

Spatial Exploration of Drivers in Maryland's Commercial Poultry Production



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Abstract

Poultry is the most consumed meat in the United States, with the Delmarva region (Delaware, Maryland's Eastern Shore, and Virginia's Eastern Shore) being a key production hub. This study utilizes spatial and economic analysis to examine heterogeneous factors driving broiler production concentration at the Census block group level, including geophysical characteristics, production infrastructure, and demographic patterns in Maryland. Data for the analysis was collected and updated through Spring 2024, and all analysis was conducted in 2024. The resulting findings and visualizations offer farm managers and consultants a tool for assessing broiler production dynamics. This research provides insights that can shape

land use planning, resource allocation, and technical assistance programs in regions characterized by intensive commercial broiler production, as well as supporting informed policy decisions.

INTRODUCTION

Poultry production has evolved over the last half-century from dual-purpose backyard birds to highly specialized, integrated systems with regional production centers. Domestic poultry production surpassed beef and pork in the late 1990s to become the highest-consumed protein in the United States (U.S.) (Livestock Marketing Information Center, 2022). Broilers, chickens raised for meat, are birds selectively bred for their muscle composition, rapid growth rate, and hardiness. Additionally, broilers are highly efficient in converting feedstock energy into meat products for human consumption, outperforming other livestock meat sources, including cows and pigs, in feed-to-meat conversion rates (ERS, 2023).

Vertical integration and increased demand for chicken meat has led to increased production levels and intensification of production, with some notable spatial patterns. The structure of the poultry industry and integration lead to transportation efficiencies and location strategies that minimize costs in moving birds from houses to processing and the customer (MacDonald, 2014). The continued increase in demand for poultry products, domestically and globally, has further intensified broiler growth in the U.S. Currently, broiler production is predominantly located in Southern states, with Georgia, Alabama, and Arkansas as the top three and Maryland in the top ten (USDA NASS, 2024b). Further, all of Maryland's commercially concentrated broiler production is on the Eastern Shore, part of the Delmarva Peninsula region, which includes all of Delaware, the Eastern Shore counties of Maryland, and the Eastern Shore counties of Virginia (USDA NASS, 2024b).

Figure 1 illustrates 2022 broiler production, measured as chicken sales, in headcount, at the county level as adapted from the United States Department of Agriculture's National Agricultural Statistics Service's (USDA NASS) Census of Agriculture (USDA Census Bureau, 2024b). The prominence of these production regions stems from the locations of growers, integrators, and supply chains that distribute broiler products to the market. By analyzing Maryland's Concentrated Animal Feeding Operation (CAFO) permits, this study develops a geodatabase and estimates broiler production's economic and geographic drivers at the Census block group level. Using Maryland as a case study, our analysis provides novel insights into the spatial dynamics of broiler production.

Background

Today, broiler production is concentrated in the Southern U.S. region (Georgia, Alabama, Florida, and South Carolina), which, in 2023, accounted for 30.95% of national broiler output (USDA NASS, 2024b). The Southern region is followed by the Delta (Arkansas, Louisiana, and Mississippi) and Eastern Mountain regions (Kentucky, North Carolina, Tennessee, Virginia, and West Virginia) (USDA NASS, 2024b). The industry's interdependence with corn and soybean production is pivotal, as broiler feed predominantly consists of these two commodities. Additionally, improved feed conversion efficiency, further optimized feed rations, and economies of scale in recent decades have played an increasingly critical role in the cost efficiency of broiler production (MacDonald, 2014; Mallick et al., 2020).

While commercial-scale broiler production is nationally distributed, it is spatially concentrated in several, distinct regions, as illustrated in Figure 1. Maryland is a notable case study for its legacy of balancing intensive food production and environmental stewardship, particularly its efforts to protect the Chesapeake Bay. Today, approximately 47.9% of the state's agricultural market value is tied to poultry production (USDA NASS, 2024b). More specifically, cash receipts from poultry and eggs were valued at approximately \$1.6 billion in both 2017 and 2022 NASS Census results, positioning Maryland as the seventh-largest broiler producer in the U.S. (USDA NASS, 2024b).

Perdue Farms, founded and based in Salisbury, Maryland, was instrumental in the growth of the Delmarva broiler industry. In the 1960s, the company invested in grain and soybean processing and, in 1968, opened its first processing plant (Perdue, 2024).

Perdue further advanced the industry by introducing the PERDUE® brand to the New York City market, which has had a lasting impact on poultry marketing and production. These efforts have contributed to the agricultural infrastructure that underpins Maryland's broiler industry today.

As the broiler industry has grown in scale and concentration, public access to agricultural data has become increasingly important. The Maryland Public Information Act, enacted in 2014, provides a valuable resource by granting public access to government records, including detailed data on business operations. This legislation offers insights into M/CAFOs, including broiler capacity—the maximum number of birds housed at a time—and the location of broiler operations with General Discharge permits. As outlined by COMAR 26.08.04.09N(3), these permits require operators to submit a Notice of Intent and necessary plans, which undergo public review through a public participation process. Maryland also distinguishes between two types of Animal Feeding Operation (AFO) permits: CAFOs and Maryland Animal Feeding Operations (MAFOs), each subject to different regulatory requirements.

According to a report by the Natural Resources Defense Council, Maryland and Tennessee stand out as the most transparent states regarding information and data on CAFOs (Devine and Baron, 2019; Lee Miller and Muren, 2019). Although efforts were made to collaborate with state agencies in Delaware and Virginia to obtain comparable data in 2024, we were informed that these states require residency to fulfill Freedom of Information Act requests, a restriction that prevented us from accessing data for the entire Delmarva region. As a result, our analysis relies exclusively on Maryland's M/CAFO, which is regulated and reported by the Maryland Department of Environment (MDE).

Integrating Geography and Economics

This research utilizes a novel approach to analyzing Maryland's broiler industry by integrating Geographic Information Systems (GIS) with applied agricultural economic models. The GIS toolbox and modeling techniques employed provide new insights into the spatial dimensions of the broiler industry, examining factors like land use patterns, soil health, and nutrient runoff risk zones. When coupled with agricultural economic models, these tools allow for an assessment of the financial viability of varying land management strategies, offering an untried framework for

evaluating the industry's supply chains and their linkage to production and markets.

This integration provides a novel approach to addressing key challenges in regions like Maryland's Eastern Shore, where competing agricultural and environmental interests make land use decisions particularly complex. A comprehensive and systematic approach that combines the two fields while also addressing the sustainability of poultry litter management, as observed in studies that have used GIS-based decision support systems to enhance litter management, reduces nutrient runoff and optimizes transportation strategies (Kang et al., 2008).

A previously created visual representation of this concentration is shown in Figure 2, which maps all active M/CAFOs in Maryland in 2023. In Figure 2, the orange dots represent broiler M/CAFOs, all of which are located within the nine counties of Maryland's Eastern Shore, while dairy and beef cattle are distributed throughout the rest of the state. This regional concentration underscores broiler production's dominance on the Eastern Shore, where 86.9% of Maryland's poultry inventory is located in Worcester, Caroline, Somerset, and Wicomico counties (Lansing et al., 2023). The concentration of broiler production in these four counties raises pressing questions about its underlying factors and associated environmental and economic impacts, guiding these research efforts.

Building on literature like the work in "Synthesized Population Databases: A Geospatial Database of US Poultry Farms," GIS offers insights into managing CAFOs while also addressing gaps in available data about broiler production systems (Bruhn et al., 2012). As broiler production continues to expand, GIS resources can reveal patterns and relationships within data layers, such as considerations at the intersection of environmental management challenges like the identification of suitable land areas and timing for litter application and predicting nutrient exceedance risks due to increased production (Xu et al., 1993).

GIS facilitates the integration of diverse spatial data into a comprehensive database that supports sustainable farm management practices and improves the economic and ecological viability of agricultural systems (Rao et al., 2000). While much of the available information focuses on crop management, there is less data on CAFOs, particularly in broiler production, revealing a gap in the literature on CAFOs' regional impacts. Integrating GIS into the commercial broiler industry studies could enhance understanding of nutrient flows, land use pressures, and environmental

effects, especially in regions where agricultural expansion faces ecological limitations (Zhang and Cao, 2019).

MATERIALS AND METHODS

This research uses an integrated GIS approach to analyze broiler production in Maryland at the Census block group level. The study consists of two key steps: (1) consolidation and integration of geophysical, production, and infrastructure information to each block group and (2) econometric modeling from the geodatabase. This section outlines the data sources, geographic extent, analytical processes, and econometric models employed.

Study Area

The study area focuses on Maryland's Eastern Shore, the state's primary area for commercial-scale broiler production. All broiler C/MAFOs are located exclusively in this region, making Maryland's Eastern Shore the natural focus for analyzing the dynamics of the state's broiler production. Covering approximately 3,800 square miles across nine counties, the Eastern Shore is largely agriculturally-focused, with a landscape anchored in corn and soybean production, which are key feed sources for broilers (Meyer, 2018).

The study region has a predominantly rural character, with an average population density of 138 residents per square mile, although there is significant variation. Salisbury, the region's largest city, exceeds 2,000 residents per square mile, while many areas are much less populated (Meyer, 2018). The Eastern Shore's demographic profile includes an older population, with 19% aged 65 or older, and a predominantly white population (73%), though Black and Latinx communities are growing (Meyer, 2018).

Data Sources and ArcGIS Pro Workflow

Under the Maryland Public Information Act, we accessed site-specific permitting data from MDE that regulates C/MAFOs that discharge pollutants into state waters. The permit data included permitted facility addresses, which were geocoded using the *ArcGIS World Geocoding Service* in ArcGIS Pro, integrated into our geodatabase, and aligned with other spatial datasets for analysis.

Demographic and geographic data were collected at the U.S. Census block group level, the smallest geographic unit for which the Census Bureau collects

sample data. Block groups typically contain between 600 and 3,000 people and 240 to 1,200 housing units (US Census Bureau, 2024a). Using block groups as the observation unit enabled a more detailed analysis of localized demographic and socioeconomic factors as these datasets included population counts, racial demographics, and socioeconomic indicators, which provided insight into local variations in population that could influence resource allocation and decision-making on Maryland's Eastern Shore.

To analyze agricultural factors related to poultry feed production, we incorporated NASS's Cropscape – Cropland Data Layer (CDL), which provides a raster crop classification dataset. Corn and soybean acreage, as primary poultry feed sources, were estimated for both 2010 and 2020 (USDA NASS, 2024a). This was done using the *Summarize Categorical Raster* tool in ArcGIS Pro, which calculated the total number of pixels corresponding to corn and soybeans within each block group. Since each pixel in the NASS CDL represents 900 square meters (30 meters by 30 meters), pixel counts were multiplied by this area to estimate the total crop acreage in each block group. The data was then used to calculate the proportion of potential poultry feed sources by dividing the total corn and soybean acreage within each block group by the total corn and soybean acreage in Maryland.

In addition to agricultural acreage data, the study incorporated transportation infrastructure data to evaluate the accessibility of poultry-related industries to key transportation routes. Data on railroads and major highways, including interstates, Maryland state routes, and U.S. routes, was integrated into the geodatabase within ArcGIS Pro. The polyline shapefiles for these transportation routes were obtained from the Maryland Department of Transportation's GIS "Open Data Portal" (Maryland Department of Transportation, 2024), then filtered by type to only include federal interstates, state highways, and freight rail, which were then clipped within the boundaries of the block groups, allowing us to calculate the total length of railroads and highways within each block group. This was achieved using the *Calculate Geometry Attributes* tool in ArcGIS Pro, which provided the total length of transportation routes in kilometers, later converted to miles for reporting consistency. The transportation infrastructure data was integrated into the analysis to evaluate the logistical factors involved in transporting feed and poultry products and the impact of proximity to major transportation routes and market access on the location of high-capacity broiler operations.

The spatial analysis was conducted using various GIS tools within ArcGIS Pro to assess geographic relationships between poultry facilities, agricultural production, and transportation infrastructure. The *Near* function in ArcGIS Pro was used to calculate the Euclidean distance between the centroid of each block group and Salisbury, Maryland—the location of Perdue's corporate headquarters and poultry processing plant. Directional orientation data for each block group in relation to Salisbury was also calculated and classified into categories (North, South, East, West) to refine our understanding of spatial orientation.

Geodatabase Creation

After the spatial datasets were processed in ArcGIS Pro, Python was used to finalize data cleaning, summarization, and transformation for econometric analysis. The geospatial data, combined with population data from the 2010 and 2020 U.S. Census, was linked using National Historical Geographic Information System (NHGIS) crosswalk data to align block group boundaries over time (Manson et al., 2024). This involved merging the 2010 population data with the NHGIS crosswalk and applying interpolation weights to adjust population figures for changes in geographic boundaries. Population attributes such as total population and racial demographics were adjusted using these weights to ensure comparability across Census years. Null values were replaced with zero to ensure consistency across calculations.

After preprocessing in Python, the cleaned and processed data, including demographic, agricultural, and infrastructure variables, was stored in a single geodatabase. This geodatabase was then imported into Stata for the econometric analysis, where it was used to evaluate the impact of demographic and geographic factors on the poultry industry.

The data sources used for this study are summarized in Table 1.

Econometric Methodology

The objective of this study is to understand the heterogeneous factors contributing to broiler production in Maryland and how geospatial elements contribute to those production areas. However, many block groups have no level of poultry production, which leads to masses of zeros in the estimations. In order to econometrically model the factors influencing the concentration of broiler production in Maryland, we used a two-step process, where the first step models the likelihood of having birds in a block group,

and the second step models the factors contributing to bird concentration. This two-stage process was first introduced by Heckman (1979). The process calculates an inverse mills ratio (IMR) as an intermediary step to account for sample biases used in the factor model, which truncates the data to positive poultry production by block group. To generalize the analysis, we account for the truncated data with the IMR. We briefly discuss the models used below.

The first stage uses a probit model on the binary variable *Production* and can be characterized as:

$$Production_i = \beta_k X_i + \varepsilon_i \quad (1)$$

where *Production* is a function of explanatory variables focused on block groups (land, water proportion, road length, and rail length), block demographics (non-white population, urban population proportion, and median household income), and broiler production factors (distance to Salisbury and grain production), β parameter estimates, and an error term ε . Salisbury, the largest broiler processor in the region, is used to account for the hub-like production where birds are processed in central locations, but the actual processing centers for each location is unknown. This model predicts the likelihood that a given block would produce any broilers, which would also account for urban blocks that would not likely have commercial poultry production based on zoning rules and population densities, but the IMR accounts for the truncated left-end tail of the distribution. Using the predicted outcomes from Equation 1, we create the IMR using Equation 2:

$$IMR = \frac{\phi(x)}{\Phi(x)} \quad (2)$$

where the IMR is the ratio of the probability distribution function of (ϕ) to the cumulative distribution function (Φ) of the standard normal distribution (Heckman, 1979). The IMR is then used in the second stage of the analysis.

In the second stage, we only model the factors against those blocks that had any level of production to estimate the factors contributing to a block group's broiler capacity. The second stage is presented in Equation 3:

$$Broilers_i = \beta_k X_i + IMR_i + \varepsilon_i \quad \text{where } Broilers_i > 0 \quad (3)$$

where broilers represent the count of broilers in a given block group, include additional factors focused on changes in population density, population growth, grain production changes, and income changes,

with all else as previously described. All models were estimated using Stata 18. Robust standard errors were used to account for heteroskedasticity in the data. A summary of all factors included in the analysis in either stage is provided in Table 2.

RESULTS

This section presents findings from the geodatabase and the econometric analysis of Maryland's commercial broiler production between 2010 and 2024. The analysis includes spatial relationships between geographic features and broiler capacity, followed by econometric modeling to explore the factors influencing the likelihood of broiler production and broiler concentration in Census block groups with production.

Geospatial Data Relationships

Figure 3 provides a visualization of total broiler capacity across Census block groups in Maryland's Eastern Shore, with darker shades of purple representing areas with higher concentrations of broilers. Salisbury, the region's primary processing hub, is marked with a yellow star. Notably, there are few broiler M/AFOs directly within Salisbury due to its urban nature, where land use is focused on non-agricultural purposes. This urbanization factor is explored further in the econometric analysis.

An important spatial relationship uncovered in the geodatabase analysis is the negative correlation between the proportion of water within a block group and its total broiler capacity. In Figure 4, broiler capacity ("Broiler_Capacity") is mapped in orange, and the proportion of water coverage ("Prop_Water") is shaded in blue. The correlation coefficient of -0.12 indicates that the number of broilers in a block group decreases significantly as water coverage increases. This relationship is intuitive: areas with higher water coverage, typically coastal or near large bodies of water like the Chesapeake Bay, are less suitable for broiler operations due to environmental constraints and land-use restrictions. The relationship resembles a 1/x pattern or inverse relationship where even small increases in water proportion lead to sharp declines in broiler capacity, particularly in block groups with moderate to high water coverage.

Broiler Production Likelihood

The marginal effects for the broiler production likelihood model are presented in Table 3. Factors include block group geographic factors, production

factors, and demographic factors. For block group factors, geophysical factors such as water coverage and physical land mass were considered, for example, for each additional percent of a block group covered in water, there was a 0.3% ($p < 0.01$) decrease in the likelihood of commercial broiler production. Beyond the obvious implications of water coverage, this also may reflect block groups closer to the coast or the Chesapeake Bay area, which brings its own environmental factors that would reduce and inhibit broiler production, consistent with the geospatial analysis described above.

Regarding drivers of broiler production location decisions, processing, and access to feed is also critical. Rail length, distance to Salisbury, the largest broiler processor in the region, and grain production proportion (Grain%) are all significant factors in explaining broiler production. Rail and grain explain feed access, where feed movement may help explain the importance of rail systems and the proximity to grain sources. Feed accounts for 70-80% of the cost of raising a broiler nutritive values, and reasonable price (Mallick et al., 2020). With the growing demand for egg and poultry meat, the demand for poultry feed is also increasing. Most of the feed ingredients which are used in poultry feed are also used for human nutrition. So these major feed ingredients and cumulatively poultry feed are facing market competition with increased cost. This study proposed linear programming, thus, minimizing the distance to feed helps reduce transportation costs. The negative relationship with Salisbury, which gives a -0.2% ($p < 0.01$) reduction in the likelihood of broiler production for each additional kilometer away from the processor, indicates a geographic pull centered on processing. With the average distance of 60 kilometers, the average influence on location likelihood is 12%. The geographical accessibility to processing would be important for areas with multiple processing centers that may drive the clustering of production.

As for demographics, the proportion of an urban block group is inversely related to its broiler production. For each percent higher in urban population proportion, the likelihood of the block containing broilers decreases by 0.3% ($p < 0.01$). The higher the urbanization, the higher the value and competition for land and subsequent challenges to broiler-producing opportunities. This is consistent with previous studies that found fewer production facilities located in or near denser suburban areas with higher population density and a more diverse population that are not in core agricultural producing areas (Parker et al., 2018).

Factors Affecting Broiler Concentrations

Using the production model results, we now account for the censoring of Census blocks to model only the blocks with positive broiler capacity. Broiler capacity is driven predominantly by block group factors and geographic factors, specifically, water is a significant capacity factor, as shown by the likelihood model and in Figure 4. For each additional proportion of the block covered in water, there are 10.2k fewer birds ($p < 0.05$), which would imply that block groups with higher water coverage producing broilers do so at smaller concentrations than those with less water coverage. A limitation of the current study is that the granular broiler data is static. An interesting extension of this result would be to study the dynamics of broiler capacity over time concerning land value, which may show the value of land increasing near desirable ocean and lakefront properties. However, given the limited data, we can observe that block groups with more water produce significantly fewer birds.

Regarding block demographics, we again show that population density in broiler-producing blocks significantly decreases broiler capacity. For each percent increase in the population density of a block group, the block's broiler capacity decreases by 3.753k broilers, which would support the general idea that production occurs in rural, less-populated areas. In the current static model, population growth was not a significant contributor to broiler capacity, but there may be longer-term effects that cannot be captured. Future modeling efforts could estimate changing demographics on production concentrations.

To emphasize the importance of proximity to urban centers with processing, distribution, and market access, it is notable that the only significant production driver of broiler capacity was the distance to Salisbury, a key hub for these essential services. For each additional kilometer away from the Salisbury processing plant, a block produces 6k fewer broilers. With an average distance of 60.6 kilometers, the production radii around the processing center could serve as a general guideline for the geographic market reach of processing capacity. A commercial broiler grower is contracted with specific processing plants. The geographical radii empirically show the gravity that processing plants have in concentrating production and could indicate continued intensification and concentration of broiler production within a feasible processing distance to Salisbury or around processing plants. For future planning purposes, this may help stakeholders and policymakers understand the agricultural and

environmental implications of increased production as well as the continued demand for public infrastructure to ensure business continuity. It will also help provide some understanding for longer-term tax flow expectations.

CONCLUSION

Urbanization and land-use changes will continue to reshape the agricultural landscape, presenting new challenges for Maryland's broiler industry. The industry faces issues such as urban encroachment, environmental regulation, the need for efficient access to processing facilities, and other downstream supply chains, all of which are likely to lead to increased intensification in specific, localized areas of broiler production. By utilizing publicly available M/CAFO permits, this study mapped and analyzed broiler production at the Census block group level, providing a clearer understanding of where production is concentrated and the factors driving these decisions.

This multidisciplinary approach represents a novel advancement in agricultural data analysis by offering a more detailed and precise view of broiler production locations. Such insights are crucial for policymakers, agricultural consultants, and industry leaders navigating the evolving production landscape. The ability to evaluate factors at the block group level, rather than relying on broader county-level data, allows for a more granular understanding of the nuances affecting broiler production. This granularity is essential for decision-making, resource allocation, and environmental monitoring, particularly concerning processing accessibility and demographic changes.

The results of this study highlight the significant roles that proximity to processing centers and less-densely populated areas play in shaping production patterns. As the industry continues to adapt to land-use pressures, the insights provided by this analysis offer a framework for predicting where intensification is likely to occur. By identifying the current key drivers of production at a local level, this research provides valuable tools for anticipating shifts in the broiler industry and ensuring that Maryland's agricultural sector remains resilient and responsive to environmental and economic demands.

In creating a comprehensive geodatabase of the M/CAFO broiler population in Maryland at the Census block group level, we have enabled a more precise evaluation of production factors. This detailed analysis underscores the importance of processing centers, access to transportation infrastructure, and agrarian

land availability in driving broiler production. As these factors continue to evolve, the Maryland broiler industry will need to adapt accordingly, and the results from this study provide a means for better predicting where future production intensification may occur. Moreover, the methods used in this study provide a roadmap of how GIS and agricultural economic methods could contribute to discussions of new and evolving regional siting of agricultural facilities, a timely issue given new investments that continue to be made under the USDA's Food System Transformation, introduced in the White House's recent Plan to Build Back Better framework (USDA Stories, 2022).

Future research should consider applying the methods developed here to other industries, such as beef and hog processing, as well as other commercial agricultural operations, to continue to explore how land-use pressures and industry-specific factors affect production patterns. Building on this research, future work could analyze animal health events and the effects of production regionalization, such as the spatial dynamics of highly pathogenic avian influenza and the associated regional stresses, including the operational and economic disruptions experienced by Maryland's poultry industry during the 2022 outbreak. This could provide critical insights into how intensification affects biosecurity and economic resilience.

Additionally, future studies should investigate the potential impacts of processing plant closures or shifts in consumer preferences toward non-CAFO or less-intensive poultry production systems. These shifts could require more land for production, thus, it would be essential to evaluate whether sufficient land exists within the production region, or if these changes might necessitate production movement to other geographic regions. This understanding would inform planning efforts to balance environmental sustainability, economic viability, and consumer demand.

Policymakers and conservation groups can play a pivotal role in supporting balanced changes by leveraging zoning regulations, providing funding for sustainable farming practices, and offering field support to assist farmers in adapting to new production models or regulations. These efforts could help ensure that the agricultural landscape evolves in a way that is both economically and environmentally sustainable, fostering resilience in Maryland's agricultural sector while addressing the challenges posed by urbanization and land-use changes.

REFERENCES

- Bruhn, M.C., B. Munoz, J. Cajka, G. Smith, R.J. Curry, D.K. Wagener, and W.D. Wheaton. (2012). "Synthesized Population Databases: A Geospatial Database of US Poultry Farms." *Methods Report*. RTI Press, MR-0023-1201: 1–24. <https://doi.org/10.3768/rtipress.2012.mr.0023.1201>.
- Devine, J., and V. Baron. 2019. "CAFOs: What We Don't Know Is Hurting Us." NRDC. September 23, 2019. <https://www.nrdc.org/resources/cafos-what-we-dont-know-hurting-us>.
- ERS. 2023. *Poultry Sector at a Glance*. USDA Economic Research Service. Updated January 5, 2025. <https://www.ers.usda.gov/topics/animal-products/poultry-eggs/sector-at-a-glance/>.
- Heckman, J.J. 1979. "Sample Selection Bias as a Specification Error." *Econometrica* 47(1): 153–161. JSTOR. <https://doi.org/10.62276>.
- Kang, M.S., P. Srivastava, T. Tyson, J.P. Fulton, W.F. Owsley, and K.H. Yoo. 2008. "A Comprehensive GIS-based poultry Litter Management System for Nutrient Management Planning and Litter Transportation." *Computers and Electronics in Agriculture* 64(2): 212–224. <https://doi.org/10.1016/j.compag.2008.05.013>.
- Lansing, S., S. Dill, K. Everts, A. Hassanein, M. Hendricks, J. MacDonald, J. Moyle, N. Nunn, S. Potts, J. Rhodes, D. Ruppert, J. Semler, and E. Thilmany. 2023. *Maryland Animal Waste Technology Assessment and Strategy Planning* (p. 116). University of Maryland Extension. <https://extension.umd.edu/resource/maryland-animal-waste-technology-assessment-and-strategy-planning-report/>.
- Lee Miller, D., and G. Muren,. 2019. *CAFOS: WHAT WE DON'T KNOW IS HURTING US* (R: 19-06-A). <https://www.nrdc.org/sites/default/files/cafos-dont-know-hurting-us-report.pdf>
- Livestock Marketing Information Center. (2022). *Annual Meat Consumption*. <https://lmic.info/>.
- MacDonald, J.M. 2014. *Technology, Organization, and Financial Performance in U.S. Broiler Production*. Economic Information Bulletin 126. Economic Research Service. https://www.ers.usda.gov/webdocs/publications/43869/48159_eib126.pdf?v=2816.4.
- Mallick, P., K. Muduli, J.N. Biswal, and J. Pumwa. 2020. "Broiler Poultry Feed Cost Optimization Using Linear Programming Technique." *Journal of Operations and Strategic Planning* 3(1): 31–57. <https://doi.org/10.1177/2516600X19896910>.
- Manson, S., J. Schroeder, D. Van Riper, K. Knowles, T. Kugler, F. Roberts, and S. Ruggles. 2024. *Ipums national historical geographic information system: Version 19.0 [dataset]*. <http://doi.org/10.18128/D050.V19.0>
- Maryland Department of Transportation. 2024. *Maryland Road Centerlines - Comprehensive*. <https://data-maryland.opendata.arcgis.com/datasets/maryland::maryland-road-centerlines-comprehensive/about>.
- Meyer, C. 2018. *Sustaining Strong Communities on Maryland's Eastern Shore—Overview and Profile*. Maryland Center on Economic Policy. <https://mdeconomy.org/es-overview/>.
- Parker, K., J. Horowitz, A. Brown, R. Fry, D. Cohn, and R. Igielnik. 2018. *What Unites and Divides Urban, Suburban and Rural Communities* (p. 90). Pew Research Center. <https://www.pewresearch.org/social-trends/2018/05/22/demographic-and-economic-trends-in-urban-suburban-and-rural-communities/>.
- Perdue. 2024. *Our Company*. June 12, 2024. <https://corporate.perdufarm.com/company/legacy>.
- Rao, M.N., D.A. Waits, and M.L. Neilsen. 2000. "A GIS-based Modeling Approach for Implementation of Sustainable Farm Management Practices." *Environmental Modelling & Software* 15(8): 745–753. [https://doi.org/10.1016/S1364-8152\(00\)00032-3](https://doi.org/10.1016/S1364-8152(00)00032-3).
- U.S. Census Bureau. 2024a. *Glossary*. June 12, 2024. <https://www.census.gov/programs-surveys/geography/about/glossary.html>.
- U.S. Census Bureau. 2024b. *USDA Census of Agriculture 2022 - Chicken Production*. June 12, 2024. <https://www.arcgis.com/home/item.html?id=b3cd344a123b4e6ebdf8d98b3140f00c>.
- USDA Stories. 2023. *Transforming the U.S. Food System—U.S. Department of Agriculture Stories*. June 23, 2022. <https://usda.exposure.co/transforming-the-us-food-system>.
- USDA NASS. 2024a. *CroplandCROS*. June 12, 2024. <https://croplandcros.scinet.usda.gov/>.
- USDA NASS. 2024b. *Poultry Production and Value*. USDA Economics, Statistics and Market Information System. <https://usda.library.cornell.edu/concern/publications/m039k491c>.
- Xu, F., T. Prato, and C. Fulcher. 1993. "Broiler Litter Application to Land in an Agricultural Watershed: A GIS Approach." *Water Science and Technology* 28(3–5): 111–118. <https://doi.org/10.2166/wst.1993.0409>.
- Zhang, F., and N. Cao. 2019. "Application and Research Progress of Geographic Information System (GIS) in Agriculture." *2019 8th International Conference on Agro-Geoinformatics (Agro-Geoinformatics)*: 1–5. <https://doi.org/10.1109/Agro-Geoinformatics.2019.8820476>.

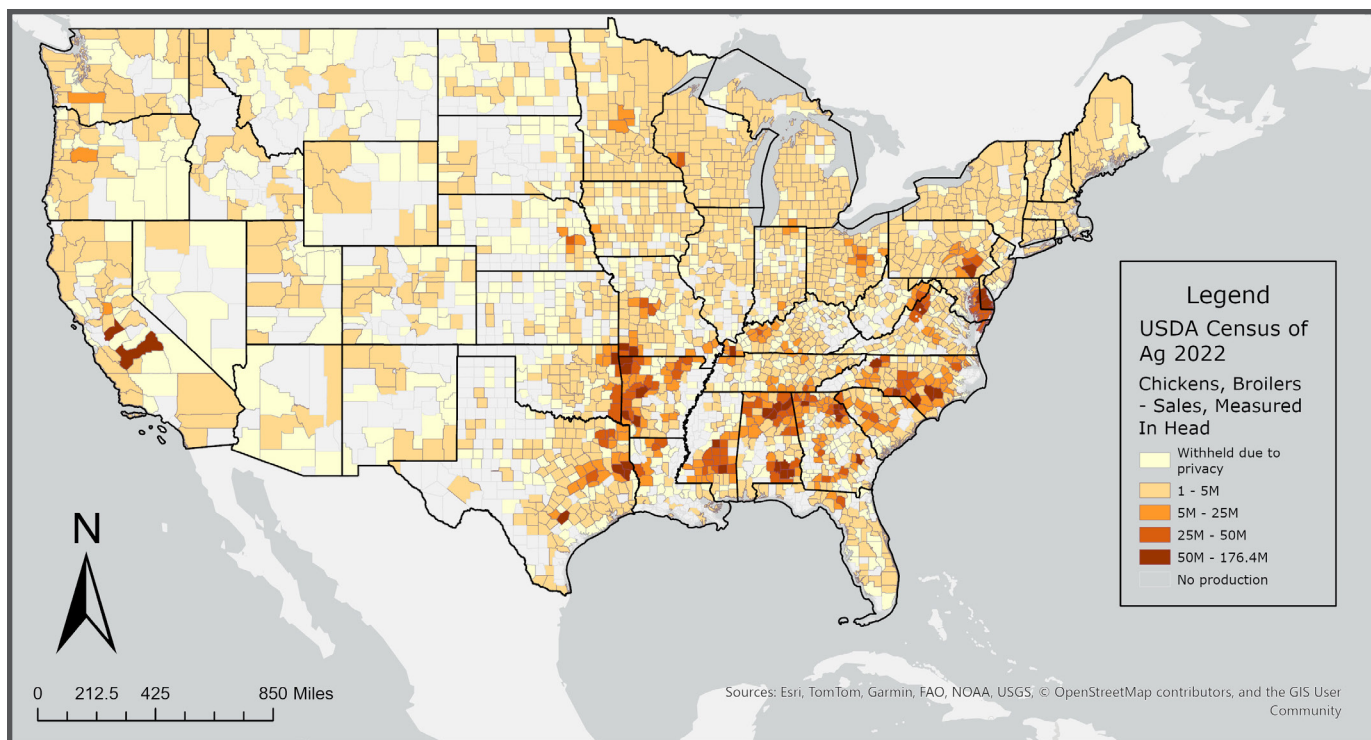


Figure 1. County-level distribution of broiler chicken sales in the United States, measured in head, based on data from the USDA's 2022 Census of Agriculture

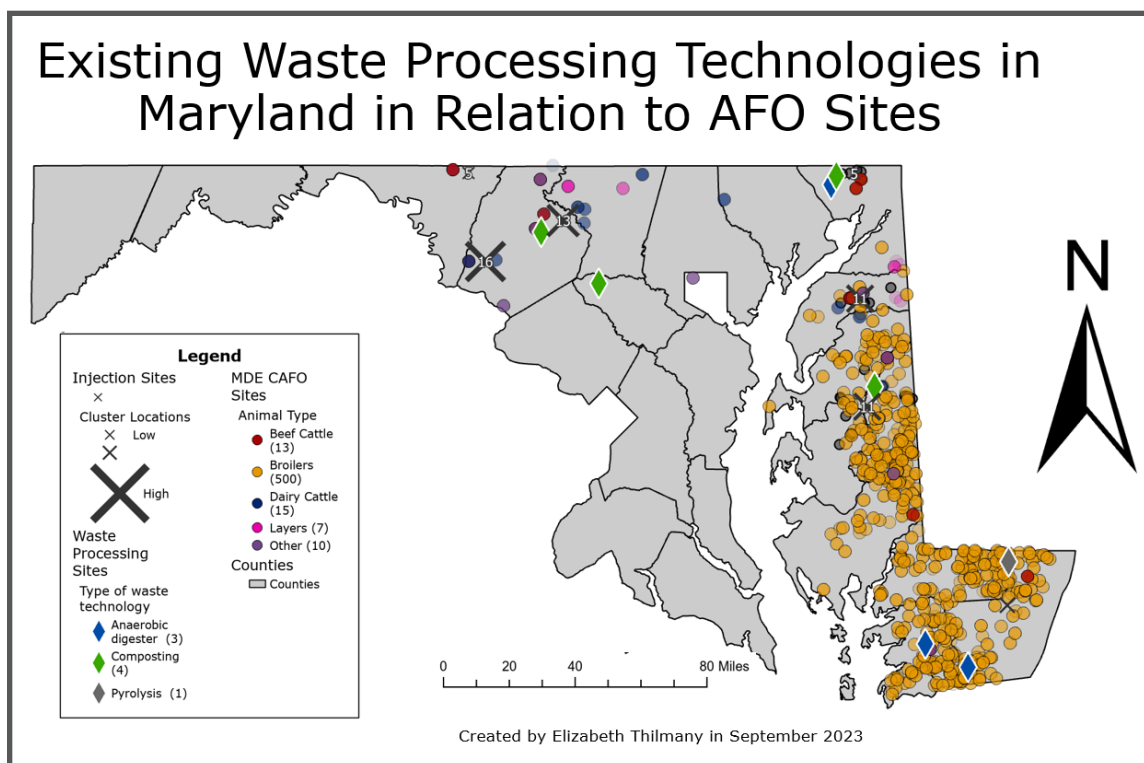


Figure 2. Distribution of active broiler M/CAFOs and animal waste technology sites in Maryland in 2023 from "Maryland Animal Waste Technology Assessment and Strategy Planning Report" (Lansing et al., 2023)

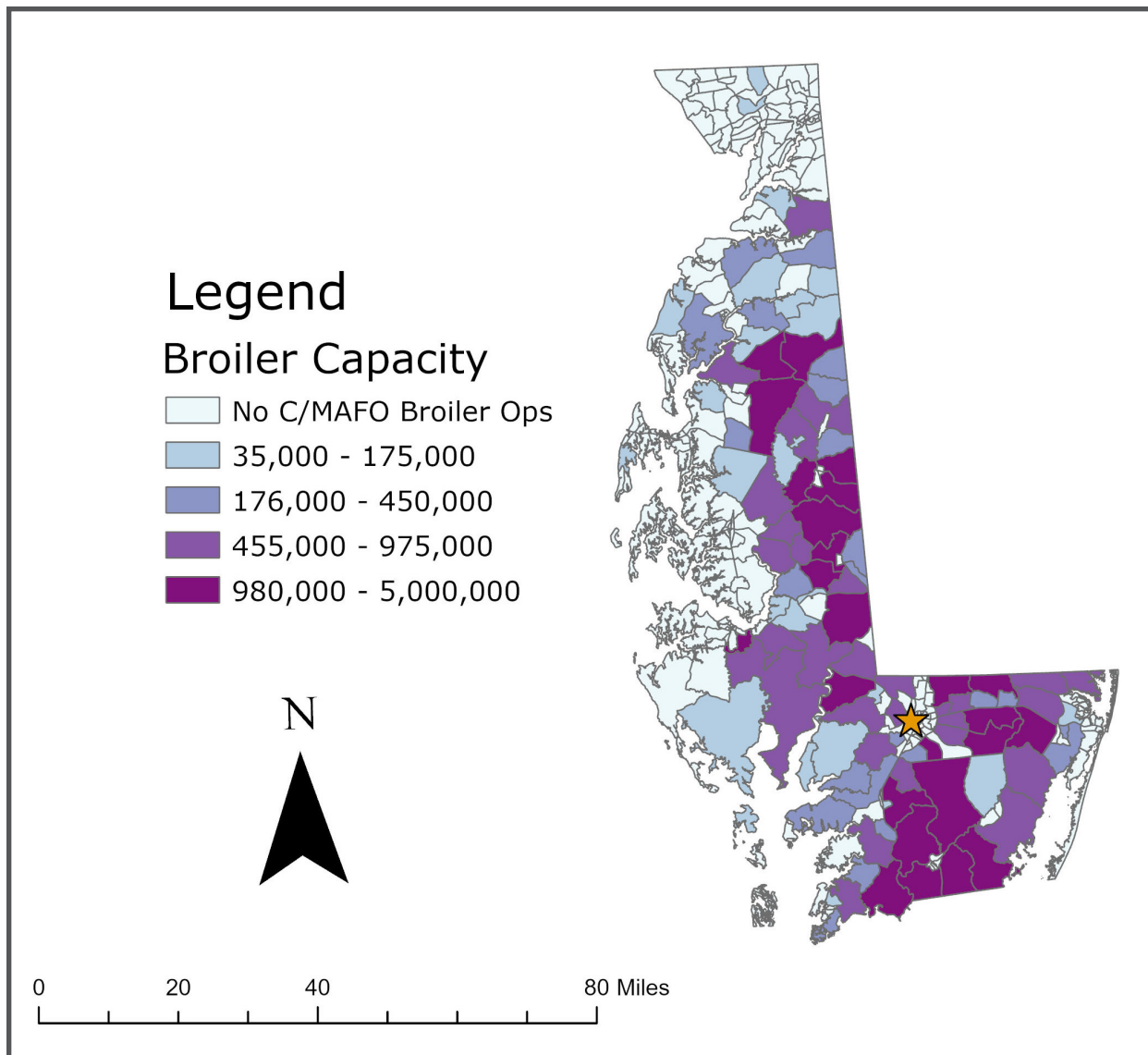


Figure 3. 2024 M/CAFO broiler capacity by Census block group in Maryland in relation to Salisbury, Maryland

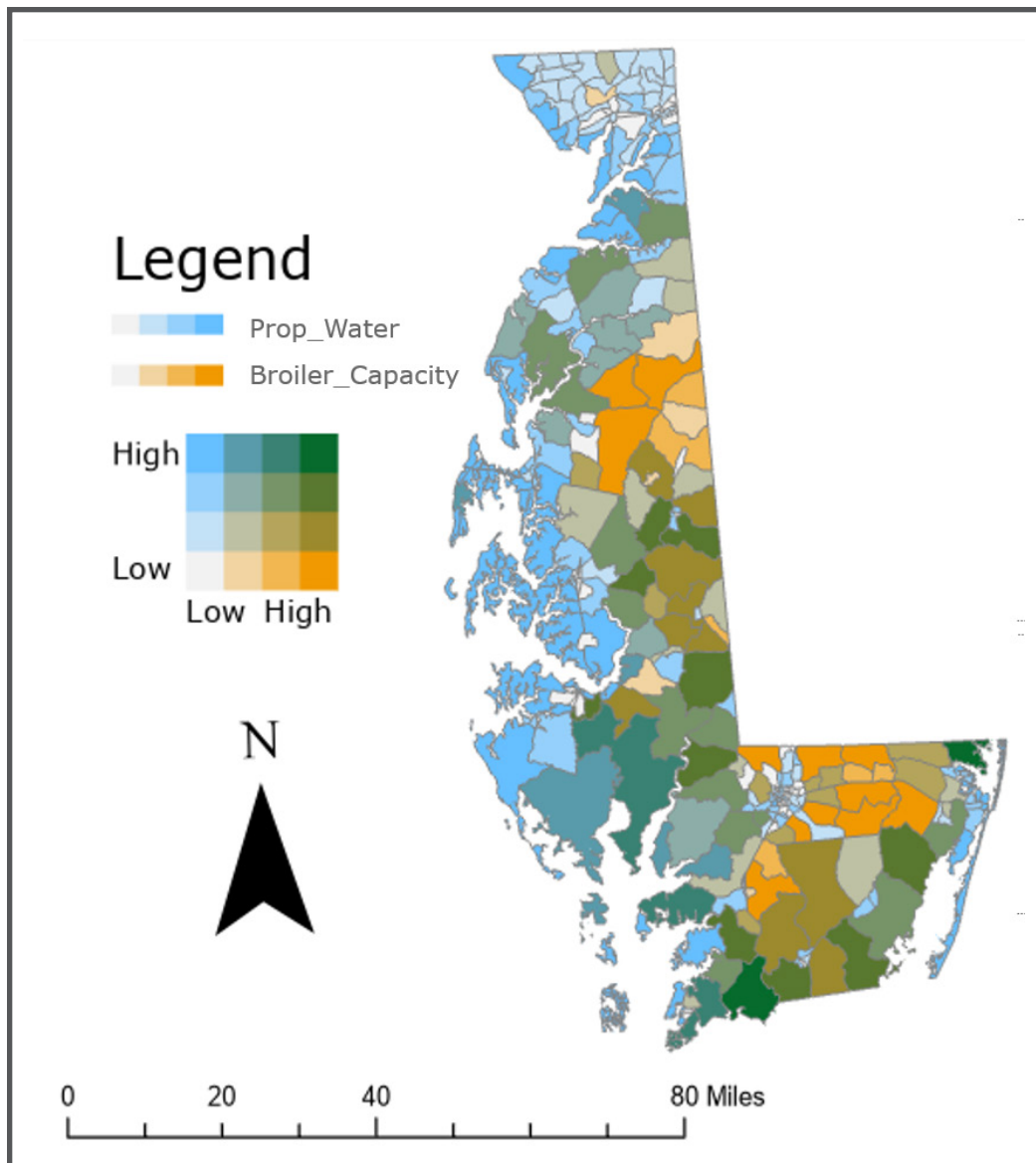


Figure 4. Relationship between broiler capacity and proportion of water in block groups

Table 1. Data Sources and Use in Study

Data Source	Description	Variables Used	Purpose in Study	Method of Acquisition
Maryland Department of the Environment (MDE) permits	Site-specific permitting data for M/CAFOs that discharge pollutants into state waters	Facility location, broiler capacity, permit type	To determine broiler capacity at each block group	Accessed via Maryland Public Information Act
U.S. Census Bureau – 2010 Population Data	Population data from the 2010 U.S. Census at the block group level	Total population, racial demographics	To analyze population demographics in relation to AFOs	Publicly available U.S. Census files
U.S. Census Bureau – 2020 Population Data	Population data from the 2020 U.S. Census at the block group level	Total population, racial demographics	To analyze changes in population demographics between 2010 and 2020	Publicly available U.S. Census files
NHGIS Crosswalk Data (2010–2020)	Crosswalk data linking 2010 and 2020 census block group boundaries for comparison	Interpolation weights, block group identifiers	To align population data across census years and adjust for boundary changes	National Historical Geographic Information System (NHGIS)
NASS Cropscape – Cropland Data Layer	Raster dataset providing detailed crop classifications	Corn and soybean acreage (2010, 2020)	To estimate potential poultry feed sources in each block group	Accessed via USDA NASS Cropscape
FSIS (Food Safety and Inspection Service)	Locations of poultry processing facilities regulated by FSIS in Maryland	Facility locations, distances from block groups	To evaluate proximity of block groups to poultry processing facilities	Publicly available FSIS data, analyzed in ArcGIS
U.S. Census Bureau – 2013 Income Data	Income data from 2013 at the Census block group level	Median household income	To assess income levels in relation to AFO distribution	Publicly available U.S. Census files
Transportation Data – Railroads	Polyline data on freight railroads in Maryland	Total length of railroads in each block group	To assess access to rail transportation for poultry and feed logistics	Maryland Department of Transportation
Transportation Data – Highways	Polyline data on major highways, including interstates, MD routes, and U.S. routes	Total length of highways in each block group	To assess access to highways for poultry and feed logistics	Maryland Department of Transportation

Table 2. Data Summary for Maryland Census Block 2010–2020

Variable	Description	N	Mean	SD	Min	Max
Broilers	Thousands of Birds	96	738.2	875.1	37.8	4,791.2
Land	100k of Sq Meters	334	251.3	363.2	3.1	2,834
Water Proportion	Proportion	334	12.7	19.4	3.0	2,834
Road Length	Kilometers	334	1.2	1.9	0.0	9.6
Rail Length	Kilometers	334	1.2	2.4	0.0	14.7
Distance to Salisbury	Kilometers	334	60.6	47.8	0.0	154.7
Non-White Population %	% of Total Population	334	21.4	19.4	1.1	96.7
Urban Population %	% of Total Population	334	38.8	43.8	0.0	100.0
Median Household Income	Thou. Dollars	334	60.9	22.9	13.3	140.9
Household Income Growth 2010-2020	% Growth	321	18.5	40.8	-60.1	252.0
Population Density 2010	Capita per Mil. Sq. Meters	334	399.2	572.9	0.0	3,050.9
Population Growth 2010-20	% Growth	334	2.4	15.5	-30.4	155.9
Grain %, 2010	% of Total Grain Acres	334	0.9	1.4	0.0	8.7
Grain Acres 2020	Thousands of Acres	334	8.3	13.2	0.0	93.3
Grain Acre Growth 2010-20	% Growth	325	-33.2	41.3	-100.0	366.7

Table 3. Results for Two-Stage Modeling for Maryland Broiler Production 2010–2020

	Production Model Marginal Effects		Broiler Model	
Land	0.010	(0.000)	0.027	(0.205)
Water Proportion	-0.003***	(0.001)	-10.248**	(5.108)
Road Length	-0.003	(0.009)	-56.071	(42.612)
Rail Length	0.015**	(0.006)	-18.428	(37.623)
Distance to Salisbury	-0.002***	(0.000)	-6.009***	(1.803)
Non-White Population %	-0.002*	(0.001)	-7.064	(6.489)
Population Growth 2010-2020			4.486	(10.246)
Grain Acre Growth 2010-2020			-6.227	(7.825)
Household Income Growth 2010-2020			-2.991	(2.403)
Population Density 2010			-3.753*	(1.941)
Grain Acres 2020			15.556	(9.920)
Median Household Income 2013	-0.001	(0.001)	-3.694	(5.651)
Urban Population %	-0.003***	(0.000)		
Grain %, 2010	0.047**	(0.022)		
IMR			-1.345	(1.479)
Constant	1.145*	(0.633)	1,424.353***	(454.723)

Observations	334	96
Pseudo R2/R2	0.603	0.247

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1