

Disparities of industrial animal operations in California, Iowa, and North Carolina

Arbor J.L. Quist¹, Jill E. Johnston¹, Mike Dolan Fliss²

¹Division of Environmental Health, Department of Population and Public Health Sciences, Keck School of Medicine, University of Southern California, Los Angeles, CA, USA

²Injury Prevention Research Center, University of North Carolina, Chapel Hill, NC, USA

Summary

Background: Concentrated animal feeding operations (CAFOs) densely house thousands of animals in confined areas. CAFOs in the United States commonly store animal manure in open lagoons and apply manure to nearby fields. These processes can pollute the water and air with pathogens and chemicals that impair the quality of life and physical health of neighboring communities. Iowa (IA) and North Carolina (NC) are two of the leading swine producers in the United States, while California (CA) is the nation's leading milk producer.

Methods: We obtained information on the location and size of swine CAFOs in IA and NC and of dairy CAFOs in CA's Central Valley. We calculated the number of animal units (AUs, a measure of the estimated weight of all the animals) in each CAFO and used the EPA definition to categorize Large CAFOs. We focused on Large CAFOs because they produce an exceptionally large amount of waste and are likely responsible for the majority of air and water pollution from CAFOs. We obtained 2019 block group demographic data and apportioned the race and ethnicity data to the 2010 census blocks. We calculated the number of Large CAFOs and total CAFOs within 3 miles of the block centroids. We compared the proportions of people of color (POC), Black, Hispanic, and American Indian residents living within 3 miles of a CAFO to the proportion of non-Hispanic White residents for the study area of each state. We used Poisson and linear regression to assess the relationship between race/ethnicity and the presence of one or more Large CAFO or the AUs of CAFOs. We also examined the proportion of people living within 3 miles of a Large CAFO by income, rurality (measured as isolation to resources), and social vulnerability.

Results: The proportion of POC, Hispanic, and American Indian residents living within 3 miles of a Large Dairy CAFO in the CA study area is 1.29, 1.54, and 1.15, times higher, respectively, than the percent of non-Hispanic Whites. In the NC study area, percent of POC, Black, Hispanic, and American Indian residents living within 3 miles of a Large CAFO is 1.42, 1.42, 1.57, and 2.20 times higher, respectively, than the percent of non-Hispanic Whites. In NC and CA, blocks with >40% POC had 738-1657 more animal units when adjusting for rurality than areas with <20% POC. In IA, White non-Hispanics are more likely to live near a Large Swine CAFO than POC. Increased census tract poverty was associated with greater exposure to Large CAFOs: the proportion of residents in Census tracts with $\geq 35\%$ of households below the 200% poverty level who live within 3 miles of a Large CAFO is about 2.5 times higher in CA and 15 times higher in NC compared to Census tracts with <20% of households below the 200% poverty level. Of people in Census tracts with the least access to resources, 81%, 27%, and 25% live <3 miles of a CAFO in IA, CA, and NC respectively. Increased tract-level social vulnerability was associated with greater resident exposure to Large CAFOs in NC and CA.

Conclusions: Swine CAFOs in NC and dairy CAFOs in CA are disproportionately located in low-income communities and near POC. Swine CAFOs in IA tend to be located in rural areas that lack access to resources. This environmental injustice harms the neighboring communities as water and air pollution associated with CAFOs are linked to adverse health effects.

Background

Animal production has intensified greatly across the United States since the 1980s.^{1,2} While the number of swine and cattle has increased, the number of farms has decreased.³ The majority of livestock in the United States is now housed in large, concentrated animal feeding operations (CAFOs), which each hold thousands of animals.³ These industrial animal operations produce enormous volumes of waste, which is often stored in uncovered manure lagoons and sprayed onto nearby land as fertilizer.⁴ Because the land cannot absorb the massive amounts of manure, pathogens and chemicals from the waste often pollute the air and water, which can harm the environment and the health of nearby residents.^{4,5}

Iowa (IA) is the United States' top swine-producing state, with approximately 23 million hogs housed in CAFOs located throughout the entire state.^{6,7} Swine CAFOs are heavily concentrated in eastern North Carolina (NC), the second leading U.S. swine producer with approximately 8.5 million hogs.^{8,9} Many studies have concluded that living near swine CAFOs is associated with worse physical and mental health.¹⁰ One NC study found that residents in ZIP codes with a high density of hogs within 2-5 km had higher all-cause mortality, infant mortality, mortality from anemia, kidney disease, tuberculosis, and septicemia, compared to ZIP codes without hog CAFOs.¹¹ Residents living within two miles of a swine CAFO in NC have reported higher incidence of headaches, runny nose, sore throat, coughing, diarrhea, and burning eyes compared to residents who do not live near intensive livestock operations.¹²

California has been the nation's leading milk producer for almost 30 years.¹³ Approximately 1.8 million dairy cows are housed in California, with most of them located in the San Joaquin Valley.¹³ Much of this region is flat with shallow water tables that are susceptible to groundwater contamination.¹⁴ In recent years, many small drinking water systems in the San Joaquin Valley Watershed have not met US EPA safe drinking water standards.¹⁵ Dairy CAFOs can contaminate water and air and can also negatively affect the health of nearby residents. A study of dairy CAFOs in the Yakima Valley, Washington State measured elevated airborne particulate matter and ammonia up to 3 miles from dairy operations.¹⁶ Particulate matter exposure has been linked to many health conditions, including asthma, chronic obstructive pulmonary disease, and stroke.¹⁷ Ammonia exposure can cause burning of the eyes, nose, and throat, and long-term exposure may have lasting effects on the respiratory system.¹⁸ Residents living near cattle, poultry, and swine CAFOs have reported increased incidence of respiratory, gastrointestinal, neurological, and stress-related symptoms.¹⁹ High intensity farming has also been associated with increased acute gastrointestinal illness hospitalizations, especially among children under age 5.²⁰

Due to the large amount of manure produced by CAFOs and the current lagoon and spray field system, surface and groundwater near CAFOs are often contaminated. Groundwater near swine CAFOs with lagoons has been found to have higher *Escherichia coli* levels than reference sites, including antibiotic-resistant *E. coli* strains.²¹ The overuse of antibiotics causes more antibiotic resistant bacteria to evolve, resulting in harder-to-treat infections and increased mortality.²² Most CAFOs give antibiotics to their animals to prevent microbial infection and promote growth; however, antibiotics can be released into surface and groundwater, exposing nearby humans.^{14,23} Antibiotics have been found in shallow groundwater downstream from dairy lagoons.¹⁴ Other pathogens linked to CAFOs include *Salmonella*, *Campylobacter*, *Yersinia enterocolitica*, *Cryptosporidium*, and *Giardia*; many of these pathogens can survive in water for several weeks and can cause acute gastrointestinal illness in exposed humans.²⁴ Researchers have found high fecal indicator bacteria concentrations near swine CAFOs.²⁵ Swine-specific microbial source-tracking markers were found to be 2.3-2.5 times more prevalent in proximal downstream surface water compared to proximal surface water upstream from swine CAFOs, and these

microbial source tracking markers were detected more frequently during the 48 hours after heavy rain.²⁵ Nutrients and pathogens from animal manure can be transported via groundwater or through soil during wet conditions.²³ A study of runoff after land application of cattle and swine manure and after simulated heavy rainfall events found *E.coli* and enterococci concentrations to be significantly higher than in runoff from control plots with no manure.²⁶

During heavy precipitation events, lagoons can flood or breach, transporting manure that may contain illness-causing pathogens. NC swine CAFOs are most densely located in areas of eastern NC that commonly flood during hurricanes, a reoccurring issue as NC is the third most hurricane-prone state.²⁷ Black residents were more likely than White residents to live in areas with flooded CAFOs in NC, according to satellite estimates after Hurricane Floyd (1999).²⁸ Breached swine manure lagoons in NC after Hurricane Fran (1996) contributed to anoxia and hypoxia in the Cape Fear watershed much more than human sewage, likely because swine waste is more concentrated than human sewage.²⁹ Although heavy rain events may contribute more to the transport of pathogens from CAFOs in NC than CA and IA, as NC has a higher average annual rainfall (50 inches) than IA (32 in) or CA (22 in),³⁰ climate change has been increasing the frequency and intensity of heavy precipitation events across various areas of the United States.³¹

NC, IA, and CA have different climates, histories, and demographics, but these three states contain thousands of CAFOs that are impacting the environment and neighbors' health. In this report, we examine the disproportionate siting of CAFOs in communities of color, low-income communities, rural communities isolated from resources, and communities with additional environmental and social vulnerabilities across these three states.

Methods

For these analyses, we abstracted NC swine CAFO permit data (2019) from NC Department of Environmental Quality,³² IA swine CAFO data from Iowa Department of Natural Resources,³³ and CA dairy CAFO data from the California Integrated Water Quality System in 2021.³⁴ We identified Large CAFOs using the United States Environmental Protection Agency's (EPA) definition (dairy CAFOs with ≥ 700 dairy cows, swine CAFOs with ≥ 2500 animals that weigh ≥ 55 lbs or CAFOs with $\geq 10,000$ animals that weigh < 55 lbs, and CAFOs with > 1000 animal units; as established in EPA 40 CFR 122.23(b)(4)).³⁵ We focused on Large CAFOs because they produce an exceptionally large amount of waste and are likely responsible for the majority of air and water pollution from CAFOs. We calculated the number of animal units (AUs) for each CAFO, to be able to compare dairy and swine CAFOs. One animal unit is equal to approximately 1000 pounds of animal weight, which is approximately the weight of a typical steer.³⁶ AUs were calculated for hogs based on the average weight of the life stage of permitted swine. (Growing feeder to finish pigs weigh 50-220 lbs—on average 135 lbs or 0.135 AU; boar studs weigh 250-550 lbs—on average 400 lbs or 0.4 AU).^{36,37}

We obtained 2019 block group demographic data (total population and number of residents by race and ethnicity) for CA, IA, and NC from the American Community Survey (ACS) and apportioned this data to the block level (using the block-block group proportions from the 2010 census). Blocks with centroids within 3 miles of a CAFO were considered exposed and blocks with centroids > 3 miles from a CAFO were considered unexposed. We chose this 3 mile threshold as CAFO exposures can travel several miles and as living within 0.5, 2, and 3 miles from a CAFO has been associated with various health outcomes.^{11,16,19,38,39} As many people indicate more than one racial/ethnic category, we used estimates of all people identifying with a race, regardless of the other categories they indicated. For example, the

Black race category in our analysis includes residents who only identified as Black as well as those who also indicated another race or ethnic group. We defined people of color as all people who identify as Hispanic and/or who identify with one or more non-White race.

As CAFOs are seldom located in urban areas, and as urban areas have different demographic patterns and environmental exposures, we excluded urban areas from analysis. In NC, we excluded cities with populations >250,000 for NC (top five populous NC cities). Since all IA cities have a population <250,000, we excluded the top 3 IA cities (population >100,000 people). As dairy CAFOs in CA were located in more urban areas than swine CAFOs in IA and NC, we excluded the most urban CA Census tracts (geographic isolation scale <3.9; threshold determined as the least isolated tract with a dairy CAFO). We sought to create a contiguous study area where CAFOs may be located in each state. In NC, we excluded counties if they do not contain swine CAFOs and they do not neighbor counties with swine CAFOs; this removed western NC from analysis. Since CA counties are very large, we only included CA counties with dairy CAFOs. All IA counties contain swine CAFOs, thus no counties were excluded from the IA analyses.

We examined the percent of population living within 3 miles of a CAFO by percent of POC. We conducted weighted Poisson regression to examine the relationships between race/ethnicity and the presence of at least one Large CAFO within 3 miles of the center of a block (weighted by census block population), with White non-Hispanic as the reference. We conducted weighted linear regression to assess the relationship between the block-level percent of POC and the number of animal units within 3 miles of a block centroid. Although we excluded the most urban areas that do not contain CAFOs, rurality still varied substantially in the study area. In adjusted models, we controlled for rurality using the cubic natural log of the population density, with the median (i.e., the median after exclusion of urban areas) subtracted to standardize the values.⁸

In additional analyses, we obtained 2019 block group median income from American Community Survey for each state and drew a 3-mile buffer around each block group centroid. We counted the number of CAFOs located in each 3-mile buffer from the centroid and the number of CAFOs located within each block group and used the largest count for each block group in order to account for differing sizes of block groups. We split block groups into six income groups and examined the percent of the population living within 3 miles from a CAFO among each income group. We conducted similar analyses for the percent of each Census tract living below the 200% federal poverty level. We similarly attributed Census tracts as exposed to CAFOs if they contained CAFOs or if CAFOs were located within 3 miles of the Census tract centroid. We also used a geographic isolation scale (a continuous measure split into quartiles based on nationwide data) that classifies Census tracts according to their access to resources, such as food, healthcare, and internet, as a measure of rurality.⁴¹ We assessed the percent of the population living in tracts within 3 miles of a CAFO among each rurality group.

We also used the CDC/ATSDR Social Vulnerability Index (SVI) and the EPA's EJScreen: Environmental Justice Screening and Mapping Tool to examine the other social and environmental exposures and vulnerabilities residents living near Large CAFOs face.^{42,43} The SVI assesses Census tract vulnerability in terms of socioeconomic status, household composition and disability, minority status and language, and housing type and transportation. EJScreen estimates environmental exposures for Census block groups for diesel particulate matter level in air, air toxics cancer risk, indicator for major direct dischargers to water, and other environmental exposures. EJScreen does not currently incorporate CAFO data into its environmental justice calculation tools, though CAFO waste can and does discharge into waterways. For both the SVI and EJScreen, we split the continuous indices into quartiles (separate quartiles for each state) and examined the percent of the population living within 3 miles from a Large CAFO.

These descriptive analyses use publicly available data to examine the environmental injustices associated with CAFOs. Because the US EPA examines statistical significance, we have included p-values and confidence intervals; however, we join many other scientists in urging against relying purely on statistical significance and p-value thresholds to interpret results.⁴⁴⁻⁴⁶ The confidence intervals (CIs) we report indicate the precision of the associations; typically, results are considered to be statistically significant if the 95% CIs do not include the null value (1 for ratio and 0 for differences). The p-values reported indicate the statistical difference between each ratio by race/ethnicity and the proportion of White non-Hispanic residents living with 3 miles of a CAFO.

In order to place these CAFO disparities analyses in context, we also describe the rurality, income, and racial demographics of California, Iowa, and North Carolina.

Results

California, North Carolina, and Iowa have different demographics, but all three states are home to thousands of CAFOs, affecting their populations in different ways. Statewide, a much larger proportion of California's population are people of color, while Iowa's residents are predominantly White non-Hispanic (Figure 1). California has a larger proportion of high-income households than Iowa and North Carolina. California has many more urban block groups than Iowa or North Carolina, and Iowa contains a larger proportion of block groups that are very rural and very isolated from resources. In general, swine CAFOs in Iowa are located in very isolated areas and dairy CAFOs are located in less isolated areas in California (Figure 2).

In general, blocks with a higher percent of people of color (POC) have a larger percent of population living within 3 miles of a CAFO in CA and NC, while the opposite was observed in IA (Figure 3). In the CA study area, the percent of POC, Hispanic, and American Indian residents living within 3 miles of a Large Dairy CAFO is 1.29, 1.54, and 1.15, times higher, respectively, than the percent of non-Hispanic Whites (Table 1; Figure 7). These rates translate into hundreds of thousands more POC living near Large CAFOs than if all residents were equally likely to live near a Large CAFO. For example, if Hispanic people in the CA Central Valley study area were exposed to Large Dairy CAFOs at the same rate as White non-Hispanics in this area, then approximately 227,600 fewer Hispanic residents would be exposed to (i.e., live <3 miles) a Large Dairy CAFO. In the NC study area, percent of POC, Black, Hispanic, and American Indian residents living within 3 miles of a Large Swine CAFO is 1.42, 1.42, 1.57, and 2.20 times higher, respectively, than the percent of non-Hispanic Whites (Table 1, Figure 6). If people of all races and ethnicities were equally exposed to Large Swine CAFOs at the same rate across the NC study area, then approximately 16,000 fewer American Indian residents, 53,000 fewer Black residents, and 29,400 fewer Hispanic residents would live <3 miles of a Large Swine CAFO in NC. In CA and NC, the racial/ethnic disparities are more apparent for the Large CAFOs than the medium CAFOs. Figures 4-6 illustrate each state's study area, location of CAFOs, and the block-level percent of POC.

Blocks with a higher percent of POC in NC and CA have, on average, more animal units within 3 miles than blocks without POC. Thus, some of the largest facilities in NC and CA are in areas with the highest percent of POC. When accounting for rurality, blocks with 60-79% POC have, on average, 1647 more animal units of dairy cattle within a 3-mile radius than blocks with 0-19% POC in CA (Table 2). In IA, when accounting for rurality, blocks with >80% POC have, on average, 1126 fewer animal units of hogs within a 3-mile radius than blocks with no POC. In NC, blocks with 60-79% POC have, on average, 1120 more animal units of swine within a 3-mile radius than blocks with no POC, when adjusting for rurality.

The increase in animal units in blocks with 40-100% POC in CA and NC is substantially higher, with 738-1657 more animal units, than areas with <20% POC.

Exposure to CAFOs differs across geographic isolation, a measure of rurality. In IA, 67% of people in Census tracts with the least access to resources live within 3 miles of a Large Swine CAFO, and 81% of them live within 3 miles of any swine CAFO (Table 3; Figure 8). In NC, a quarter of the population in the most isolated tracts in the study area lived within 3 miles of a swine CAFO. CA dairy cattle CAFOs are located in less rural areas than IA and NC, with 19% of residents in the least isolated, most urban tracts of the CA study area living within 3 miles of dairy CAFO. In CA, 45% of Large Dairy CAFOs are located in very isolated areas, while 99.5% of Large Swine CAFOs in IA and 99.9% of Large Swine CAFOs in NC are located in very isolated Census tracts (Table 4).

CAFOs are disproportionately located near low-income communities in NC and CA. The percent of residents in Census tracts with $\geq 35\%$ of households below the 200% poverty level who live within 3 miles of a Large CAFO is about 2.5 times higher in CA and 15 times higher in NC compared to Census tracts with <20% of households below the 200% poverty level (Table 5; Figure 9). No residents in NC block groups with median incomes $\geq \$90,000$ live within 3 miles of a Large CAFO, but 16% of residents in block groups with median incomes $< \$35,000$ live within 3 miles of a Large Swine CAFO (Table 6). We do not see any strong patterns between poverty level or median income and proximity to swine CAFO in IA.

Socioeconomic status is one part of the social vulnerability index, but disability and lack of transportation can also lead to social vulnerability. In CA and NC, greater social vulnerability was associated with a larger population proportion living within 3 miles of a Large CAFO, especially among the socioeconomic and household composition and disability indices (Figure 10). In IA, the proportion of the population living within 3 miles of a Large Swine CAFO is somewhat lower in areas with high social vulnerability compared to medium low vulnerability.

People who live near Large CAFOs are also often exposed to multiple other environmental exposures. In IA and NC, areas with medium high levels of various exposures, especially diesel particulate matter, major direct dischargers to water (not including CAFOs), traffic proximity and volume, and proximity to treatment storage and disposal facilities have higher proportions of the population living within 3 miles of a Large CAFO compared to areas with low levels of these exposures (Figure 11). Exposure to diesel particulate matter and traffic may be linked to the CAFOs, as trucks frequent CAFOs, carrying animals between CAFOs specialized for growing animals of different sizes and often carrying away waste. In CA, areas with higher levels of ozone and fine particulate matter in air and major direct dischargers to water are also areas with a higher proportion of residents living near a Large Dairy CAFO.

Because CAFOs in IA are so widespread throughout the state and because IA has a relatively racially homogeneous population, we also examined how swine CAFO locations in IA varied across age and education. Areas with higher-than-average percent of the population aged 70 and older have a larger proportion of the population living within 3 miles of a Large Swine CAFO, compared to areas where <8% of the population are aged 70 and older (the lowest quartile; Table 7). Additionally, areas where 5-47% of the population do not have a high school degree have a larger percent of the population living within 3 miles of a Large CAFO compared to areas where <5% of the adult population lacks a high school degree.

Conclusions

In the California study area, dairy CAFOs are disproportionately located near low-income communities and POC, particularly Hispanic and Native American residents. These are areas with other social vulnerabilities, including areas with more residents with disabilities, older residents, and lower socioeconomic status. In Iowa, swine CAFOs are located across the entire state, but especially located in rural areas that are very isolated from resources. As Iowa is predominantly White non-Hispanic with POC located mostly in the cities, a larger proportion of White non-Hispanic residents live near swine CAFOs in Iowa than POC. Swine CAFOs in IA tend to be located near older residents, who may have existing health issues, and near less educated residents. In the North Carolina study area, swine CAFOs are disproportionately located near POC, especially Native American, Hispanic, and Black residents, and in lower-income areas. Residents in these areas also have greater social vulnerabilities, including disabilities.

These results highlight the environmental injustice associated with the locations of CAFOs. This report builds on the existing literature documenting the disproportionate effect swine CAFOs have on Black, Hispanic, and Native American residents, and on low-income communities in North Carolina.^{8,47,48} These same clear environmental justice issues with race and income are not seen in Iowa, as Iowa's history and demographics differ from NC, but very isolated and rural areas of Iowa are disproportionately impacted from CAFOs.⁴⁹ These are the first analyses to our knowledge that describe the disproportionate exposure of CA dairy CAFOs to Hispanic communities.

CAFOs pollute the air, water, and soil, harming the quality of life of nearby residents and producing inequitable health effects. CAFOs are often commonly densely located in vulnerable communities, where residents may have existing health conditions. These vulnerable communities may have reduced levels of political power or representation needed to self-determine and protect the quality of their environments. Decreasing CAFO density (especially in low-income, older, and systematically marginalized communities) and improving waste management systems and flood protection to inhibit manure release into the environment may mitigate some of CAFOs' disproportionate exposures and effects.

Tables and Figures

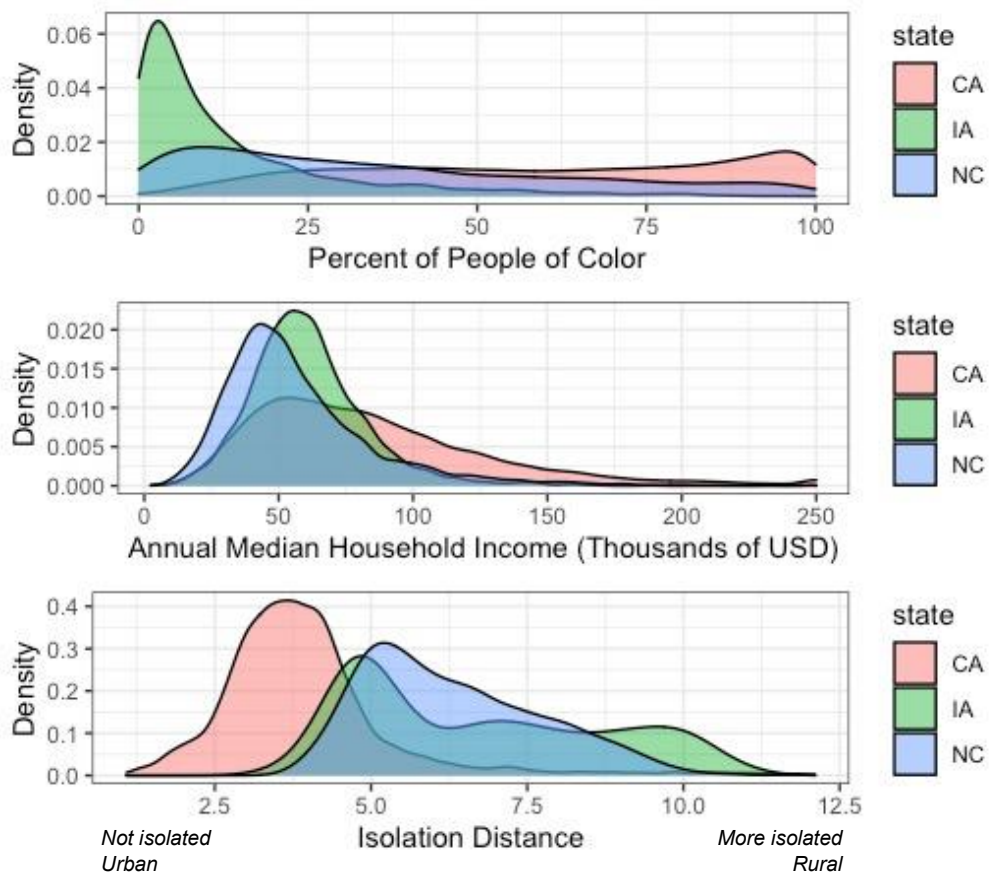


Figure 1. Statewide comparison of percent of people of color, annual median household income, and isolation distance (a measure of rurality; higher isolation distance indicates less access to resources and a more rural area), as shown in density graphs using census block group-level data from 2019 American Community Survey. Statewide, only a small percent of IA's population are people of color (POC), while CA contains many block groups with a high percent of POC, with NC falling somewhat between CA and IA. NC and IA have similar distributions of annual median household income, while CA contains many block groups with high median incomes. CA contains many more urban block groups than NC or IA, and IA has more very rural block groups than CA or IA.

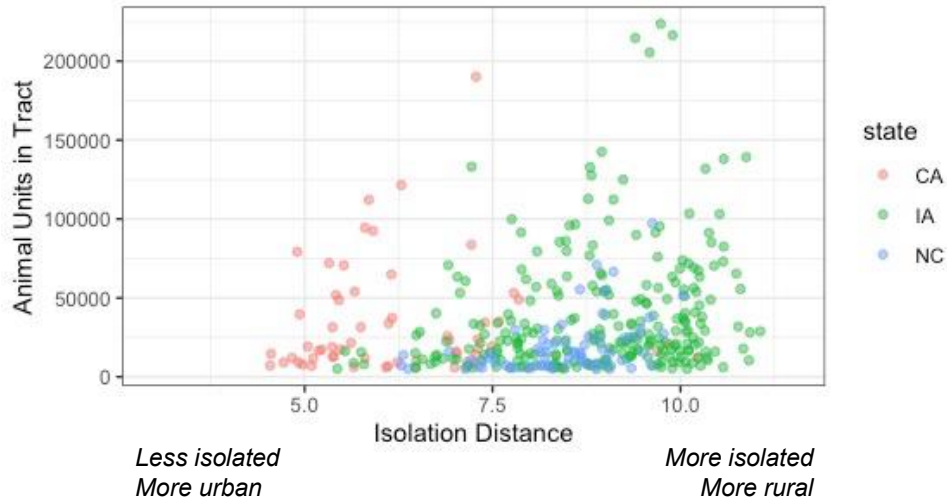


Figure 2. Number of animal units (AUs) of swine in North Carolina and Iowa and dairy cattle in California within Census tracts with over 5000 AUs by geographic isolation distance. Tracts with ≤ 5000 AUs were excluded for visual reasons because of the large numbers of these tracts (CA: 66 tracts, IA: 104, NC: 162 tracts). The continuous geographic isolation scale classifies every Census tract according to its access to resources; a higher isolation distance indicates less access to resources and a more rural area.⁴¹ The tracts with the most dairy cattle in CA are much more urban than those of IA and NC; the tracts with the most swine in IA are much more rural than those of CA and IA.

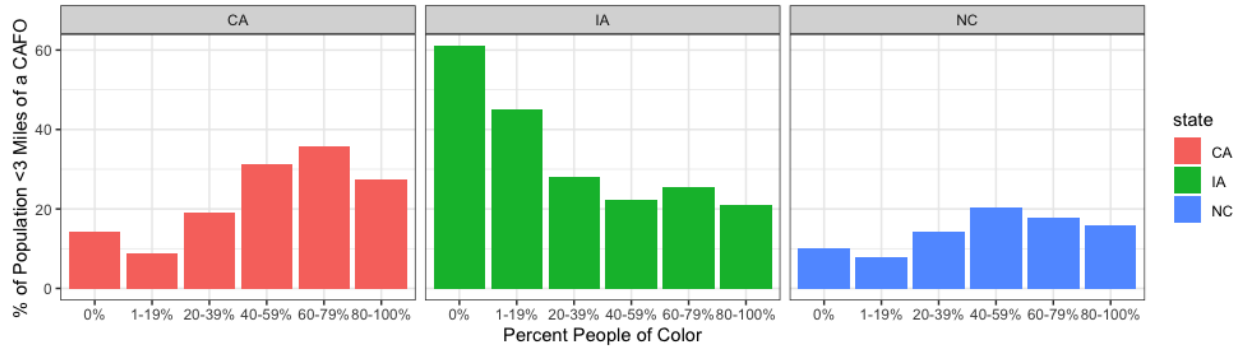


Figure 3. Percent of population living within 3 miles of any permitted dairy CAFO in CA, swine CAFO in IA, or swine CAFO in NC, within study area, by percent of people of color (POC) in census block. Areas with a higher percent of POC in CA and NC tend to have a larger proportion of their population living within 3 miles of a CAFO, while the opposite is true in IA.

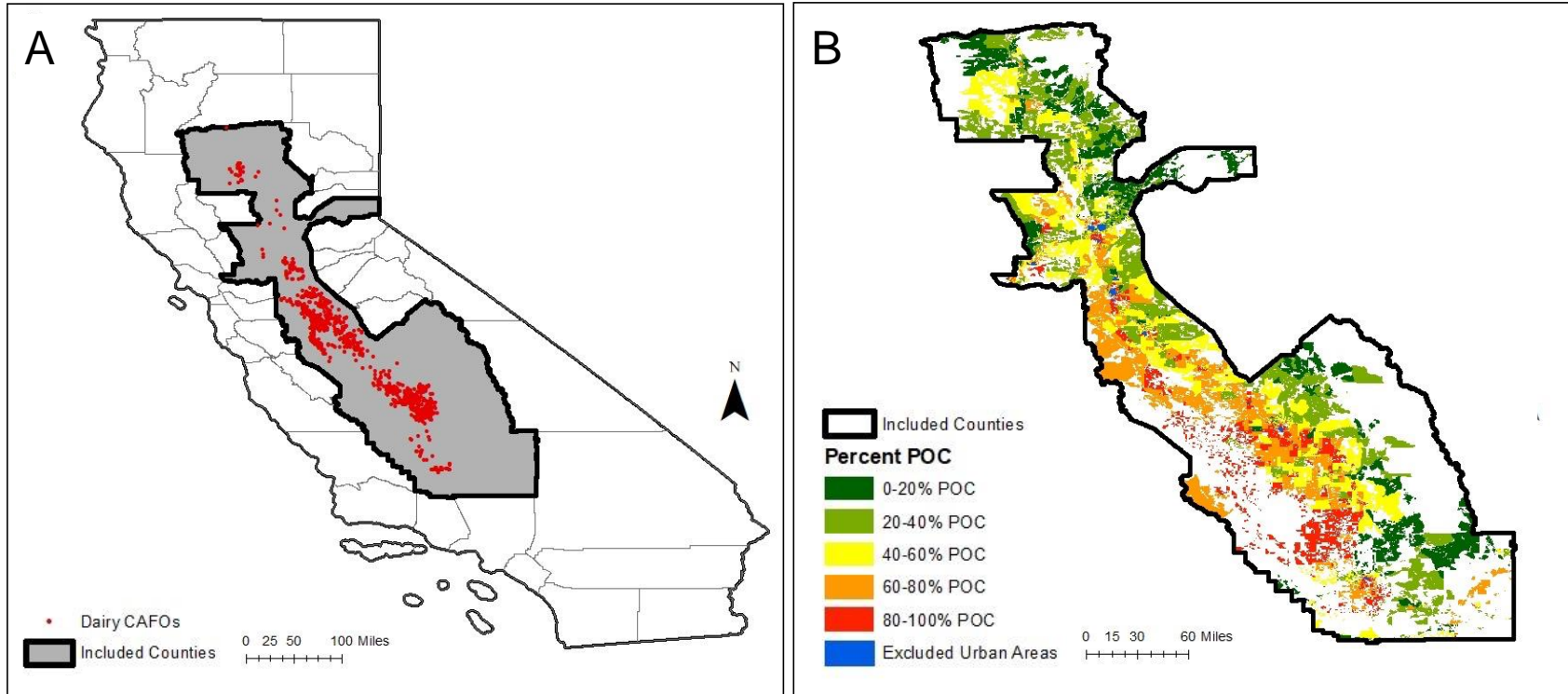


Figure 4. California (A) dairy cattle CAFOs and (B) census blocks categorized by people of color within study area. Urban areas and counties that do not contain CAFOs were excluded from study area and analysis. Dairy cattle CAFOs in CA tend to be located in areas with a higher percent of people of color (POC).

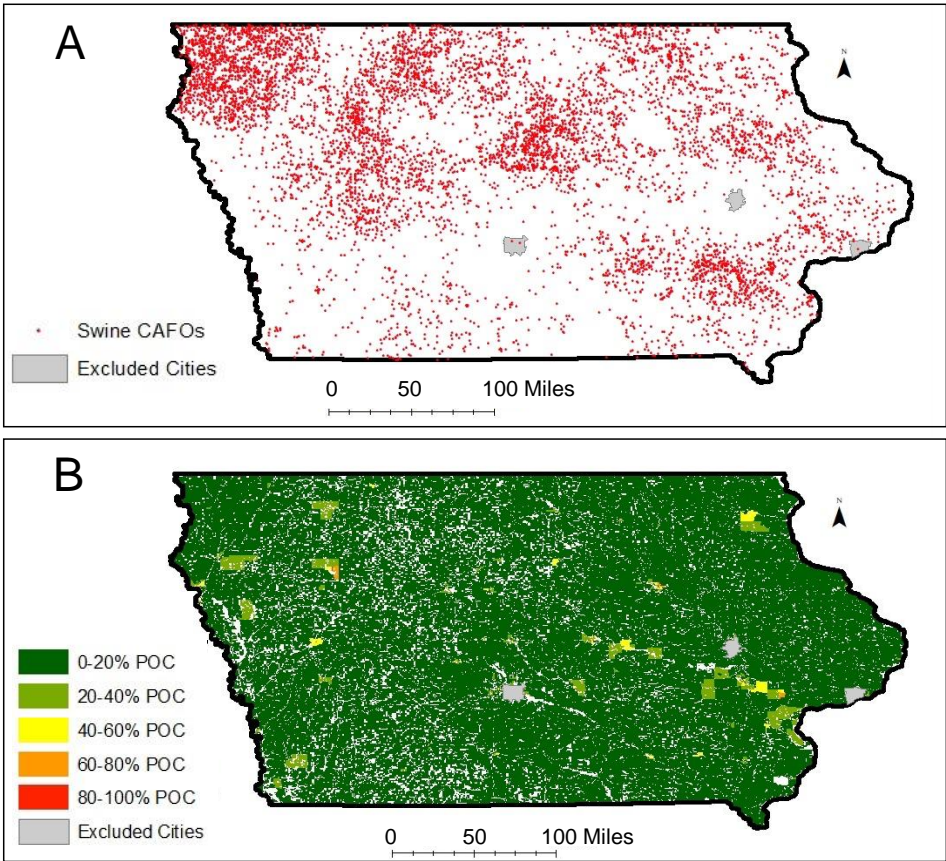


Figure 5. Iowa (A) swine CAFOs and (B) census blocks categorized by people of color (POC). The largest three cities in Iowa (populations >100,000) were excluded from study area and analysis. Swine CAFOs are located throughout IA, and there are very few blocks in IA with >40% POC.

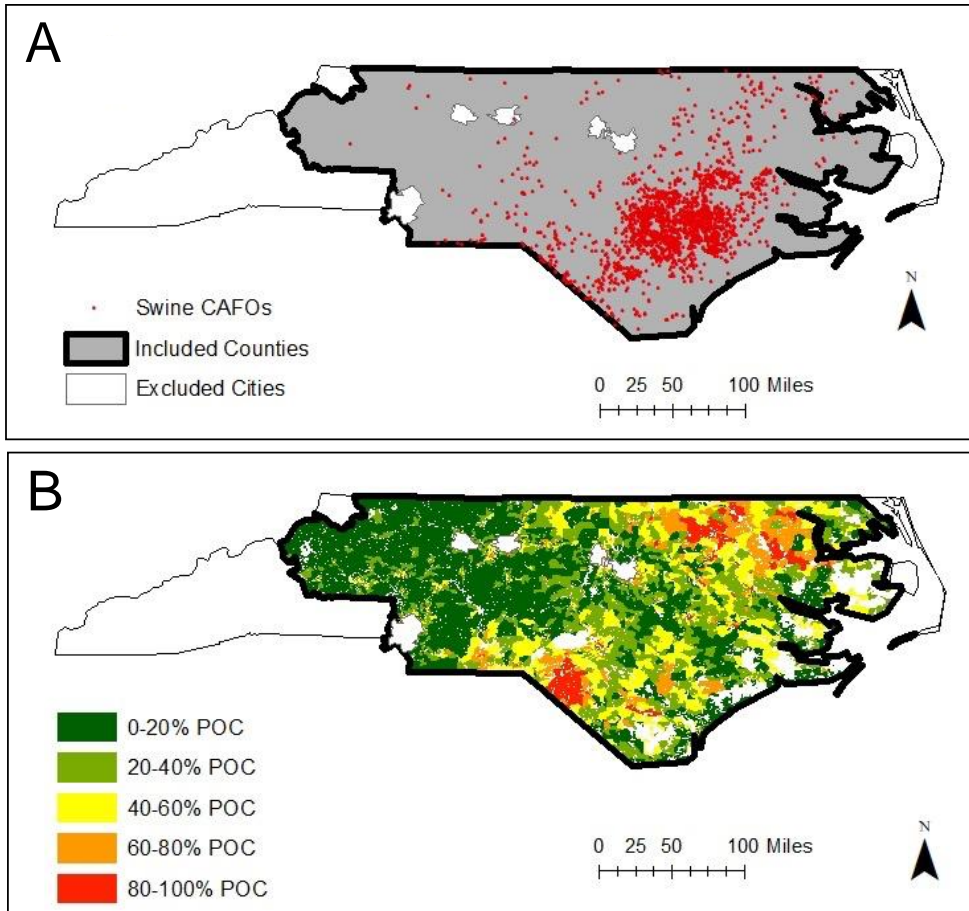


Figure 6. North Carolina (A) swine CAFOs and (B) census blocks categorized by people of color (POC). The largest five cities in North Carolina (populations >250,000) and counties that do not contain swine CAFOs and do not neighbor counties with swine CAFOs were excluded from study area and analysis. Swine CAFOs are concentrated in eastern NC where the percent of POC is higher than central/western NC.

Table 1. Ratios of POC, Black, Hispanic, and American Indian residents compared to non-Hispanic White residents living within 3 miles of a Large CAFO or a medium CAFO in CA, IA, and NC. In the CA study area, the percent of POC, Hispanic, and American Indian residents living within 3 miles of a Large Dairy CAFO is 1.29, 1.54, and 1.15, times higher, respectively, than the percent of non-Hispanic Whites. In the NC study area, percent of POC, Black, Hispanic, and American Indian residents living within 3 miles of a Large Swine CAFO is 1.42, 1.42, 1.57, and 2.20 times higher, respectively, than the percent of non-Hispanic Whites. In IA, the percent of POC living within 3 miles of a swine CAFO is lower than the percent of non-Hispanic Whites. Ratios above 1 indicate that the proportion of that racial/ethnic group living near a CAFO is higher than that of non-Hispanic Whites, with a higher ratio indicating more exposure disparity. Ratios below 1 indicate that the proportion of that racial/ethnic group living near a CAFO is lower than that of non-Hispanic Whites (the reference group). See Supplementary Table 1 for ratios of these racial/ethnicity groups within 3 miles of **any** CAFO compared to non-Hispanic White residents.

Race/Ethnicity Category	Within 3 Miles of a Large CAFO				Within 3 Miles of a Medium CAFO				Total Population
	Number of People	Percent of Population	Ratio ⁴	P-value	Number of People	Percent of Population	Ratio ⁴	P-value	
CALIFORNIA									
American Indian ¹	32,093	18.16	1.15	<0.0001	13,990	7.92	0.87	<0.0001	176,727
Asian	99,340	12.33	0.78	<0.0001	99,485	12.35	1.36	<0.0001	805,771
Black	56,679	12.12	0.76	<0.0001	44,049	9.42	1.04	<0.0001	467,687
Hispanic	647,950	24.43	1.54	<0.0001	225,697	8.51	0.94	<0.0001	2,651,833
Pacific Islander ²	10,121	15.65	0.99	0.17	7145	11.05	1.21	<0.0001	64,673
Other Race	172,391	24.42	1.54	<0.0001	61,951	8.77	0.96	<0.0001	706,067
Multiracial	58,027	15.59	0.98	<0.0001	36,779	9.88	1.09	<0.0001	372,272
POC	807,133	20.44	1.29	<0.0001	369,267	9.35	1.03	<0.0001	3,949,451
White non-Hispanic	432,553	15.85	1	1	248,407	9.1	1	1	2,729,076
Total	1,239,686	18.56			617,674	9.25			6,678,526
IOWA									
American Indian ¹	4574	20.11	0.74	<0.0001	3029	13.32	0.81	<0.0001	22,747
Asian	7085	10.19	0.37	<0.0001	11,407	16.4	0.99	0.32	69,553
Black	11,289	12.13	0.45	<0.0001	8846	9.5	0.57	<0.0001	93,095
Hispanic	31,036	21.33	0.78	<0.0001	25,018	17.19	1.04	<0.0001	145,496
Pacific Islander ²	1158	21.41	0.79	<0.0001	817	15.1	0.91	<0.0001	5409
Other Race	7064	22.26	0.82	<0.0001	5594	17.63	1.07	<0.0001	31,728
Multiracial	9115	18.34	0.67	<0.0001	6983	14.05	0.85	<0.0001	49,705
POC	52,509	16.12	0.59	<0.0001	48,096	14.76	0.89	<0.0001	325,832

White non-Hispanic	642,843	27.19	1	1	391,045	16.54	1	1	2,363,878
Total	695,353	25.85			439,142	16.33			2,689,711
<u>NORTH CAROLINA</u>									
American Indian ¹	29,327	18.54	2.20	<0.0001	11,708	7.4	1.75	<0.0001	158,167
Asian	7591	3.53	0.42	<0.0001	4009	1.87	0.44	<0.0001	214,790
Black	180,516	11.92	1.42	<0.0001	76,558	5.05	1.19	<0.0001	1,514,767
Hispanic	81,583	13.18	1.57	<0.0001	25,893	4.18	0.99	0.05	619,201
Pacific Islander ²	1174	8.71	1.03	0.23	519	3.85	0.91	0.03	13,481
Other Race	21,772	10.94	1.30	<0.0001	8828	4.44	1.05	<0.0001	199,050
Multiracial	19,358	10.27	1.22	<0.0001	9220	4.89	1.15	<0.0001	188,550
POC ³	292,306	11.97	1.42	<0.0001	114,861	4.7	1.11	<0.0001	2,442,211
White non-Hispanic	371,630	8.42	1.00	1	186,935	4.24	1.00	1	4,414,030
Total	663,936	9.68			301,797	4.4			6,856,241

¹Includes all people who indicate they are American Indian or Alaska Native residents. Race/ethnic groups are not mutually exclusive; one person may be present in multiple categories; thus, the racial and ethnic categories do not sum to the total.

²Includes all people who indicate they are Native Hawaiian or other Pacific Islander.

³People of color (POC) was calculated as the total population minus the White non-Hispanic population.

⁴Ratio of the percent of people of other racial and ethnic groups to the percent of non-Hispanic Whites who live within 3 miles of a CAFO.

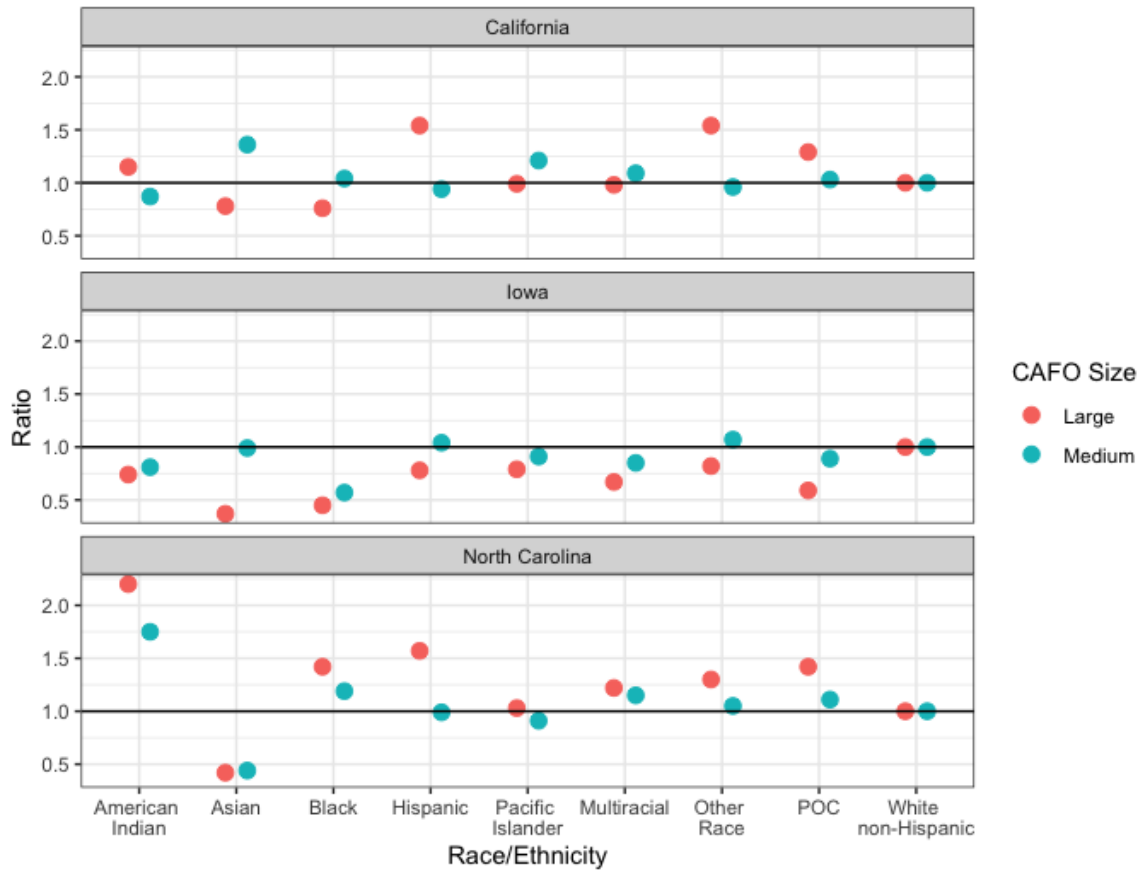


Figure 7. The ratio of residents by race/ethnicity group compared to non-Hispanic White residents living within 3 miles of a Large CAFO or a medium CAFO in CA, IA, and NC (visual representation of Table 1). Points above 1 (line on graph, the null value) indicate that the proportion of that race/ethnicity group living near a CAFO is higher than that of non-Hispanic White; points below 1 indicate that the proportion of that race/ethnicity group living near a CAFO is lower than that of non-Hispanic Whites. The ratios are farther from the null and more extreme when examining Large CAFOs than Medium CAFOs.

Table 2. Average difference in animal units within 3 miles of residents of blocks with varying percent of POC compared to blocks without POC (in CA analysis, blocks with 0-19% POC were used as the reference because very few blocks in the CA had 0% POC). In CA and NC, blocks with 40-100% POC contained many more animal units than blocks with 0-19% POC, although the opposite is true for IA.

Percent POC	CALIFORNIA		IOWA		NORTH CAROLINA	
	Unadjusted	Adjusted ¹	Unadjusted	Adjusted ¹	Unadjusted	Adjusted ¹
0%	(ref)	(ref)	(ref)	(ref)	(ref)	(ref)
1-19%	(ref)	(ref)	-918 (-1017, -818)	-88 (-185, 10)	57 (-37, 150)	273 (182, 364)
20-39%	606 (487, 725)	889 (771, 1007)	-2193 (-2306, -2080)	-798 (-910, -686)	247 (153, 340)	577 (486, 668)
40-59%	963 (847, 1080)	1400 (1284, 1516)	-2214 (-2358, -2071)	-761 (-903, -620)	434 (340, 529)	814 (722, 906)
60-79%	1139 (1024, 1254)	1657 (1542, 1772)	-2360 (-2562, -2158)	-794 (-991, -596)	701 (605, 797)	1120 (1027, 1214)
80-100%	742 (626, 858)	1366 (1250, 1483)	-2673 (-3108, -2237)	-1126 (-1547, -704)	272 (172, 372)	738 (641, 835)

¹Adjusted for the rurality using the cubic natural log of the population density.

Table 3. Percent of population living within 3 miles of a CAFO by geographic isolation in census tract (no urban areas were removed from this analysis, although counties without dairy CAFOs were excluded in CA and counties without CAFOs and not neighboring CAFOs were removed in NC). A larger percent of residents in the very isolated areas reside near Large CAFOs, especially in IA. CA has more CAFOs in urban and suburban areas (not isolated and slightly isolated areas) compared to NC and IA.

Geographic Isolation ¹	Total Population	Any CAFO		Large CAFO		No CAFOs	
		Population within 3 miles	Percent of total population	Population within 3 miles	Percent of population	Population within 3 miles	Percent of population
CALIFORNIA							
Not isolated	968,916	179,276	18.50	102,727	10.60	789,640	81.50
Slighted Isolated	4,153,714	1,098,277	26.44	652,050	15.70	3,055,437	73.56
Somewhat Isolated	1,548,899	659,343	42.57	561,302	36.24	889,556	57.43
Very Isolated	826,878	219,194	26.51	181,117	21.90	607,684	73.49
IOWA							
Not isolated	63,416	0	0	0	0	63,416	100
Slighted Isolated	592,247	215,086	36.32	5167	0.87	377,161	63.68
Somewhat Isolated	1,020,296	204,412	20.03	101,762	9.97	815,884	79.97
Very Isolated	1,463,549	1,178,730	80.54	978,559	66.86	284,819	19.46
NORTH CAROLINA							
Not isolated	64,272	0	0	0	0	64,272	100
Slighted Isolated	1,112,242	0	0	0	0	1,112,242	100
Somewhat Isolated	4,054,306	60,594	1.49	27,435	0.68	3,993,712	98.505
Very Isolated	5,034,056	1,270,767	25.24	971,211	19.29	3,763,289	74.757

¹A continuous geographic isolation scale that classifies census tract according to their access to resources was split into quartiles (based on national data) to create these categories.⁴¹

Table 4. Number of CAFOs within each Census tract, by geographic isolation (areas very isolated from resources are very rural areas). Almost all the Large CAFOs in IA and NC are in very isolated, rural areas, while the majority of Large CAFOs in CA are in less isolated areas (slightly and somewhat isolated areas, which correspond to small towns and suburban areas).

Geographic Isolation ¹	Number of Large CAFOs	Number of Medium CAFOs	Total CAFOs	Percent of Large CAFOs	Percent of Total CAFOs
CALIFORNIA					
Not isolated	1	1	2	0.15	0.19
Slightly isolated	15	17	32	2.22	3.12
Somewhat isolated	357	209	566	52.81	55.11
Very isolated	303	124	427	44.82	41.58
IOWA					
Not isolated	0	0	0	0	0
Slightly isolated	0	3	3	0	0.04
Somewhat isolated	18	50	68	0.52	0.89
Very isolated	3443	4085	7528	99.48	99.07
NORTH CAROLINA					
Not isolated	0	0	0	0	0
Slightly isolated	0	0	0	0	0
Somewhat isolated	1	2	3	0.09	0.15
Very isolated	1055	902	1957	99.91	99.85

¹A continuous geographic isolation scale that classifies census tract according to their access to resources was split into quartiles (based on national data) to create these categories.⁴¹

Figure 8. Iowa census tracts by isolation category¹⁴ and swine CAFOs. Swine CAFOs are spread across IA, especially in the very isolated areas.

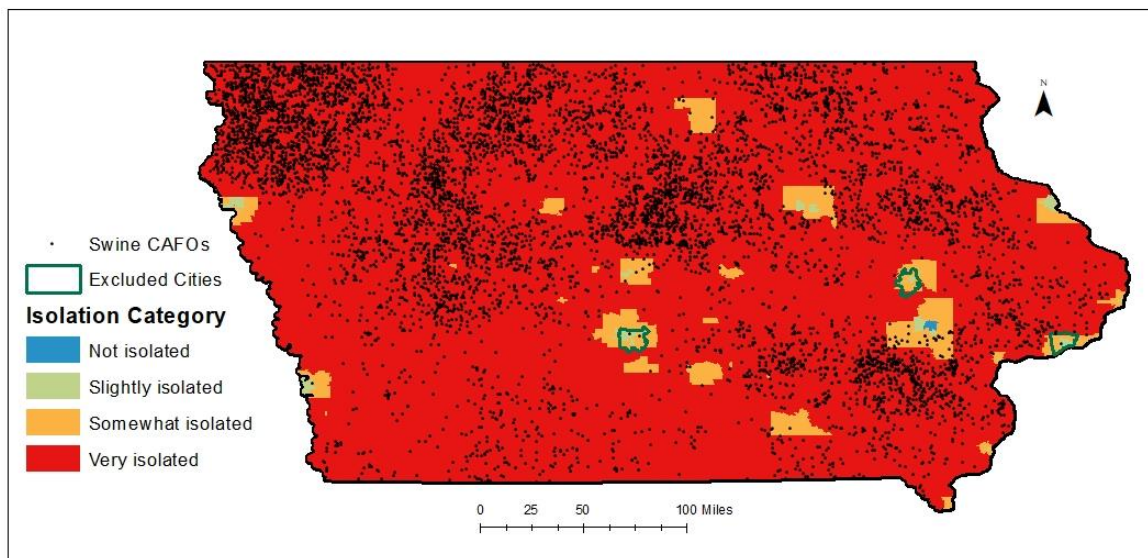


Table 5. Percent of population living within 3 miles of a Large CAFO by percent of households below the 200% poverty level by Census tract. In CA and NC, areas with a high poverty level (i.e., $\geq 35\%$ of households below the 200% poverty level) have a larger percent of their population living within 3 miles of a Large CAFO than areas with a low poverty level ($< 20\%$ of households below the 200% poverty level). In contrast, in IA, areas with higher poverty levels ($\geq 35\%$) have a lower percent of their population < 3 miles of a Large CAFO than areas with lower poverty levels ($< 35\%$). See supplementary table 2 for poverty group populations within 3 miles of *any* CAFO.

Percent of Households Below 200% Poverty Level	Population in Category < 3 Miles of a Large CAFO	Total Population in Category	Percent of Population < 3 Miles from Large CAFO	Ratio
CALIFORNIA				
Below 20%	90,933	908,350	10.01	(ref)
20-34%	537,205	2,755,714	19.49	1.95
35-49%	378,515	1,511,127	25.05	2.50
$\geq 50\%$	417,234	1,747,992	23.87	2.38
IOWA				
Below 20%	227,068	780,581	29.09	(ref)
20-34%	627,157	1,251,271	50.12	1.72
35-49%	77,516	399,609	19.40	0.67
$\geq 50\%$	2108	113,480	1.86	0.06
NORTH CAROLINA				
Below 20%	20,221	1,254,755	1.61	(ref)
20-34%	263,839	2,198,604	12.00	7.45
35-49%	474,940	2,022,555	23.48	14.58
$\geq 50\%$	239,646	1,013,171	23.65	14.69

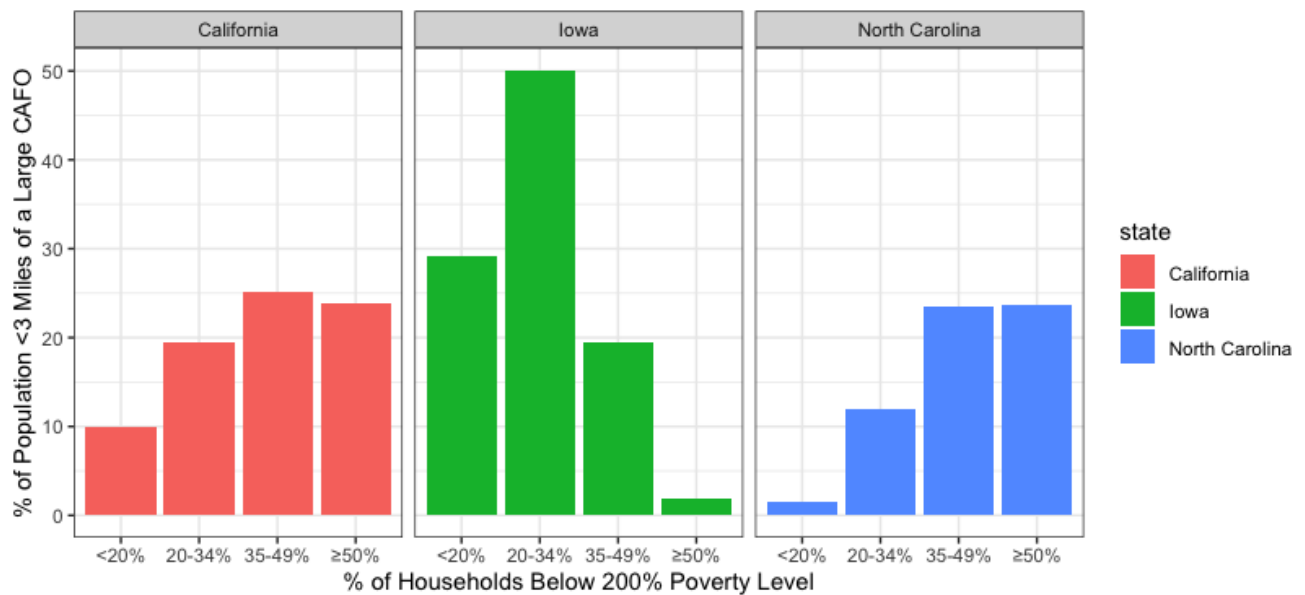


Figure 9. Percent of population living within 3 miles of a CAFO by percent of households below the 200% poverty level by Census tract (a visual representation of Table 5). In CA and NC, areas with a high poverty level (i.e., $\geq 35\%$ of households below the 200% poverty level) have a larger percent of their population living within 3 miles of a Large

CAFO than areas with a low poverty level (<20% of households below the 200% poverty level). In contrast, in IA, areas with higher poverty levels (≥35%) have a lower percent of their population <3 miles of a Large CAFO than areas with lower poverty levels (<35%).

Table 6. Percent of population living within 3 miles of a Large CAFO by median household income in each block group. In CA and IA, fewer rich households (≥\$90,000) live near Large CAFOs than poorer households.

Median Household Income Category (\$)¹	Population in Category within 3 Miles of a Large CAFO	Total Population in Category	Percent of Population within 3 Miles from a Large CAFO
CALIFORNIA			
<35,000	161,772	895,919	18.06
35,000-44,999	188,767	912,458	20.69
45,000-54,999	198,856	940,047	21.15
55,000-64,999	180,655	860,928	20.98
65,000-89,999	334,720	1,806,660	18.53
≥90,000	246,206	1,678,126	14.67
IOWA			
<35,000	22,183	171,004	12.97
35,000-44,999	76,891	278,791	27.58
45,000-54,999	175,882	460,638	38.18
55,000-64,999	226,061	524,835	43.07
65,000-89,999	298,547	771,999	38.67
≥90,000	41,443	363,113	11.41
NORTH CAROLINA			
<35,000	141,127	892,668	15.81
35,000-44,999	207,714	1,222,393	16.99
45,000-54,999	180,850	1,244,261	14.53
55,000-64,999	118,621	982,463	12.07
65,000-89,999	88,930	1,263,368	7.04
≥90,000	0	864,988	0

¹2019 block group median income from American Community Survey, urban areas excluded

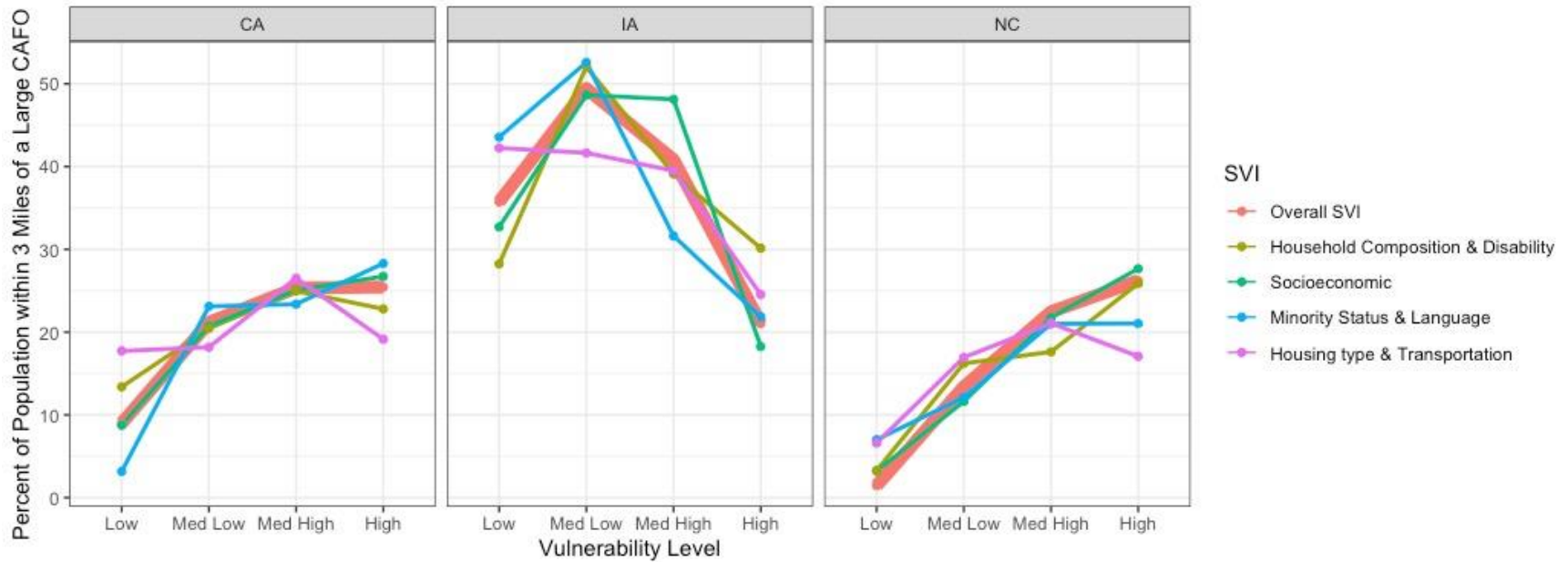


Figure 10. Percent of study population within 3 miles of a Large CAFO by varying levels of vulnerability, as measured by the social vulnerability index. Low, medium low, medium high, and high categories correspond to the state-specific social vulnerability quartiles. The thicker, peach-colored line represents the overall social vulnerability (SVI) that summarizes all categories. In CA and NC, as vulnerability increases, the percent of the population living near a Large CAFO also increases.

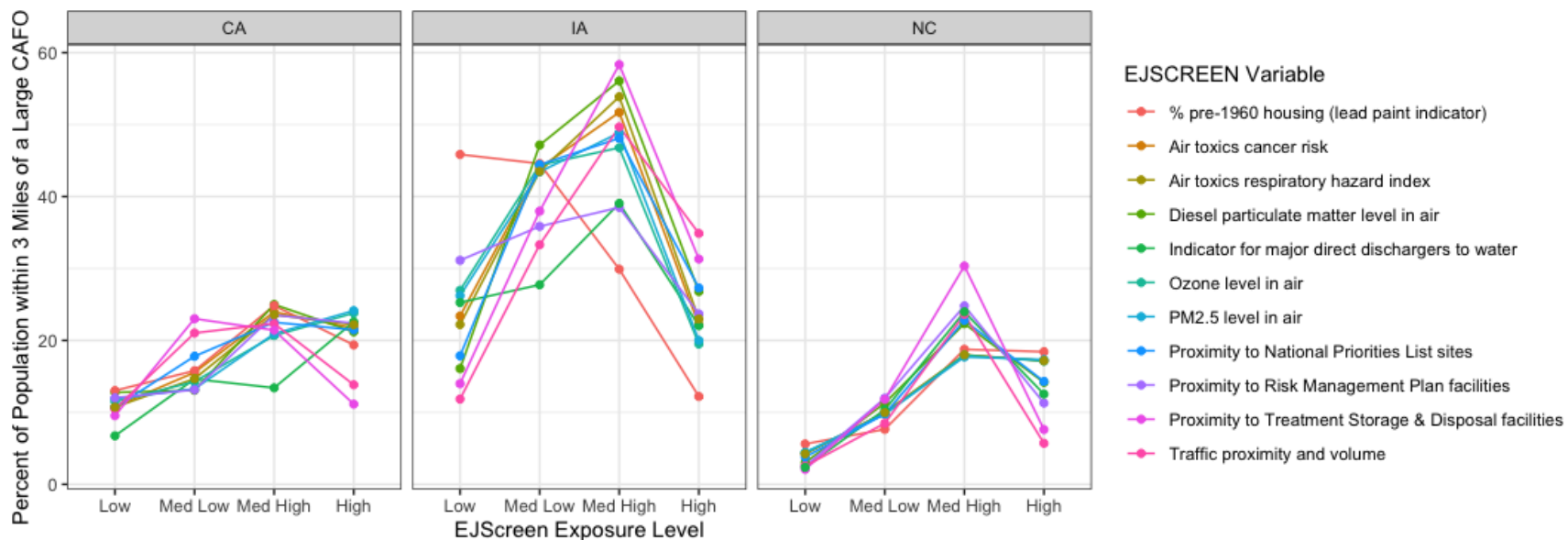


Figure 11. Percent of study population within 3 miles of a Large CAFO by varying levels of EJScreen exposure. Low, medium low, medium high, and high categories correspond to the state-specific quartiles for each EJSCREEN measure. In IA and NC, areas with medium high levels of various exposures, especially diesel particulate matter, major direct dischargers to water (not including CAFOs), traffic proximity and volume, and proximity to treatment storage and disposal facilities have higher proportions of the population living within 3 miles of a Large CAFO compared to areas with low levels of these exposures.

Table 7. Percent of population living in IA within 3 miles of a Large Swine CAFO in 2021 by percent of people aged 70 and older in census block group, within study area. In IA, areas with a low percent (<8%) of the population above age 70 also have a lower percent of the population living near swine CAFOs.

Percent of Population Age 70+	Total population	Population of adults age 70+	Total population <3 mile of a CAFO	Population of adults age 70+ <3 mile of a CAFO	Percent of total population <3 mile of a CAFO	Percent of population age 70+ <3 mile of a CAFO	Ratio
<8%	762,703	37,762	71,488	4329	9.37	11.46	1.00 (ref)
8-11%	696,104	69,640	168,030	17,008	24.14	24.42	2.13
12-15%	560,279	77,676	157,895	21,701	28.18	27.94	2.44
≥16%	582,628	122,171	133,819	27,005	22.97	22.10	1.93

Table 8. Percent of population living within 3 miles of a Large Swine CAFO in IA by percent of population with less than a high school degree in census block group, within study area. In IA, areas with a low percent (<5%) of adults without a high school degree (i.e., highly educated areas) have a lower percent of their population living near a swine CAFO than areas with a higher percent (≥5%) of the population without a high school degree.

Percent of Adults with less than a HS degree	Total population	Total population within 3 miles of a Large CAFO	Percent of population within 3 miles of a Large CAFO	Ratio
<5%	238,733	959,394	24.88	1.00
5-6%	261,096	500,098	52.21	2.10
6.5-10.5%	256,399	511,367	50.14	2.02
≥10.5%	177,621	574,082	30.94	1.24

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Supplementary Table 1. Ratios of POC, Black, Hispanic, and American Indian residents compared to non-Hispanic White residents living within 3 miles of any CAFO in CA, IA, and NC. In the CA study area, the percent of Hispanic residents living within 3 miles of any dairy CAFO is 1.32 times higher than the percent of non-Hispanic Whites. In the NC study area, percent of Black, Hispanic, and American Indian residents living within 3 miles of any swine CAFO is 1.34, 1.37, and 2.05 times higher, respectively, than the percent of non-Hispanic Whites. In IA, the percent of POC living within 3 miles of any swine CAFO is lower than that of non-Hispanic Whites.

Race/Ethnicity Category	Within 3 Miles of any CAFO				
	Number of People	Total Population	Percent of Population	Ratio ⁴	P-value
<u>CALIFORNIA</u>					
American Indian ¹	46,083	176,727	26.08	1.05	<0.0001
Asian	198,825	805,771	24.68	0.99	<0.0001
Black	100,729	467,687	21.54	0.86	<0.0001
Hispanic	873,647	2,651,833	32.95	1.32	<0.0001
Pacific Islander ²	17,266	64,673	26.7	1.07	<0.0001
Other Race	234,342	706,067	33.19	1.33	<0.0001
Multiracial	94,806	372,272	25.47	1.02	<0.0001
POC	1,176,400	3,949,451	29.79	1.19	<0.0001
White non-Hispanic	680,960	2,729,076	24.95	1	1
Total	1,857,360	6,678,526	27.81		
<u>IOWA</u>					
American Indian ¹	7603	22,747	26.08	0.76	<0.0001
Asian	18,492	69,553	24.68	0.61	<0.0001
Black	20,135	93,095	21.54	0.49	<0.0001
Hispanic	56,054	145,496	32.95	0.88	<0.0001
Pacific Islander ²	1975	5409	26.7	0.83	<0.0001
Other Race	12,658	31,728	33.19	0.91	<0.0001
Multiracial	16,098	49,705	25.47	0.74	<0.0001
POC	100,606	325,832	29.79	0.71	<0.0001
White non-Hispanic	1,033,889	2,363,878	24.95	1	1
Total	1,134,495	2,689,711	27.81		
<u>NORTH CAROLINA</u>					
American Indian ¹	41,035	158,167	25.94	2.05	<0.0001
Asian	11,600	214,790	5.4	0.43	<0.0001
Black	257,074	1,514,767	16.97	1.34	<0.0001
Hispanic	107,476	619,201	17.36	1.37	<0.0001
Pacific Islander ²	1693	13,481	12.56	0.99	0.74
Other Race	30,600	199,050	15.37	1.22	<0.0001
Multiracial	28,579	188,550	15.16	1.2	<0.0001
POC ³	407,168	2,442,211	16.67	1.32	<0.0001
White non-Hispanic	558,566	4,414,030	12.65	1	1
Total	965,733	6,856,241	14.09		

¹Includes all people who indicate they are American Indian or Alaska Native residents. Race/ethnic groups are not mutually exclusive; one person may be present in multiple categories; thus, the racial and ethnic categories do not sum to the total.

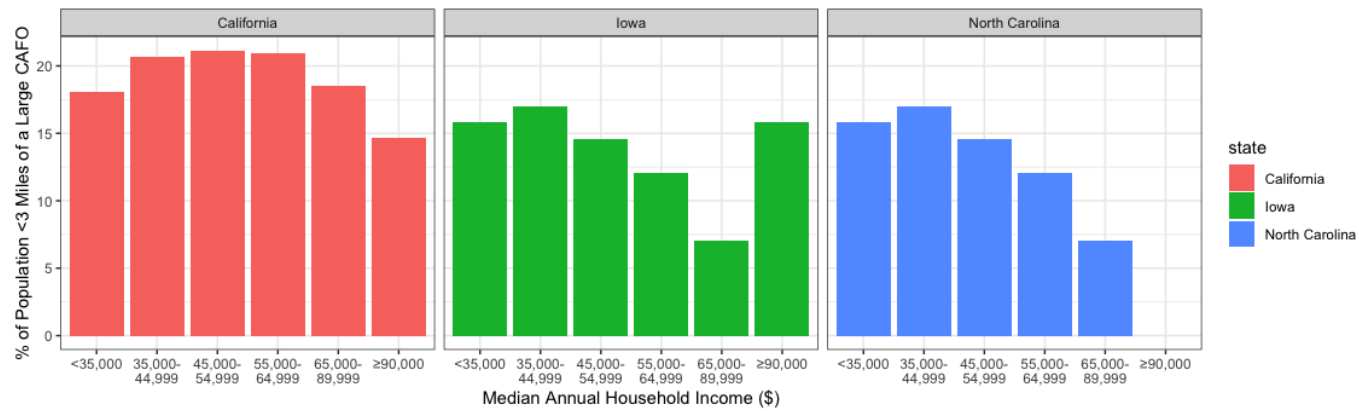
²Includes all people who indicate they are Native Hawaiian or other Pacific Islander.

³People of color (POC) was calculated as the total population minus the White non-Hispanic population.

⁴Ratio of the percent of people of other racial and ethnic groups to the percent of non-Hispanic Whites who live within 3 miles of a CAFO.

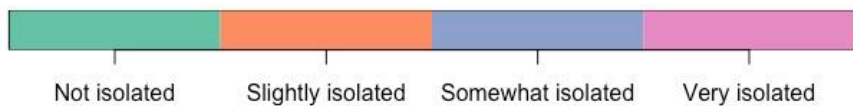
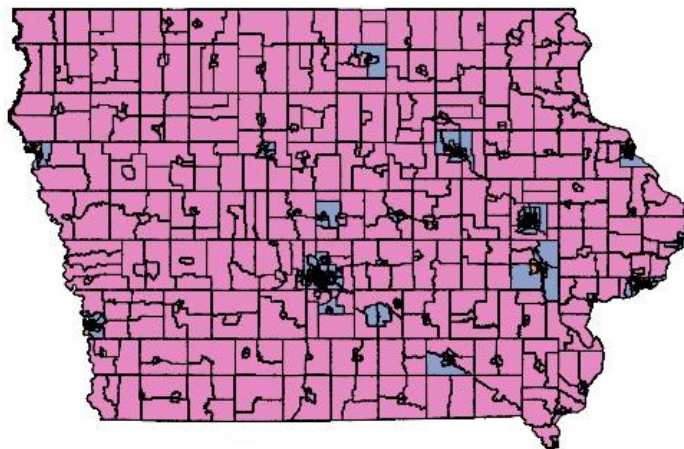
*Supplementary Table 2. Percent of population living within 3 miles of **any** CAFO by percent of households below the 200% poverty level by Census tract. In CA and NC, areas with a high poverty level (i.e., $\geq 35\%$ of households below the 200% poverty level) have a larger percent of their population living within 3 miles of a Large CAFO than areas with a low poverty level ($< 20\%$ of households below the 200% poverty level). In contrast, in IA, areas with higher poverty levels ($\geq 35\%$) have a lower percent of their population < 3 miles of a Large CAFO than areas with lower poverty levels ($< 35\%$).*

Percent of Households Below 200% Poverty Level	Population in Category <3 Miles of any CAFO	Total Population in Category	Percent of Population <3 Miles from Large CAFO	Ratio
CALIFORNIA				
Below 20%	362,826	1,673,184	21.68	1.00
20-34%	580,035	1,990,880	29.13	1.34
35-49%	576,616	1,511,127	38.16	1.76
$\geq 50\%$	550,360	1747,992	31.49	1.45
IOWA				
Below 20%	278,996	780,581	35.74	1.00
20-34%	759,383	1,251,271	60.69	1.70
35-49%	101,825	399,609	25.48	0.71
$\geq 50\%$	2108	113,480	1.86	0.05
NORTH CAROLINA				
Below 20%	42,595	1,254,755	3.39	1.00
20-34%	365,619	2,198,604	16.63	4.90
35-49%	635,957	2,022,555	31.44	9.26
$\geq 50\%$	287,190	1,013,171	28.35	8.35

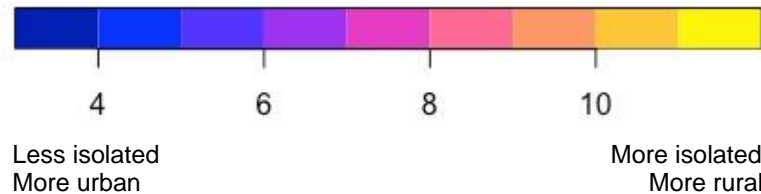
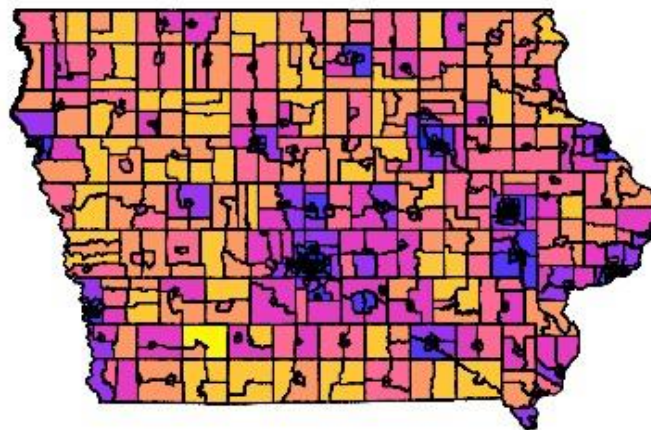


Supplementary Figure 1. Percent of population living within 3 miles of a CAFO by median household income in each block group (a visual of Table 6). In CA and IA, fewer rich households ($\geq \$90,000$) live near Large CAFOs than poorer households.

Isolation Categories



Isolation Values



Supplementary Figure 2. Isolation categories and isolation values highlighting how widespread very isolated, rural areas are in Iowa.