% confidence level [CI] = 12.26, 12.97; 5.41, 6.13).

Table 4. **Sociological characteristics within one mile (< 1.0 mi) of a CAFO and greater than one mile (> 1.0 mi) of a CAFO.** American Community Survey (ACS) 2013 5-year estimates were downloaded from census.gov. CAFO locations data downloaded from the California Integrated Water Quality System (CIWQS). OR = Odds Ratio. CI = Confidence interval. * = p-value < 0.0001.

Attribute	**OR**	**95% CI**
Race		
Non-Latinx White vs. People of Color	1.17	(1.15, 1.19)*
Non-Latinx White vs. Latinx	1.55	(1.52, 1.58)*
Non-Latinx White vs. Black	0.41	(0.38, 0.43)*
Non-Latinx White vs. Asian	0.40	(0.39, 0.42)*
Non-Latinx White vs. Native/American Indian	1.41	(1.30, 1.53)*
Non-Latinx White vs. Pacific Islander	1.03	(0.89, 1.19)*
Median Household Annual Income: <$60,000, vs. >$60,000 (2013 inflation-adjusted $USD)	2.86	(2.82, 2.90)*
Education (Adults ≥ 25 years old)		
Less than High School vs. High School and more than High School	2.25	(2.21, 2.28)*
High School and Some College vs. College and Graduate	2.89	(2.82, 2.97)*
Female vs. Male Householder	0.92	(0.90, 0.95)*
Labor		
Male Laborers in Agriculture/Mining vs. Other Male Laborers in all other sectors	12.62	(12.26, 12.97)*
Female Laborers in Agriculture/Mining vs. Other Female Laborers in all other sectors	5.76	(5.41, 6.13)*

DISCUSSION

Racial and socioeconomic disparities in the distribution of CAFO facilities in the Central Valley supports a growing body of evidence of disparities in environmental burden related to animal feeding operations. I found that disparities in environmental burden were closely associated with lower income block groups as well as people of color, adding on to similar findings by Lenhardt and Ogneva Himmelberger 2013 and Wing et al. 2000. All findings were statistically significant, suggesting that multi-level disparities were associated with proximity to CAFO facilities.

I found that the odds of living near a CAFO varied by racial group, suggesting the importance of specificity when assessing racial variables in environmental health and justice research. Using dichotomous analysis, individuals that identified themselves as Latinx, Native, or Pacific Islander were significantly more likely to live within 1 mile of a CAFO than Non-Latinx Whites. Latinx individuals were the most likely of any group to live in proximity to a CAFO facility in comparison to Non-Latinx Whites. Alternatively, individuals that identified as Black or Asian were significantly less likely to live within 1 mile of a CAFO facility. However, when people of color were considered together as a group, they were more likely to live within one mile of a CAFO facility than Non-Latinx Whites. The significance of the people of color odds ratio suggests that the number of Latinx, Native, and Pacific Islanders had a greater influence on the odds ratio than Black and Asian populations; this result was likely due to the fact that Latinx, Native, and Pacific Islanders constitute larger proportions of the population when taken together than Black and Asian populations. Therefore, it is important to take into account the influence of all racial groups included within a given analysis when employing odds ratios.

Income was another significant factor of CAFO proximity. However, the applicability of this variable is more limited than the aforementioned racial variables in that I lacked actual counts of the number of income earners and their respective incomes across block groups. To make up for the lack of data, I assumed that all individuals within a block group had annual incomes that matched the median annual household income of their respective block group. For example, if a block group had 6,000 people and a median annual household income of less than \$60,000, then all 6,000 inhabitants were counted under the > \$60,000 variable. This technique does not account for the potential variation of annual household incomes across block groups and may exaggerate the value of the income odds ratio. However, this technique is useful in that it offers a preview into potential relations of income and CAFO proximity, yet the income odds ratio should not be used as an adequate point of comparison for the odds ratios I obtained for racial and other socioeconomic variables due to the roughness of the measurement taken.

Gender and householder status was not a significant factor of CAFO proximity because the value for the odds ratio is close to 1, suggesting that proximity and householder gender cannot be associated with one another. This differs from Alvarez and Evans 2021, which found that the percent of female householders to be a significant sociological factor that could be used in environmental justice research. Comparable findings are associated with gender ratios in the population, as with Mohai et al. 2009, which found that there was no significant disparity in the proximity of environmental hazards between male and female individuals. These results reveal that more nuanced approaches to gender must be examined more closely in future environmental inequality studies.

Employment in the agricultural/mining sector was the most significant factor within my analysis because it yielded the greatest odds ratios, suggesting that male and female agricultural/mining workers were far more likely to live within one mile of a CAFO than those employed within other sectors. This result is not as surprising as my other results because I expected that greater numbers of agricultural workers lived closer to CAFO facilities than in the rest of California due to the intensity of agricultural production in the Central Valley. Although localized employment cannot be assumed within this, this variable is interesting because it carries the implication of occupational exposures within CAFO facilities (i.e., via working within a facility or in an agricultural operation nearby) as explored within Heederik et al. 2007. Additionally, the odds ratio for men was significantly higher than that for women. This difference illustrates a gendered concentration of male employment in the agricultural/mining industry in the Central Valley, and may carry further implications regarding gendered exposure to CAFO-related pollutants.

Limitations and future directions

My analyses contained several limitations worthy of discussion. As discussed by Mohai et al. 2009, the assessment of proximity to sites of environmental hazard is at best an indirect measure of environmental exposure. Environmental exposure is a complex process which involves many different aspects of how an individual interacts with their environment. Effective risk assessments require both qualitative (e.g., strength of evidence) and quantitative (e.g., exposure origin, host susceptibility, risk magnitude) information to draw conclusions about environmental risk (Faustmann and Omenn 2013). Data concerning the volumes and toxicities of air, water, land land pollutants can be scarce or lack fine spatial resolution (Mohai et al. 2009). Census and ACS data is similarly limited in its specificity at the individual level, as I lacked sufficient data about income and other cross-sectional metrics of environmental justice. This problem was most evident for my income variable, as I could not obtain information at the individual level about income nor income distribution data by census block group. As a result, I relied on rough estimates to consider my income variable.

Given the disparities I found within neighborhoods in close proximity to CAFO operations in the Central Valley, an important next step in future analyses would be to examine how such disparities affect health and mortality in the communities they impact the most. In addition to traditional risk assessment surveys, research structures such as community-based participatory research (CBPR) enhance the relevance and rigor of environmental justice research by engaging scientists and communities to collaborate in knowledge co production (Morello-Frosch and Balaz 2015). CBPR additionally pools a body of diverse skills into learning environments that contribute to community capacity building, partnerships, and empowerment. Communities engaged with research are engaged to advance community-supported policy and work with policymakers to collaborate on issues of environmental risk and hazard (Minkler et al. 2008). Collaborating with communities on CAFOs in the Central Valley may allow the development of a greater understanding of the physical, mental, and social outcomes of CAFO proximity to California neighborhoods. Sharing control of CAFO research may additionally increase community engagement and establish trust between researchers and Central Valley communities. Such research is essential in the Central Valley, where communities may face overlapping environmental exposures (i.e., coexposures) due to the density of agricultural operations. Such research methodology aims to establish the effects of CAFO facilities on the environmental riskscape of California and to empower communities to seek environmental justice.

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