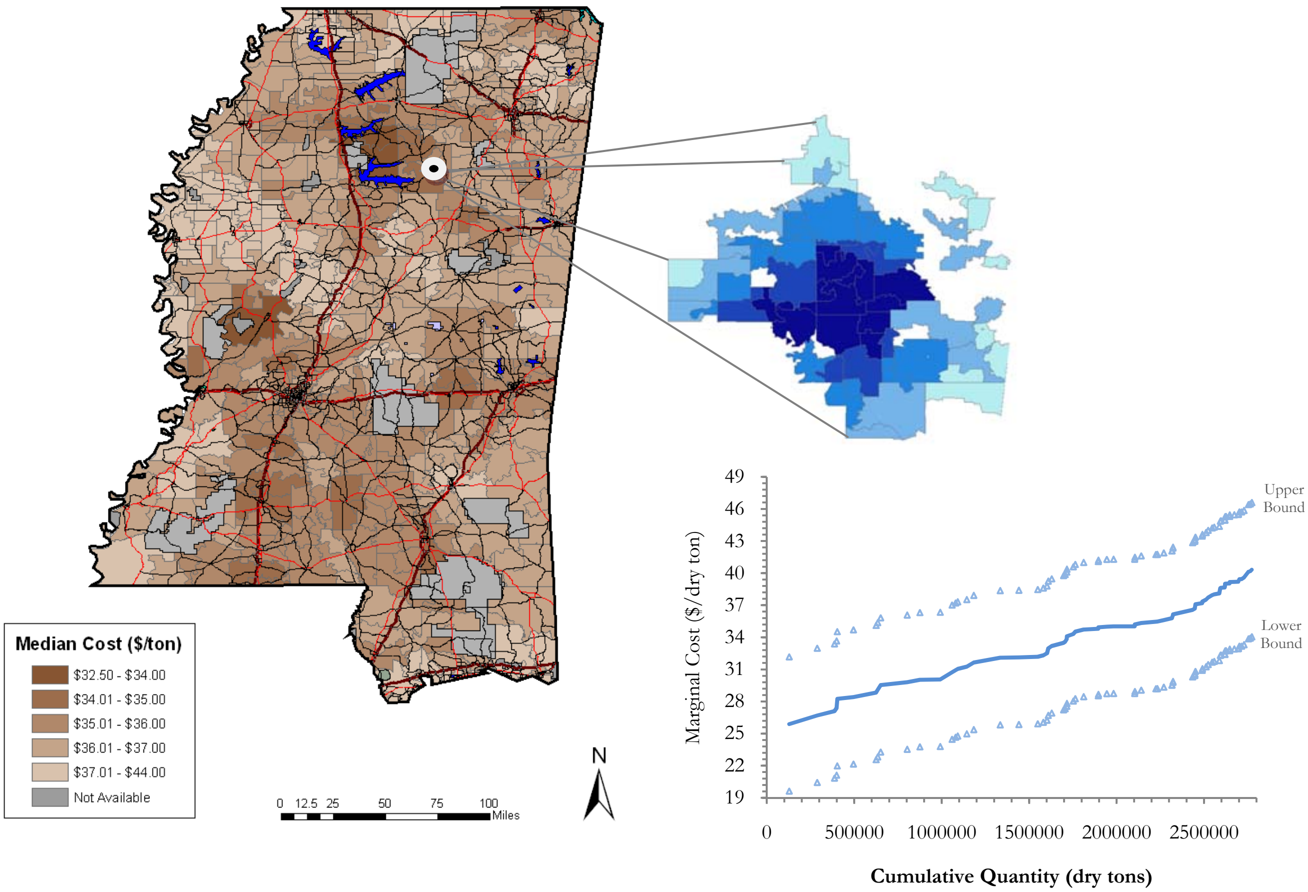
Regional Comparative Advantage for Woody Biofuels Production



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Regional Comparative Advantage for Woody Biofuels Production

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Executive Summary

The economic availability of woody biomass for the southeastern United States is summarized in this final report for the U.S. Department of Transportation, Southeastern Sun Grant Center research contract R11-0515-016 as administered by the University of Tennessee. Geo-referenced economic supply curves (marginal cost curves) for woody biomass producers' for the 13 southern states are developed using the BioSAT Model (Biomass Site Assessment Tool, www.biosat.net).[1] The overall goal of the research was to improve the understanding of costs for mill and logging residues that make-up the woody biomass supply chain, an essential first-step for market organization of this emerging industry. The project had three objectives that were aggregated to provide spatially explicit economic data for potential producers of bioenergy and biofuels: 1) use the SubRegional Timber Supply (SRTS) model with USDA Forest Service inventory data in an economic supply and demand framework to project timber inventory, supply, and price into the future for estimating logging residues; 2) develop a cost model for mill residues; and 3) develop a trucking transportation cost model for biomass. The three objectives of the research study were met which led to regional comparisons of the economic supply of woody biomass for the southeastern U.S. and identification of least cost bio-basins.

Potential bio-basins were aggregated as groupings of 5-digit Zip Code Tabulation Areas (ZCTAs). Resource cost data (e.g., mill residue prices) are obtained from Timber Mart South (TMS). The transportation cost model of BioSAT estimated fixed and variable trucking costs based on the shortest travel time and shortest travel distance between supply ZCTAs and a demand ZCTA, given the road network of a bio-basin. Dry-van trailers were assumed in the trucking cost model. Microsoft© MapPoint® 2006 was used to estimate the shortest travel time routes and distances between ZCTAs. Road networks in MapPoint® are a combination of the Geographic Data Technology, Inc. (GDT) and Navteq data. The Subregional Timber Supply (SRTS) model was used to estimate current logging residues and project future logging residues for the southeastern U.S. up to the year 2050. Forest resource data were obtained from the USDA Forest Service, Forest Inventory and Analysis Database (FIADB) version 3.0. The Fuel Reduction Cost Simulator (FRCS), as modified for the Billion Ton Study, was used to estimate the costs of harvesting logging residues. Softwood and hardwood logging residue costs were estimated for "chipping tops and limbs at the

[1] Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.

landing" (referred to as logging residue costs "at landing") and for "in woods harvesting of sub-merchantable material" (referred to as logging residue costs "in woods"). Costs for procuring mill residues were estimated for "clean softwood," "clean hardwood," "unclean softwood," "unclean hardwood," and combination of these categories (e.g., "total residues," "total softwood residues," and "total hardwood residues").

Least cost bio-basins for total "softwood" mill residues (clean and unclean) were identified for south-central and southeast GA, and southern MS. Average total costs (ATC) ranged from \$27.51 to \$35.91 per dry ton with marginal costs (MC) ranging from \$43.03 to \$45.15 per dry ton. 90% confidence bounds on the MC of total "softwood" mill residues were ± \$6.89 per dry ton. Least cost bio-basins for "clean softwood" mill residues were located in west-central GA. ATC ranged from \$39.88 to \$42.47 per dry ton and MC ranged from \$40.98 to \$43.45 per dry ton. Least cost bio-basins for "clean hardwood" mill residues were located in southern and central VA. ATC ranged from \$46.30 to \$47.65 per dry ton and MC ranged from \$42.25 to \$43.79 per dry ton.

Least cost bio-basins for "at landing" softwood logging residues were located in southeast MS, northern LA, southern AR, and central SC. ATC ranged from \$27.34 to \$28.68 per dry ton and MC ranged from \$28.03 to \$32.87 per dry ton. Least cost bio-basins for "at landing" hardwood logging residues were located in northeast NC, southeast VA, and east-central MS. ATC ranged from \$26.24 to \$27.64 per dry ton and MC varied from \$26.91 to \$29.67 per dry ton.

Least cost bio-basins for "in woods" softwood logging residues were located in northeast GA and northeast SC. ATC ranged from \$187.67 to \$196.56 per dry ton and MC ranged from \$191.08 to \$198.52 per dry ton. Least cost bio-basins for "in woods" hardwood logging residues were located predominately in MS. ATC ranged from \$194.77 to \$198.95 per dry ton and MC ranged from \$192.80 to \$199.41 per dry ton.

SRTS model projections indicated that GA and MS have the largest and most economically sustainable supply of softwood logging residues from both the growing and non-growing stocks. GA has projected economically sustainable softwood logging residues from the growing stock of approximately 550,000 dry tons per year until 2050, with additional softwood logging residues from the non-growing stock of approximately 1,000,000 dry tons per year until 2050. MS has projected economically sustainable softwood logging residues from the growing stock of approximately

350,000 dry tons per year until 2050 with an additional 850,000 dry tons per year from the non-growing stock until 2050.

MS, GA, and AL have the largest and most economically sustainable supply of hardwood logging residues from the growing stock. MS has projected hardwood logging residues from the growing stock that appear sustainable at a level of approximately 650,000 dry tons per year until 2050. GA has the steepest projected increases in hardwood logging residues from the growing stock from approximately 500,000 dry tons per year in 2005 to approximately 600,000 dry tons per year in 2050. AL has economically sustainable hardwood logging residues from the growing stock of approximately 550,000 dry tons per year in 2050.

TN and MS have the steepest projected increases in economically sustainable supplies of hardwood logging residues from the non-growing stock. TN's economically sustainable hardwood logging residues from the non-growing stock were projected to consistently increase from approximately 900,000 dry tons per year in 2005 to 1,200,000 dry tons per year by 2050. MS's economically sustainable hardwood logging residues from non-growing stock were projected to increase slightly from approximately 900,000 dry tons per year in 2005 to 1,000,000 dry tons per year in 2050.

Introduction

As Elbehri (2007) noted replacing petroleum products with bio-based fuels and energy presents several technical, economic, and research challenges, one of which is the availability of biomass feedstock. Elbehri (2007) also noted that lack of biomass production capacity, high relative costs of production, logistics, and transportation of feedstocks are potential constraints that need to be better understood. The goal of this U.S. Department of Transportation, Southeastern Sun Grant Center sponsored research project (http://sungrant.tennessee.edu/) was to assess the economic availability of woody biomass for the southeastern United States and improve the understanding of costs that make-up the woody biomass supply chain. This final report summarizes the findings and methods of the study and presents geo-referenced economic supply curves for woody biomass producers' (marginal cost curves) for the 13 southern states. An important outcome of this research was the development of a model (Biomass Site Assessment Tool – "BioSAT") accessible in the public domain on the web site www.biosat.net.

The 20th century was marked by rapid growth and increased prosperity in the world. By 2020, the world's energy consumption is predicted to be 40% higher than it is today, even in the presence of the global 2008/2009 economic recession (Energy Information Agency 2006). Key sources of oil for U.S. markets are located in complex geopolitical environments that increase risk to the U.S. economy.[2] Since the 1970s, macroeconomists have viewed changes in the price of oil as an important source of economic fluctuations, as well as a paradigm of a global shock, likely to affect many economies simultaneously (Blanchard and Gali 2007). There has been a renewed interest in bioenergy and biofuels given the rapid rise in nominal prices of oil which peaked at $147.27 per barrel on July 11, 2008. Even though nominal oil prices have declined since July, 2008, the renewed interest in bioenergy and biofuels, combined with a growing interest in reducing greenhouse gases, has created a plethora of research questions concerning the use of cellulosic biomass for energy and fuels.

Woody biomass is a renewable resource procured from multiple sources which include land clearings, landscaping, industrial byproducts, and abundant forest resources (Caputo 2009). Developing any new industry, however, involves establishing many relationships (Altman and

[2]About 59% of our current oil use is imported, with approximately 20% coming from the Persian Gulf (Caputo 2009).

Johnson 2008). Assessing the economic capability and stability of the bioenergy supply chain infrastructure is essential for market organization of this emerging industry, and is the key question addressed by this study. A plethora of literature exists on the economic availability of biomass (Young and Ostermeier 1989, Young et al. 1991; Lunnan 1997; Walsh 1998, 2000; DiPardo 2000; Ugarte et al. 2000, 2006, 2007; Walsh 2008; Biomass Research and Development Board 2008; Western Governors Association 2008; Biomass Research and Development Board 2008, Perez et al. 2009, Galik et al. 2009, and others). A recent report by the U.S. Department of Agriculture and Department of Energy concluded that 1.3 billion tons of biomass are available annually for energy production (Perlack et al. 2005). Perlack et al. (2005) indicated that the nation's forests represent a strategic asset in meeting the national goal of replacing 30% of the domestic petroleum consumption by 2030.

However, the renewed interest in the use of woody biomass for bioenergy and biofuels is not without its caveats. The recent Southern Forest Resource Assessment identified several resource trends which will affect future availability of the southern timber resource for biofuel production (Wear and Greis 2002, Wear et al. 2007). Wear et al. (2007) noted that the current decade marks the first time that southern pine inventory has not increased since the U.S. Forest Service has been conducting inventories. Increased utilization of hardwoods and pines for other uses in the last decade (e.g. OSB), have largely offset losses in pulp capacity in the South. Southwide decreases (40%) in acres planted and loss of timberland to urbanization imply that even under current demand, the future inventory is not likely to follow historical trends (Wear and Greis 2002, Wear et al. 2007). However, the conclusions made by Wear et al. (2007) were prior to the deep economic recession of 2008/2009 which has seen record low housing starts, wood consumption, and permanent decommissioning of manufacturing capacity by the forest products industrial sector.

Aggregate south wide trends may mask significant regional differences in resource availability and current demand (Figure 1). The focus of this research is on identifying and projecting spatial comparative advantage for biomass delivered fiber costs which include: 1) resource costs, 2) logging costs, and 3) transportation costs. While prior studies have examined the availability of wood for biomass or the transportation costs associated with cellulosic biomass (Langholtz et al. 2006, Perlack at al. 2005, Jensen et al. 2002, Noon and Day 1997), this study is unique in that costs associated with providing woody biomass to biorefineries are updated periodically (bi-monthly, quarterly, and annually) and available for 13 southeastern states at the 5-digit zip code tabulation area (ZCTA) on a public domain web site (www.biosat.net). The project develops geo-referenced estimates of logging and transportation costs and incorporates these costs into an existing timber supply model to develop marginal cost curves for woody biomass delivered to biorefineries at different locations throughout the southern United States. In a separate study, Liu (2009) provides a logistic regression based method (with a de-clustering algorithm) for locating potential biorefineries and biofuels that use woody biomass.

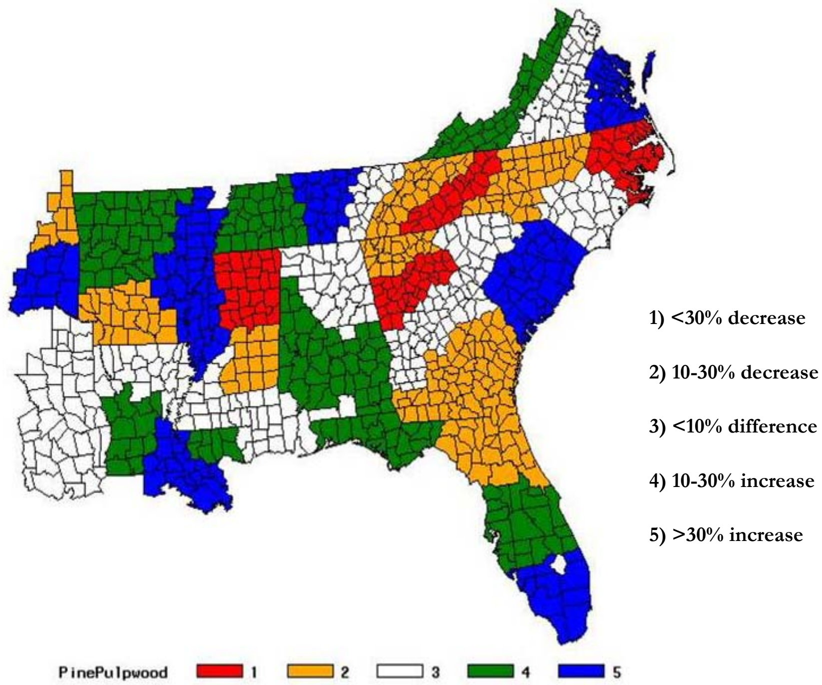

Figure 1. 2006 Southern Regional Timber Supply (SRTS) model projected pine pulpwood inventory shift, 2002-2022 (Abt 2008).

The proposed project is directly applicable to the goals of the U.S. Department of Transportation (DOT) Southeastern Sun Grant Center. The model can be used as a tool to help ensure optimum, low cost production of bioenergy and biofuels which are essential for the nation's energy security. Moreover, the study addresses a specific need of the Southeastern Sun Grant Center identified in the 2008 request for proposals: "optimized models for convenient assessment of agricultural and forest biomass availability, and regional biorefinery siting."

Objectives

The project had three objectives that were aggregated to provide spatially explicit economic data for potential producers of bioenergy and biofuels: 1) use the SubRegional Timber Supply

(SRTS) model with USDA Forest Service inventory data in an economic supply and demand framework to project timber inventory, supply, and price into the future for estimating logging residues; 2) develop a cost model for mill residues; and 3) develop a transportation model to calculate the costs of transporting biomass to potential biorefinery sites. The three objectives led to regional comparisons of the economic supply of woody biomass for the southeastern U.S., and identification of least cost locations for bio-basins.

The scope of the study is the 13 southeastern United States.[3] The resolution of the study is the Zip Code Tabulation Area (ZCTA), see U.S. Census Bureau (2000).[4] A significant enhancement to the original objectives of the study is the development of the Phase I Biomass Site Assessment Tool (BioSAT), www.BioSAT.net. Development of the BioSAT model and corresponding website were done in conjunction with a separately funded study by the U.S. Forest Service Southern Research Station. The U.S. Forest Service study also assesses costs associated with supplying agricultural residues within potential bio-basins for biorefineries and biofuels producers.

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[3] Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.

[4] ZIP Code Tabulation Areas (ZCTAs™) are a relatively new statistical entity developed by the U.S. Census Bureau (2000) for tabulating summary statistics from Census 2000. This new entity was developed to overcome the difficulties in precisely defining the land area covered by each ZIP Code®. Defining the extent of an area is necessary in order to accurately tabulate census data for that area. ZCTAs are generalized area representations of U.S. Postal Service (USPS) ZIP Code service areas. Simply put, each one is built by aggregating the Census 2000 blocks, whose addresses use a given ZIP Code, into a ZCTA which gets that ZIP Code assigned as its ZCTA code. They represent the majority USPS five-digit ZIP Code found in a given area. For those areas where it is difficult to determine the prevailing five-digit ZIP Code, the higher-level three-digit ZIP Code is used for the ZCTA code, see http://www.census.gov/geo/ZCTA/zcta.html (accessed July 22, 2009).

Methods

The algorithm (flow chart form) for developing the geo-referenced supply curves is presented in a fold out attachment at end of report. The BioSAT model has three main cost components: resource, harvesting, and transportation. Forest resource data are obtained from the USDA Forest Service current FIA inventory data (U.S. Department of Agriculture, Forest Service 2008).

Forest Resource Data

County level estimates of all-live total biomass, as well as average annual growth, removals, and mortality were obtained from the Forest Inventory and Analysis Database (FIADB) version 3.0 (U.S. Department of Agriculture, Forest Service 2008). The latest complete cycle of data for each state was used (Table 1). New FIA data, when available, will be updated in the model. All quantity data were presented on a dry ton basis.

Table 1. State and year of USFS FIA inventory data.

State	Year
Alabama	2007
Arkansas	2007
Florida	2006
Georgia	2007
Kentucky	2006
Louisiana	2005
Mississippi	2006
North Carolina	2006
Oklahoma	1993
South Carolina	2006
Tennessee	2006
Texas	2007
Virginia	2007

County level estimates were allocated to "zip code tabulation areas" (ZCTAs) based on area proportionality, e.g., if a ZCTA accounts for ten percent of a county, ten percent of the county's data are assigned to that ZCTA. If a ZCTA boundary crosses multiple counties, proportions for each county were summed.

ZCTAs are based on the 2000 census definition and were obtained from the U.S. Census Bureau (U.S. Census Bureau 2000). Area proportionality was performed using ArcGIS which produces a file containing ZCTAs, county Federal Information and Processing Standard (FIPS) codes, and the percentage each county has in the ZCTAs (http://www.esri.com/software/arcgis/ Accessed January 5, 2009). An ORACLE™ database was created for this file of FIA and BT2 county level data. ZCTA level estimates were derived from the information in this database (http://www.oracle.com/database/index.html accessed January 5, 2009).

As ZCTAs do not account for all zip codes, files containing all possible zip codes as of January 31, 2008 were used from zip-codes.com (http://www.zip-codes.com/ Accessed January 5, 2009). This file contains the zip code, latitude, and longitude of the mail office associated with each zip code. These points were then assigned to the corresponding ZCTA. Users can query BioSAT using any zip code, although the results were based on ZCTAs. i.e., there were 13,463 zip codes and 9,221 ZCTAs in the 13-state study region as of December 2009.

Confidence bounds of individual county level FIA data can be wide. Therefore, estimates of individual ZCTAs were not used in this study, but ZCTAs were aggregated together into larger groupings of "bio-basins" where confidence bounds may be comparable to aggregate county groupings. Confidence bounds of the resource supply in any given bio-basin which is a grouping of ZCTAs do not offer any improvement over existing studies which aggregate county-level resource supply data. However, using the ZCTA as the demand point for biomass with the surrounding road network of the ZCTAs that make up a potential bio-basin may offer improvement of cost estimates when compared to studies which rely on estimates based on the centroid of the county. Counties can be large and have geographic barriers that impact transportation time and distance (e.g., bridges over large waterways, mountains, large metropolitan areas, etc.). ZCTAs offer improved precision of travel time and distance for road networks from biomass supply ZCTAs to a potential demand ZCTA. Validation of the trucking cost model data for BioSAT was within two percent of actual trucking costs.[5]

Land use change of ZCTAs was not considered in the current study, i.e., a ZCTA that is predominately classified as pine plantation is assumed to remain as pine plantation. All ZCTAs

[5] Pemberton Truck Lines, Inc. (Knoxville, TN); Skyline Transportation, Inc. (Knoxville, TN); Mason Dixon, Inc. (Scottsboro, AL); and one forest products company that requested anonymity.

classified as water, unproductive lands, national parks, or national forests were considered to have zero biomass available.

Resource Costs

Resources cost data (e.g., stumpage, mill residue prices, etc.) for the southeastern U.S. were obtained from Timber Mart South (TMS) and updated in the model quarterly; see http://www.tmart-south.com/tmart/ (Accessed January 12, 2009).[6] TMS mill residue price data (e.g., hardwood sawdust, pine sawdust, pine shavings, etc.) for a state were allocated equally to all ZCTAs. There are currently no estimates for logging residue stumpage available in the public domain. Logging residue stumpage was given a value of $1/dry ton in the BioSAT model.

Transportation Costs

Transportation Network

Microsoft© MapPoint® 2006 (http://www.microsoft.com/MapPoint/en-us/default.aspx Accessed January 5, 2009) was used in BioSAT to provide the shortest travel time routes and distances between ZCTAs. Road networks in MapPoint® are a combination of the Geographic Data Technology, Inc. (GDT) and Navteq data. GDT data were used for rural areas and small to medium size cities. Navteq data were used for major metropolitan areas.

The GDT data are based on "Tele Atlas Dynamap Streets" which are designed for address level geocoding (http://www.teleatlas.com/index.htm Accessed January 12 2009). When an address level geocode is not available, the GDT data set uses cascading accuracy at the ZIP+4, ZIP+2, and ZIP Code centroid to return the highest level of geocode for the address. ZIP code boundary data are based on the Dynamap/5-Digit ZIP code Boundary data from Tele Atlas North America. It is designed to identify the boundaries of United States Postal Service ZIP Codes. Navteq maps provide a highly accurate representation of the detailed road network including up to 260 attributes like turn restrictions, physical barriers and gates, one-way streets, restricted access, and relative road heights http://www.navteq.com/about/whatis.html Accessed January 12 2009).

[6]Timber Mart South (TMS) does not report price data for Oklahoma, TMS price data for Arkansas and Texas are averaged and used for Oklahoma. TMS does not report for Kentucky. Kentucky's price reporting system was used in the BioSAT model (Nevins, C.G. 2009. Kentucky's growing gold. Kentucky Division of Forestry. Frankfort, KY. Vol. XLIX, No. 2.

Trucking Costs

The transportation cost model estimated fixed and variable trucking costs based on the shortest travel time and shortest travel distance for a bio-basins road network. The analysis in this paper assumes dry-van storage trailers for trucking given that mill residues and logging residues were the biomass type being hauled.

Trucking costs of the BioSAT model were estimated using equations (1), (2), (3), and (4) between each supply $ZCTA_{(j)}$ and demand $ZCTA_{(i)}$ within a bio-basin Q_i. Trucking costs were sorted by least cost between each supply $ZCTA_{(j)}$ and demand $ZCTA_{(i)}$. Trucking variable costs were a function of travel time between ZCTAs and trucking fixed costs were a function of travel distance between ZCTAs. The least cost set of supply ZCTAs to meet a demand quantity were generally dependent on shortest travel time between a supply $ZCTA_{(j)}$ and demand $ZCTA_{(i)}$.

The trucking cost model in equations (1), (2), (3), and (4) was an adaptation of the model by Berwack and Farooq (2003). The following cost equations were assumed:

$$\text{Total Truck Cost} = \sum_{r=1}^{z} \left(\left(V_{t,s(i,j)} + V_{d,s(i,j)} + F_{d,s(i,j)} \right) \times B_{(i,j)} \right) \tag{1}$$

where, $V_{t,s(i,j)}$ = variable cost for t for s of (i,j),
$V_{d,s(i,j)}$ = variable cost for d for s of (i,j),
$F_{d,s(i,j)}$ = fixed cost for d for s of (i,j),
$B_{(i,j)} = Q_i/C_s$ = total hauls for each (i,j) for all routes r, $r = 1 \ldots z$,
C_s = legal trailer capacity for s,
Q_i = annual capacity of demand ZCTA, i ($i = 1 \ldots m$),
d = round-trip travel distance (i,j),
i = demand ZCTA, $i = 1 \ldots m$,
j = supply ZCTA, $j = 1 \ldots n$,
m = total number of biomass supply ZCTAs,
n = total number of biomass supply ZCTAs,
r = route (i, j), r = $1 \ldots z$,
s = U.S. state, $q = 1 \ldots 33$,
t = round-trip travel time (i,j).

$$V_{d,s(i,j)} = D_{d,s(i,j)} + M_{d(i,j)} + T_{d(i,j)} \tag{2}$$

where, $D_{d,s(i,j)}$ = diesel fuel cost for d for s of (i, j),
$M_{d(i,j)}$ = maintenance and repair cost for d for (i, j),
$T_{d(i,j)}$ = tire cost for d for (i, j).

$$V_{t,s(i,j)} = L_{t,s(i,j)} \tag{3}$$

where, $L_{t(i,j)}$ = labor cost for *t* for *s* of (*i,j*),

$$F_{d,s(i,j)} = E_{d(i,j)} + S_{s(i,j)} + N_{s(i,j)} + O_{d(i,j)} + I_{s(i,j)} \tag{4}$$

where, $E_{d(i,j)}$ = equipment cost for *d* for (*i,j*),
$S_{s(i,j)}$ = tax for *s* for (*i,j*),
$N_{s(i,j)}$ = license fee for *s* for (*i,j*),
$O_{d(i,j)}$ = management and overhead cost for *d* for (*i,j*),
$I_{s(i,j)}$ = insurance cost for *s* for (*i,j*).

Diesel fuel cost efficiencies; tire variable costs; tax and license fees; and management and overhead costs of the Berwack and Farooq (2003) model were modified for the BioSAT model. Modifications to the Berwack and Farooq (2003) model came after a review of the model was conducted in October 2008 with three trucking companies[7] and one wood-using company that requested anonymity. The trucking cost model was assumed to be for contract carriers. In most cases, contract carriers would be the least cost scenario for truck transportation for any potential biomass consuming facility (personal communication: see footnote 4).

Total trucking costs were a function of: variables costs which were a function of haul time; variable costs which were a function of haul distance; fixed costs which were a function of haul distance; and the quantity demanded at a ZCTA demand point. The variable cost inputs for the trucking model (e.g., diesel fuel, labor wages, etc.) were updated bi-monthly in the BioSAT model (Energy Information Administration 2009). Minimum transportation travel times and distances between ZCTAs in a bio-basin were estimated from Microsoft© MapPoint® 2006 (http://www.microsoft.com/MapPoint/en-us/default.aspx Accessed January 5, 2009).

Harvesting Costs

Logging Residues

The Subregional Timber Supply (SRTS) model was used to estimate and predict logging residues for the southeastern U.S. SRTS uses U.S. Forest Service FIA data to project timber supply

[7] Pemberton Truck Lines, Inc. (Knoxville, TN); Skyline Transportation, Inc. (Knoxville, TN); and Mason Dixon, Inc. (Scottsboro, AL).

trends based on current conditions and the economic responses in timber markets (Abt et al. 2000). Abt et al. (2000) note that SRTS is a partial equilibrium market simulation model that can be used to analyze various forest resource and timber supply situations. It uses a biological inventory projection model and a conventional supply/demand framework to project future timber prices and inventories given exogenous assumptions about land area and demand.

SRTS was developed initially to provide an economic overlay to traditional timber inventory models, e.g., ATLAS (Mill and Kincaid 1992), and to develop a consistent methodology for disaggregating the impacts of national and global models, e.g., TAMM (Adams and Haynes 1996), that treated the South as a homogenous supply region (Abt et al. 2000). Timber market and inventory modules are the two major SRTS model components. Market parameters are first used to solve for equilibrium price changes, where the market is defined by all of the included subregions. Price and supply shift information from the individual regions are used to calculate harvest change by subregion.

The internal inventory module in SRTS is based on the GRITS model (Cubbage et al. 1990). GRITS extrapolated forest inventories based on USDA Forest Service FIA estimates of timberland area, timber inventory, timber growth rates, and timber removals. GRITS classifies data into 10-year age class groups by broad species group (softwoods and hardwoods) and forest management type (planted pine, natural pine, oak-pine, upland hardwood, and lowland hardwood). FIA data by species group, forest management type, and 10-year age class are summarized for each relevant region in the analysis. Land area trends by forest management type are exogenous to the model. Within a management type, the model can allocate harvest across age classes based on starting harvest proportions, current inventory proportions, or oldest age class first (Abt et al. 2000).

Logging Residue Costs

The Fuel Reduction Cost Simulator (FRCS) as modified for the Billion Ton Study (Perlack et al. 2005) by Dykrsta (2008) was used to estimate the costs of harvesting logging residues (Fight et al. 2006; Stokes 1992). The original FRCS model was designed to simulate fuel-reduction treatments in the Interior West, where wildfire is a significant problem (Dykstra 2008). The FRCS was substantially revised by Dykstra (2008) including the development of new procedures to simulate harvests in the North (North Central and Northeast), the South, and the coastal West as well as the

Interior West. Logging residue costs are estimated for "chipping tops and limbs at the landing" and "in woods harvesting of sub-merchantable material."

In the modified FRCS model the following harvesting operations are assumed for biomass collection (Dykstra 2008):

- Manual felling and whole-tree extraction, either with conventional skidders or with cable systems; the simulator uses cable systems if the average ground slope is 40% or more;
- Mechanized felling and whole-tree skidding where mechanized felling is not used with cable yarding.

For ground-based logging (defined as "in woods" logging residue in this report), the FRCS model calculated the production rates and costs for both of the possible alternatives (manual felling and mechanized felling). The model then selected the lower-cost alternative for use in deriving the supply curve for the Billion Ton Study which is the same approach that is used in the BioSAT model. The variable cost inputs for the FRCS model (e.g., diesel fuel, labor wages, etc.) are updated bi-monthly in the BioSAT model. Forest resource input data were obtained from the logging residue estimates of the SRTS model (Abt et al. 2000).

Results and Discussion

Mill Residues

Categories in the BioSAT model for mill residues were "clean softwood," "clean hardwood," "unclean softwood," "unclean hardwood," and totals of any combination or all of these categories (e.g., "total residues," "total softwood residues," and "total hardwood residues"). The maximum quantity available in a bio-basin and the associated total cost (TC), average total cost (ATC), and marginal cost (MC) in $/dry ton were estimated for each of the residue categories assuming a maximum 160-mile one-way haul distance.

Total Mill Residues. -- The top ten ZCTA locations in the southeast for bioenergy and biofuels plants based on minimum ATC that would use all types of "mill residues" (softwood and hardwood, clean and unclean), assuming a maximum 160-mile one-way haul distance by truck, were located in southwest AL, southeast GA, south-central MS, northwest LA, west central AL, southeast LA, and north central GA (see bio-basins in Figure 2). Average total costs (ATC) varied from $21.12/dry ton to $49.77/dry ton; the median of the marginal costs varied from $33.20/dry ton to $36.94/dry ton (Table 2).

Table 2. Top ten locations for mill residues based on average total cost (160-mile one-way haul).

Rank	ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	36458	Monroe	AL	Mexia	2,322,544	$49,052,142	$21.12	$35.21
2	31515	Appling	GA	Baxley	1,956,798	$47,653,959	$28.92	$35.17
3	39657	Pike	MS	Osyka	1,531,040	$49,218,980	$32.15	$34.26
4	39667	Walthall	MS	Tylertown	1,502,236	$50,393,797	$33.55	$35.84
5	71034	Red River	LA	Hall Summit	1,478,630	$49,773,819	$33.66	$35.72
6	36783	Marengo	AL	Thomaston	1,482,160	$50,048,716	$33.77	$33.20
7	70444	Tangipahoa	LA	Kentwood	1,340,099	$50,142,997	$37.42	$34.24
8	30459	Bulloch	GA	Statesboro	1,017,213	$50,181,372	$49.33	$35.38
9	31085	Jasper	GA	Shady Dale	1,003,819	$49,703,080	$49.51	$36.62
10	30056	Jasper	GA	Newborn	1,004,763	$50,007,194	$49.77	$36.94

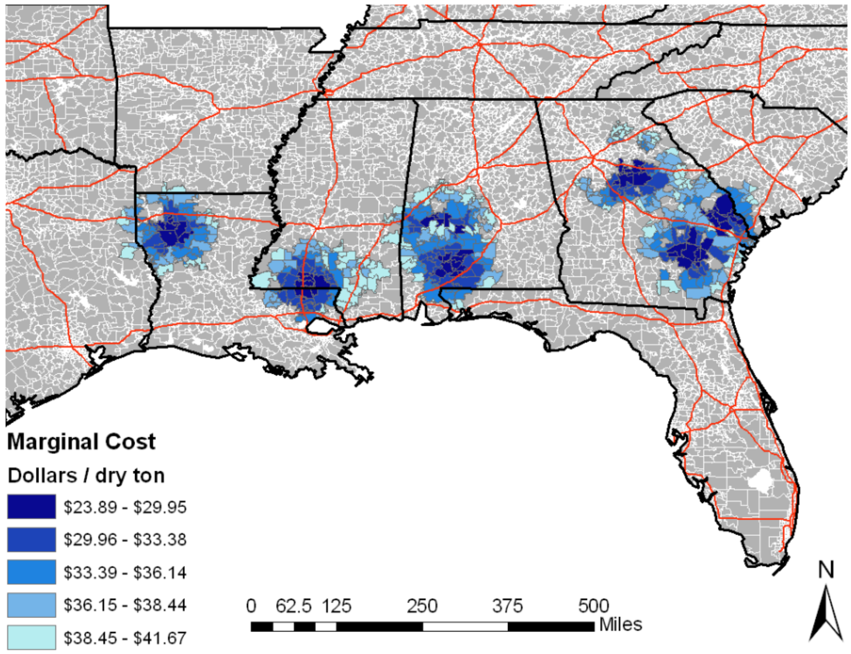


Figure 2. Locations of overlapping bio-basins for top ten ZCTA sites for total mill residues.

The marginal cost curves (i.e., producers' supply curves) for each demand ZCTA illustrate the differences in costs for potential bioenergy/biofuels producers at different levels of consumption (Figure 3). ZCTA 36458 (Mexia, AL, Monroe County) has the lowest average total cost and has a MC curve less steep relative to other ZCTAs in the region (Figure 4). A one-way

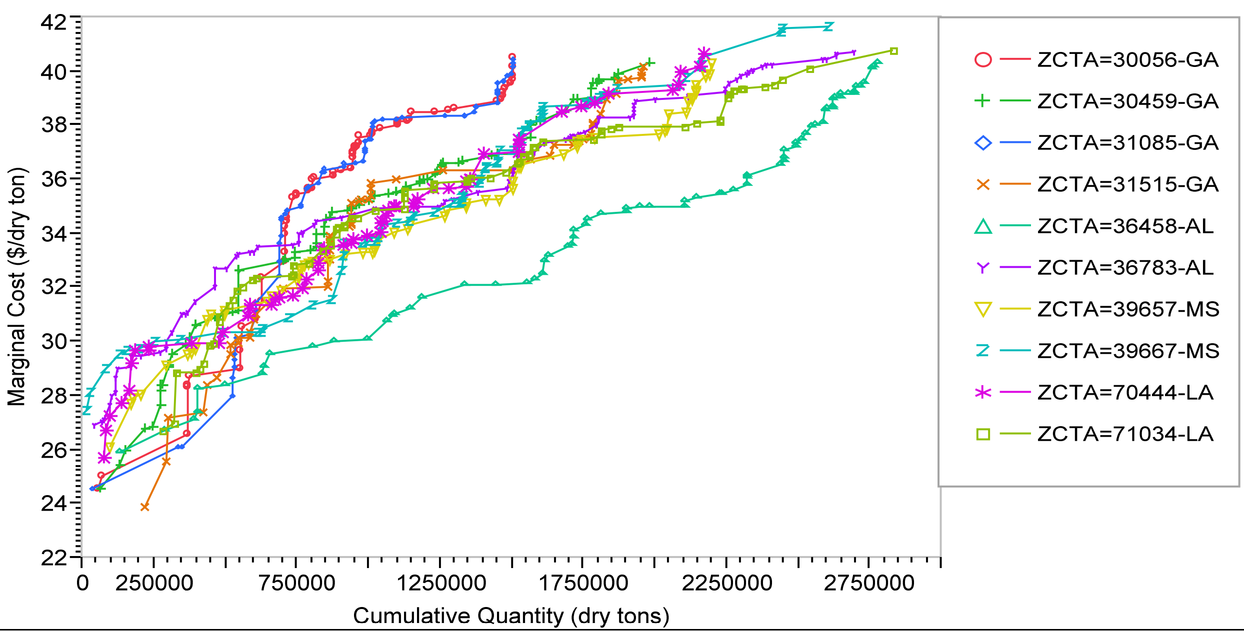


Figure 3. MC curves for top ten sites by ZCTA for total mill residues.

analysis of variance (ANOVA) of marginal costs indicated significant differences ($\alpha = 0.05$) in the average marginal cost (Figure 5). Bio-basins maps for the top ten sites are given in Appendix A.

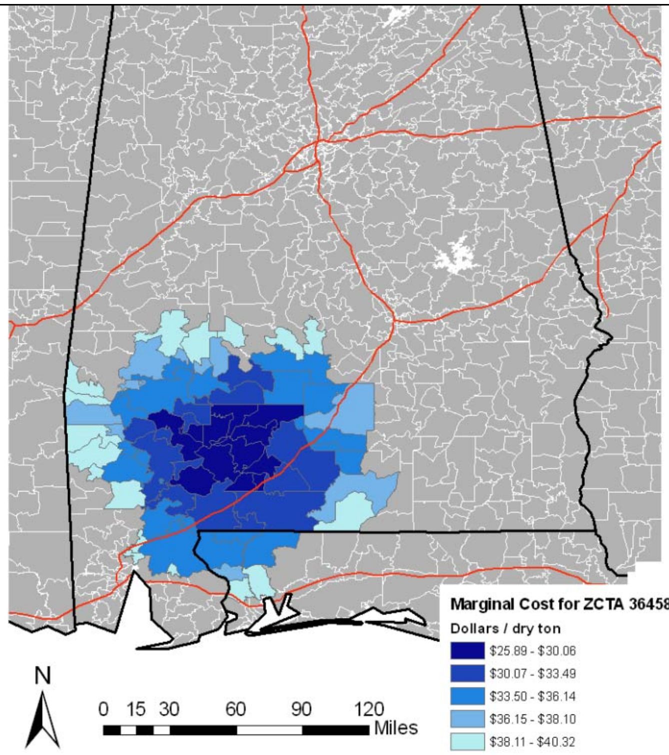
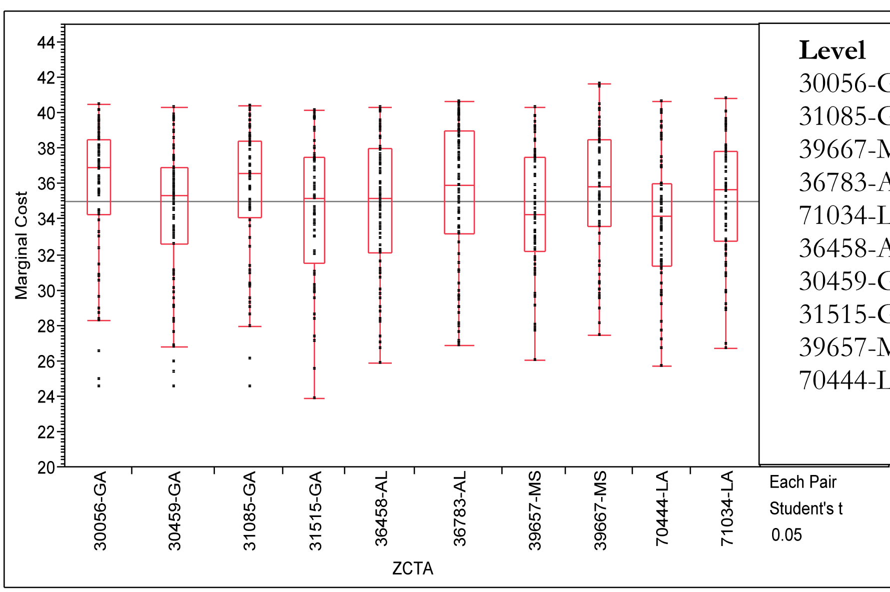


Figure 4. Bio-basin for ZCTA 36458 (Mexia, AL, Monroe County).



Level			Mean
30056-GA	A		35.724225
31085-GA	A		35.690278
39667-MS	A		35.538310
36783-AL	A		35.504731
71034-LA	A		35.162838
36458-AL	A	B	34.750137
30459-GA	A	B	34.594023
31515-GA	A	B	34.523692
39657-MS	A	B	34.484091
70444-LA		B	33.876833

Levels not connected by same letter are significantly different ($\alpha = 0.05$)

Figure 5. Oneway analysis of marginal costs for top ten ZCTAs for total mill residues.

A 90% confidence bound on total mill residue marginal costs for the least cost bio-basin location (ZCTA 36458 Mexia, AL, Monroe County) vary by approximately $6.27 per dry ton (Figure 6). The confidence bounds were developed using the Bonferroni method (Hardle 1990; Young 2010).[8]

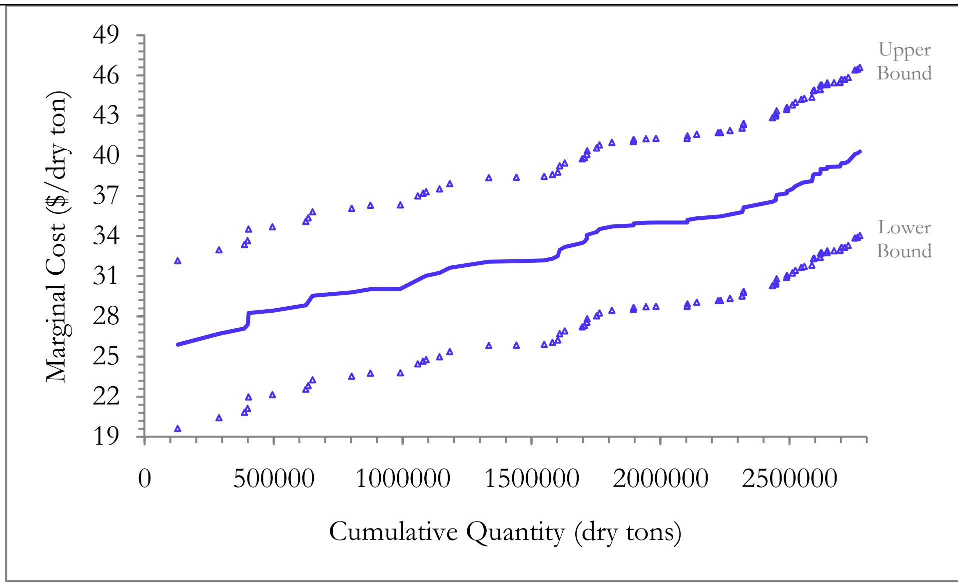


Figure 6. 90% confidence bound for the marginal costs for total mill residues for bio-basin for ZCTA 36458 (Mexia, AL, Monroe County).

To contrast to the least cost bio-basins for total mill residues, the ten highest cost bio-basins are illustrated by ZCTA in Figure 7. The bio-basins are located predominately in Western North Carolina and North-Central Arkansas. The disparity in road networks in these bio-basins relative to the least cost bio-basins led to steeper marginal cost curves.

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[8] Bonferroni method is $\bar{Y} \pm z_{(1-\alpha)/(2n)} \bullet s_i (1+\frac{1}{k})^{1/2}$ for i = 1, 2, ….., *n*, where $\bar{Y}$ is the average of *k* observed marginal costs for the biobasin, $z_{(1-\alpha)/(2n)}$ is the 1 – a percentile of a standard normal distribution, s_i is the standard deviation for i = 1, 2, ….*n*.

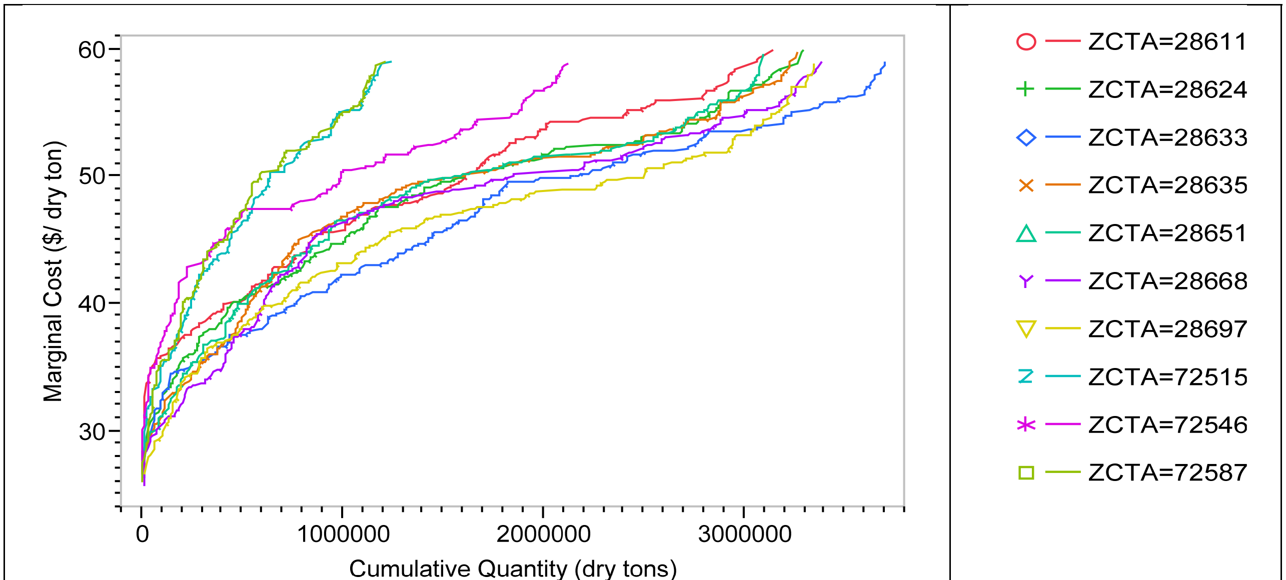

Figure 7. MC curves for highest cost ZCTAs for total mill residues.

Softwood Mill Residues. -- The top ten ZCTA locations in the southeast for total "softwood" mill residues (clean and unclean), assuming a maximum 160-mile one-way haul distance, were located in south-central and southeast GA, and southern MS (Table 3). Average total costs (ATC) varied from $27.51/dry ton to $35.91/dry ton; the median of the marginal costs varied from $43.03/dry ton to $45.15/dry ton where MC curves rose steeply (Table 3, Figure 8). The model did not discriminate between the top nine rankings for this biomass type. ZCTA 39043, Brandon MS (#1 rank) was statistically different (α = 0.05) from ZCTA 39662, Ruth MS (#10 rank). The 90% confidence bound on MC for the bio-basin supporting demand ZCTA 39043 was ± $6.59/dry ton.

Table 3. Top ten locations for total softwood mill residues based on average total cost.

Rank	ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	39043	Rankin	MS	Brandon	2,214,806	$60,925,630	$27.51	$44.92
2	31049	Emanuel	GA	Kite	1,963,635	$59,888,164	$30.50	$45.06
3	30401	Emanuel	GA	Swainsboro	1,913,135	$59,858,080	$31.29	$43.22
4	31002	Emanuel	GA	Adrian	1,884,047	$58,966,001	$31.30	$44.01
5	30811	Burke	GA	Gough	1,887,877	$60,075,036	$31.82	$45.15
6	39654	Lawrence	MS	Monticello	1,862,971	$60,537,982	$32.50	$44.01
7	30410	Montgomery	GA	Ailey	1,855,894	$60,832,347	$32.78	$44.34
8	30474	Toombs	GA	Vidalia	1,790,243	$60,095,817	$33.57	$44.02
9	30475	Toombs	GA	Vidalia	1,792,820	$61,091,709	$34.08	$43.79
10	39662	Lincoln	MS	Ruth	1,701,886	$61,112,221	$35.91	$43.03

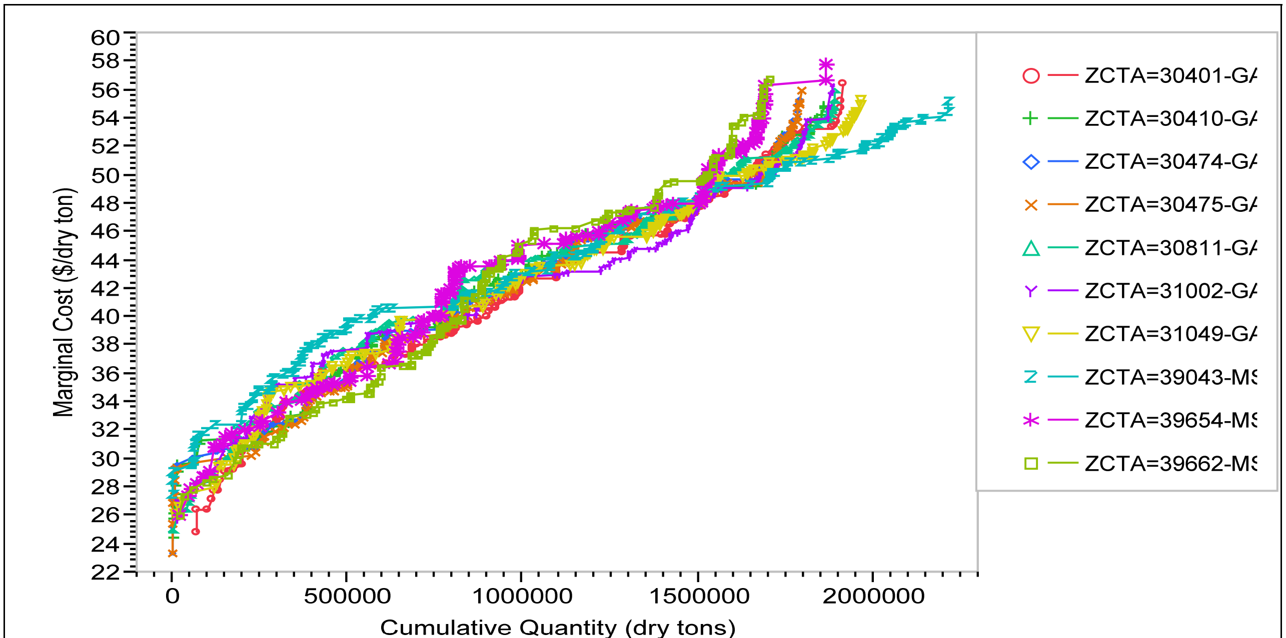

Figure 8. MC curves for top ten sites by ZCTA for total "softwood" mill residues.

<u>Clean Softwood Mill Residues</u>. -- The top ten ZCTA locations in the southeast for "clean softwood" mill residues, assuming a maximum 160-mile one-way haul distance, were all located in west-central GA (Table 4). Average total costs (ATC) varied from $39.88/dry ton to $42.47/dry ton. Median marginal costs varied from $40.98/dry ton to $43.45/dry ton. The model did not discriminate statistically between the top ten rankings for this biomass type based on ATC. ZCTAs 31599 and 31545 (both Jesup, GA) were in close proximity to each other and have preferable marginal cost curves relative to other ZCTAs up to 350,000 dry tons per year (Figure 9).

Table 4. Top ten locations for total "clean" softwood mill residues based on average total cost.

Rank	ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	31599	Wayne	GA	Jesup	501,088	$19,983,476	$39.88	$43.19
2	31545	Wayne	GA	Jesup	502,806	$20,131,082	$40.04	$43.45
3	30204	Lamar	GA	Barnesville	501,165	$20,313,902	$40.53	$40.98
4	30461	Bulloch	GA	Statesboro	515,279	$21,160,252	$41.07	$42.86
5	31816	Meriwether	GA	Manchester	502,621	$20,956,550	$41.69	$41.39
6	31046	Monroe	GA	Juliette	506,373	$21,166,812	$41.80	$42.49
7	31097	Upson	GA	Yatesville	509,651	$21,306,511	$41.81	$41.04
8	31807	Harris	GA	Ellerslie	502,379	$21,029,119	$41.86	$41.53
9	31812	Talbot	GA	Junction City	506,809	$21,290,431	$42.01	$41.37
10	31804	Harris	GA	Cataula	500,972	$21,274,235	$42.47	$41.80

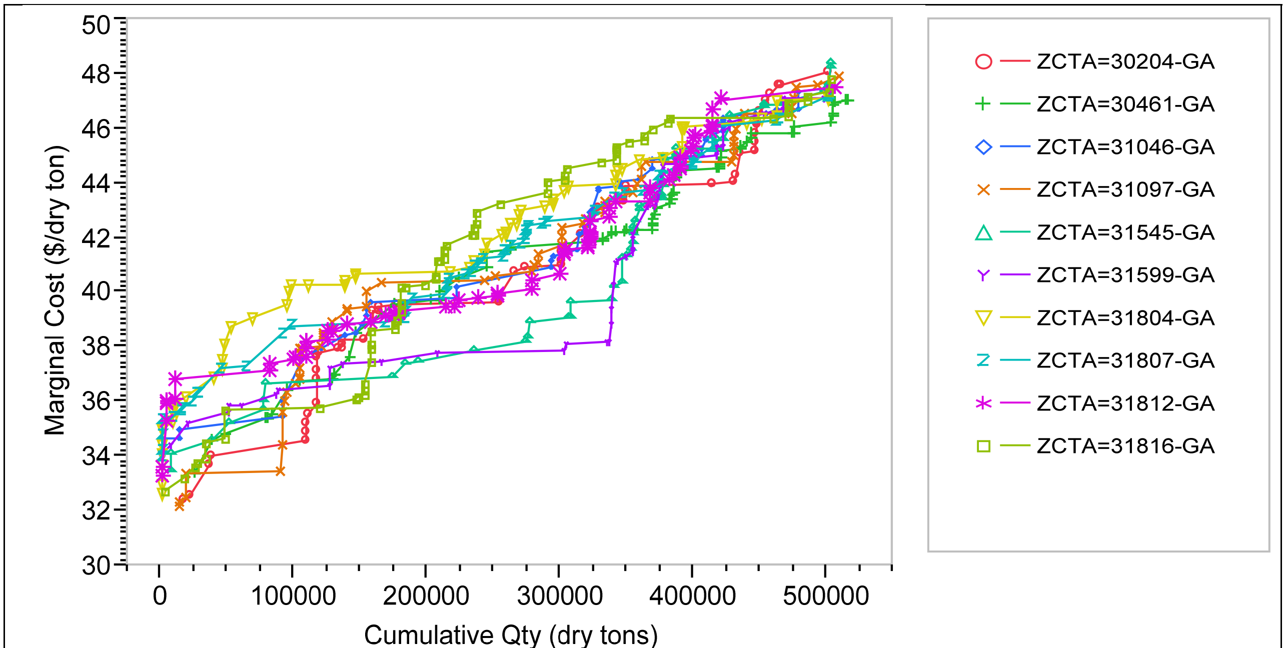

Figure 9. MC curves for top ten sites by ZCTA for total "clean" softwood mill residues.

Unclean Softwood Mill Residues. -- The top ten ZCTA locations in the southeast for total "unclean softwood" mill residues (e.g., bark), assuming a maximum 160-mile one-way haul distance, were all located in southeast OK (Table 5). ATC varied from $12.09/dry ton to $16.65/dry ton. Median marginal costs were relatively steep and varied from $25.85/dry ton to $29.25/dry ton. The least cost ZCTA 74754, was statistically different (α = 0.05) from ZCTAs 74761, 74728, and 74766. ZCTA 74728 (Battiest, OK, McCurtain County) has the least cost MC curve relative to other ZCTAs up to 700,000 dry tons per year (Figure 10).

Table 5. Top ten locations for total "unclean" softwood mill residues based on average total cost.

Rank	ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	74754	McCurtain	OK	Ringold	525,018	$6,783,270	$12.09	$27.32
2	74722	McCurtain	OK	Battiest	545,906	$6,344,047	$12.23	$25.85
3	74752	McCurtain	OK	Pickens	531,771	$6,531,640	$12.58	$26.22
4	74735	Choctaw	OK	Fort Towson	525,080	$7,563,554	$13.45	$26.50
5	74724	McCurtain	OK	Bethel	598,272	$7,016,809	$13.58	$26.25
6	74764	McCurtain	OK	Valliant	613,895	$7,967,295	$14.58	$26.40
7	74549	Le Flore	OK	Kiamichi	510,716	$7,799,143	$14.86	$29.25
8	74761	Choctaw	OK	Swink	525,080	$8,213,085	$14.98	$27.72
9	74728	McCurtain	OK	Broken Bow	740,757	$8,693,166	$15.59	$26.04
10	74766	McCurtain	OK	Wright City	667,299	$8,567,884	$16.65	$27.29

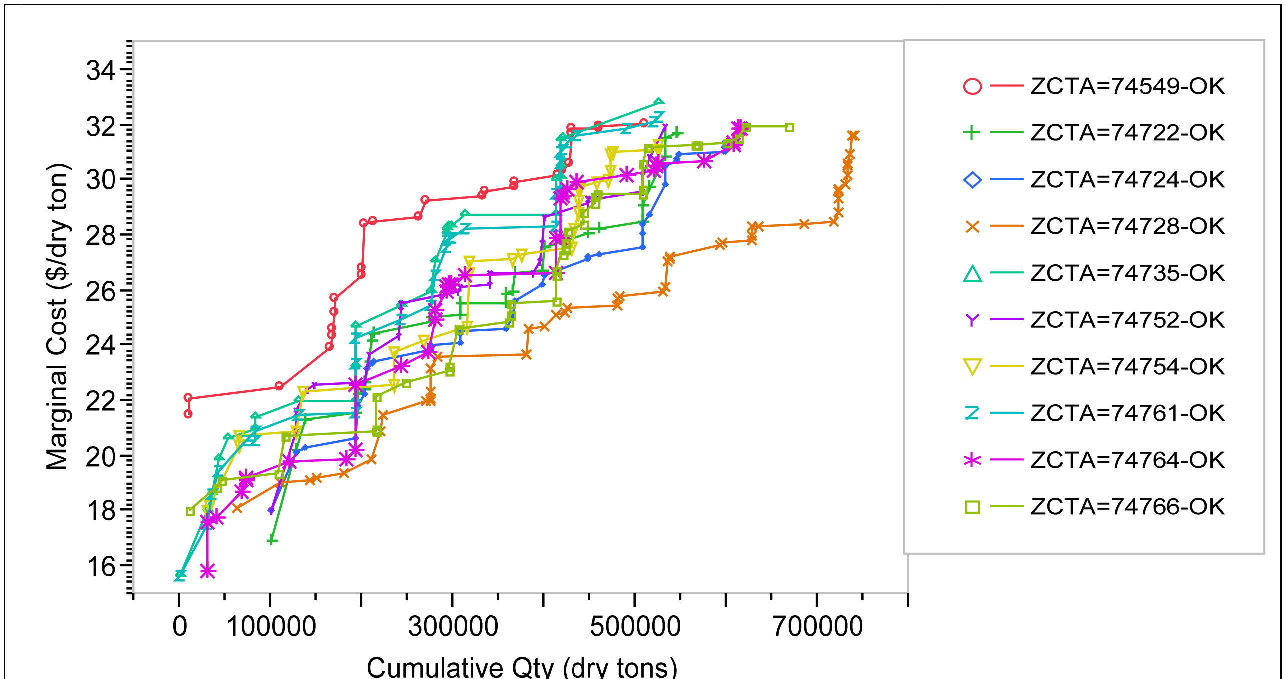

Figure 10. MC curves for top ten sites by ZCTA for total "unclean" softwood mill residues.

Hardwood Mill Residues. -- The top ten ZCTA locations in the southeast for bioenergy and biofuels plants that would use "hardwood" mill residues (clean and unclean), assuming a maximum 160-mile one-way haul distance, were located in southeast GA, southeast TX, southern AR, and west-central LA. ATC varied from $28.87/dry ton to $30.44/dry ton. Median MC varied from $29.18/dry ton to $37.30/dry ton (Table 6, Figure 11). The model did not discriminate statistically (α = 0.05) between the top three rankings for this biomass type based on ATC.

Table 6. Top ten locations for total hardwood mill residues based on average total cost.

Rank	ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	71631	Bradley	AR	Tinsman	1,372,760	$39,631,581	$28.87	$35.04
2	77334	Walker	TX	Dodge	1,763,224	$50,992,438	$28.92	$37.25
3	31556	Pierce	GA	Offerman	1,067,309	$31,122,730	$29.16	$35.44
4	71419	Sabine	LA	Converse	1,781,246	$52,885,194	$29.69	$36.72
5	77070	Harris	TX	Houston	1,283,493	$38,376,441	$29.90	$30.04
6	71652	Cleveland	AR	Kingsland	1,697,454	$50,889,671	$29.98	$35.48
7	31560	Wayne	GA	Screven	1,105,680	$33,303,082	$30.12	$37.30
8	77382	Montgomery	TX	Woodlands	1,418,296	$42,875,088	$30.23	$33.14
9	77066	Harris	TX	Houston	1,401,838	$42,573,820	$30.37	$29.62
10	77088	Harris	TX	Houston	1,326,466	$40,377,625	$30.44	$29.18

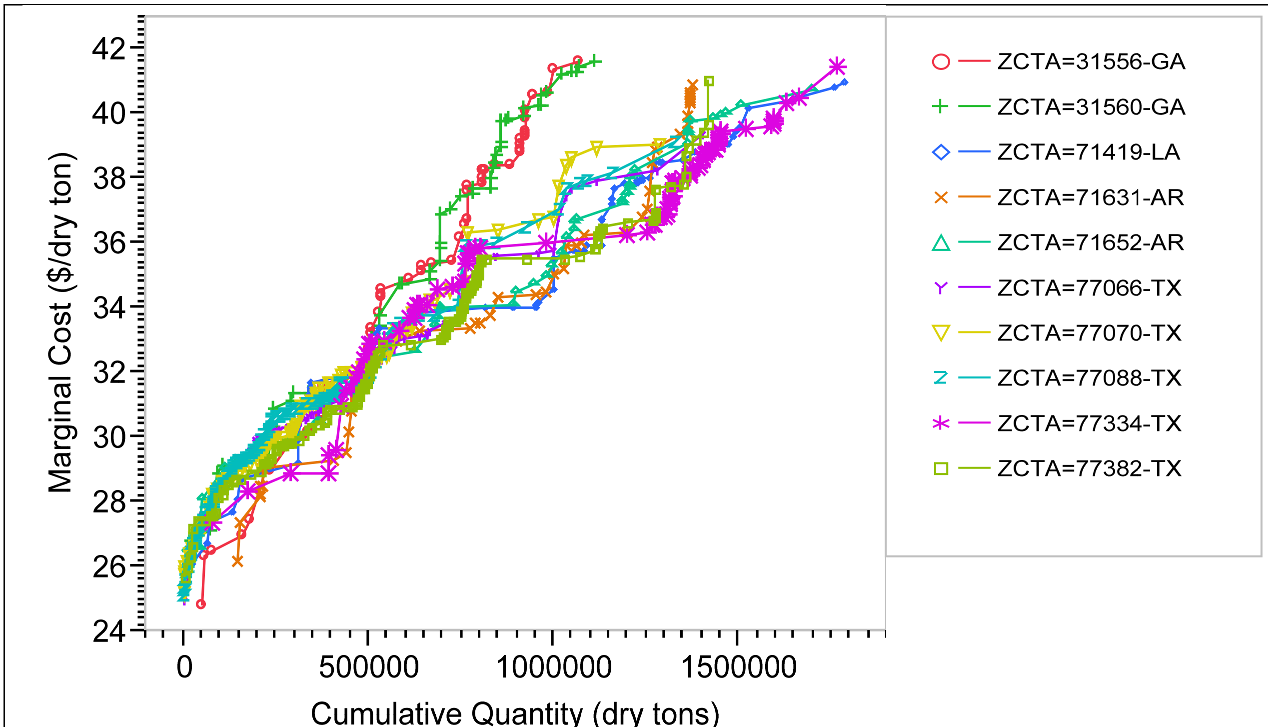

Figure 11. MC curves for top ten sites by ZCTA for total hardwood mill residues.

Clean Hardwood Mill Residues. -- The top ten ZCTA locations in the southeast for bioenergy and biofuels plants that would use "clean hardwood" mill residues, assuming a maximum 160-mile one-way haul distance by truck, were located in southern and central VA. ATC varied from $46.30/dry ton to $47.65/dry ton. Median MC varied from $42.25/dry ton to $43.79/dry ton (Table 7). The model did not discriminate statistically (α = 0.05) between the top seven rankings for this biomass type based on ATC. MC curves had distinct crossings but had differences below 150,000 dry tons per year. ZCTAs 22943 and 22964 had least cost MC curves relative to other ZCTAs above 150,000 dry tons per year (Figure 12).

Table 7. Top ten locations for total "clean" hardwood mill residues based on average total cost.

Rank	ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	23842	Pr. George	VA	Disputanta	279,092	$12,921,960	$46.30	$43.23
2	24020	Roanoke	VA	Hollins	309,107	$14,336,383	$46.38	$43.12
3	22943	Albemarle	VA	Greenwood	293,243	$13,682,718	$46.66	$42.25
4	23075	Henrico	VA	Highland Spg	263,891	$12,331,626	$46.73	$43.04
5	22964	Nelson	VA	Piney River	332,868	$15,668,097	$47.07	$42.71
6	23223	Richmond	VA	Richmond	278,353	$13,121,560	$47.14	$42.94
7	23875	Pr. George	VA	Prince George	265,107	$12,531,608	$47.27	$43.79
8	23222	Richmond	VA	Richmond	296,238	$14,003,170	$47.27	$42.33
9	24090	Botetourt	VA	Fincastle	252,934	$11,971,366	$47.33	$43.30
10	24421	Augusta	VA	Churchville	243,092	$11,583,334	$47.65	$42.48

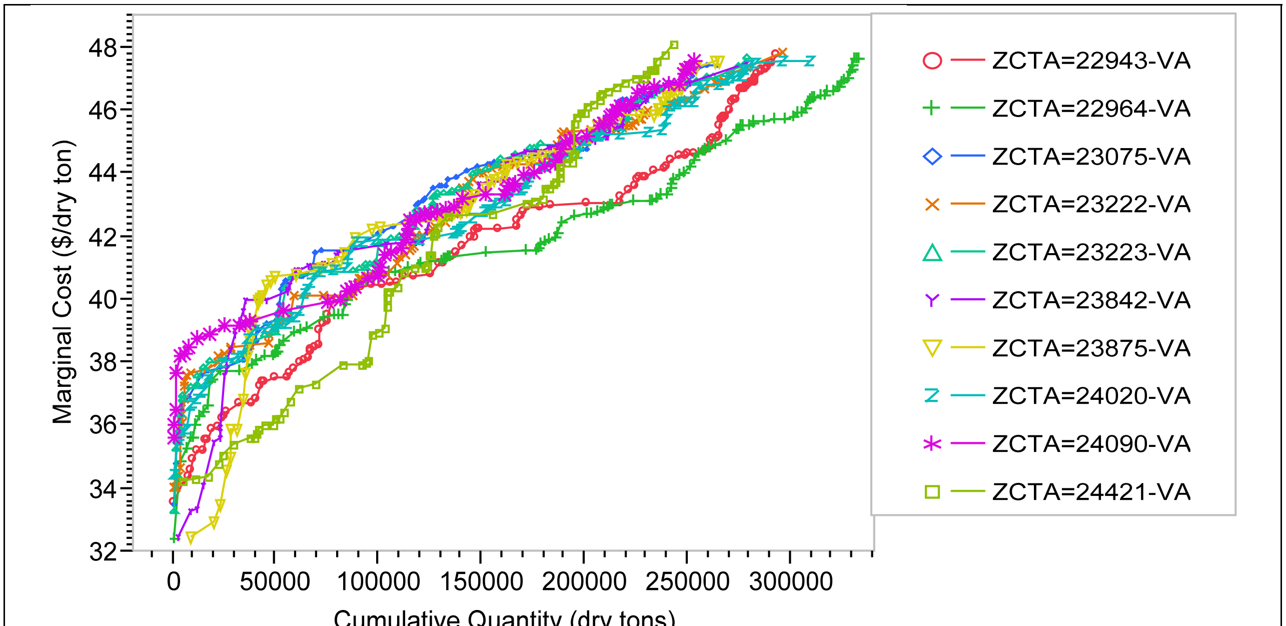

Figure 12. MC curves for top ten sites by ZCTA for total "clean" hardwood mill residues.

Unclean Hardwood Mill Residues. -- The top ten ZCTA locations for "unclean hardwood" mill residues, assuming a maximum 160-mile one-way haul distance by truck, were located in southeast central TX, southwest AL, south-central KY, and west LA. ATC varied from $24.78/dry ton to $27.03/dry ton. Median MC varied from $26.08/dry ton to $28.33/dry ton (Table 8). The model did not discriminate statistically ($\alpha = 0.05$) between the top ten rankings for this biomass type based on ATC. ZCTA 75766 (Jacksonville, TX, Cherokee County) had the least cost MC curve relative to other ZCTAs up to 150,000 dry tons per year (Figure 13).

Table 8. Top ten locations for total "unclean" hardwood mill residues based on average total cost.

Rank	ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	75766	Cherokee	TX	Jacksonville	527,336	$13,070,018	$24.78	$26.91
5	36726	Wilcox	AL	Camden	518,358	$13,468,075	$25.98	$27.79
7	75702	Smith	TX	Tyler	518,964	$13,535,270	$26.08	$26.66
4	75712	Smith	TX	Tyler	512,344	$13,410,519	$26.17	$26.08
2	36736	Marengo	AL	Dixons Mills	504,486	$13,322,423	$26.41	$26.51
6	42759	Cumberland	KY	Marrowbone	508,941	$13,501,494	$26.53	$28.33
3	36728	Wilcox	AL	Prairie	504,302	$13,397,040	$26.57	$27.54
9	75757	Cherokee	TX	Mt. Selman	509,348	$13,604,610	$26.71	$27.60
8	36702	Dallas	AL	Selma	503,080	$13,541,060	$26.92	$26.45
10	71049	De Soto	LA	Logansport	503,985	$13,621,955	$27.03	$28.01

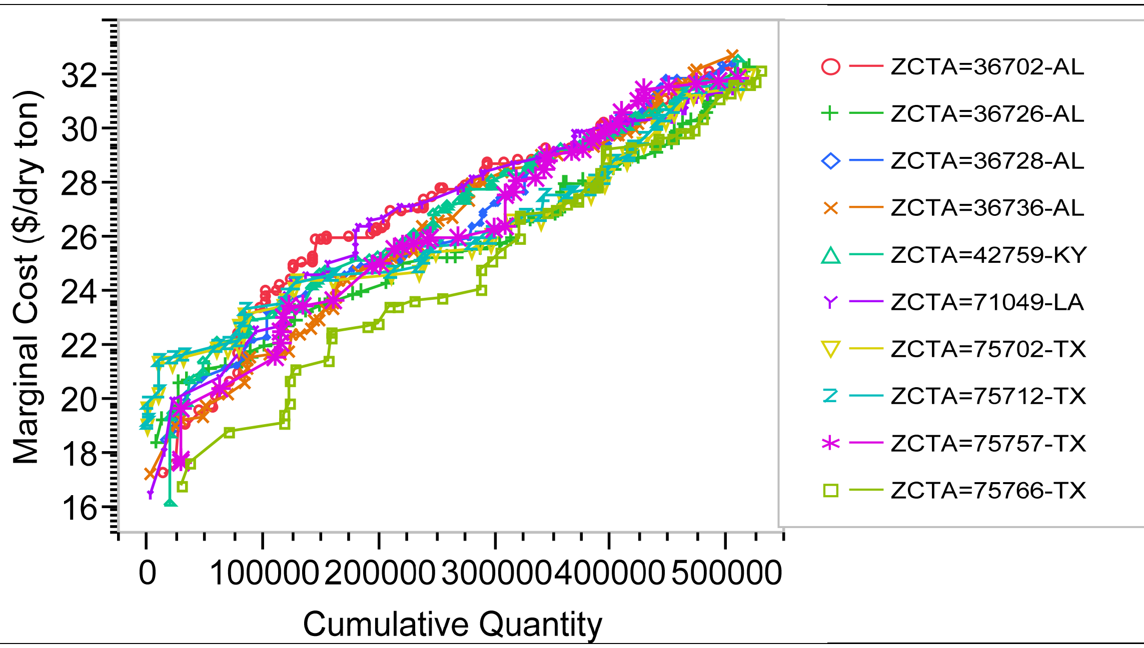

Figure 13. MC curves for top ten sites by ZCTA for total "unclean" hardwood mill residues.

GIS maps of marginal costs for mill residues by ZCTA are illustrated in Appendix B. "Kriged" GIS maps of marginal costs for mill residues by ZCTA are illustrated in Appendix C.

Logging Residues

Categories in the BioSAT model for logging residues were "softwood – at landing," "hardwood – at landing," "softwood – in woods," "hardwood – in woods," and combinations of these categories. The maximum quantity available in a bio-basin and the associated total cost (TC), average total cost (ATC), and marginal cost (MC) in $/dry ton were estimated for each of the residue categories assuming a maximum 160-mile one-way haul distance.

<u>**Total Logging Residues "At Landing."**</u> -- The top ten ZCTA locations in the Southeast for bioenergy and biofuels plants that would use all types (softwood and hardwood) of "logging residues" harvested by chipping top and limbs "at the landing" of a traditional merchantable harvest (assuming a maximum 160-mile one-way haul distance) were located in central NC, northeast GA, and central TN (Table 9). ATC varied from $26.93/dry ton to $27.59/dry ton. Median MC varied from $27.21/dry ton to $29.18/dry ton (Table 9). The model did not discriminate statistically (α = 0.05) between the top five rankings for this biomass type based on ATC. There was no comparable advantage for the MC curves for the top ten sites (Figure 14). See GIS maps in Appendices D and E.

Table 9. Top ten locations for total logging residues "at landing" based on average total cost.

Rank	ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	27412	Guilford	NC	Greensboro	502,198	$13,599,152	$26.93	$27.99
2	38501	Putnam	TN	Cookeville	511,366	$13,719,978	$26.94	$27.21
3	27403	Guilford	NC	Greensboro	502,663	$13,656,959	$26.99	$28.02
4	30604	Clarke	GA	Athens	501,664	$13,734,656	$27.27	$28.33
5	30602	Clarke	GA	Athens	501,809	$13,780,111	$27.34	$28.92
6	27498	Guilford	NC	Greensboro	506,446	$13,716,390	$27.41	$27.66
7	27419	Guilford	NC	Greensboro	500,535	$13,755,368	$27.45	$27.95
8	30606	Clarke	GA	Athens	500,382	$13,782,215	$27.52	$28.41
9	37134	Humphreys	TN	New Johnsonville	500,063	$13,774,854	$27.54	$29.18
10	29471	Dorchester	SC	Reevesville	507,943	$13,800,431	$27.59	$28.65

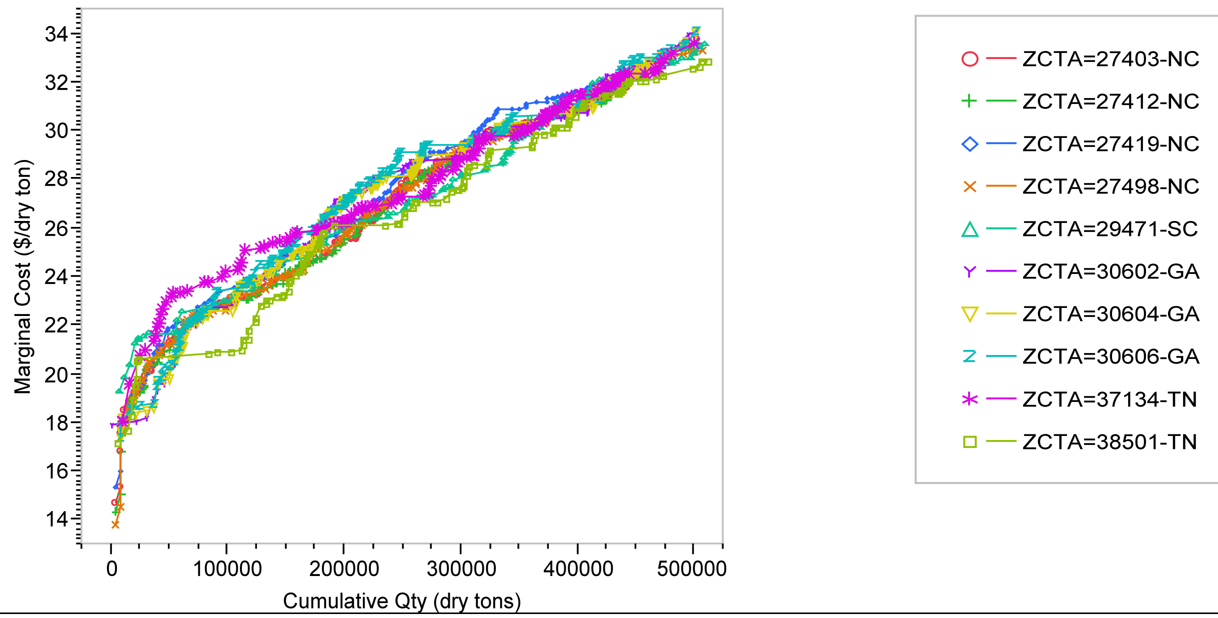

Figure 14. MC curves for top ten sites by ZCTA for total logging residues "at landing."

A "kriged" map of softwood and hardwood logging residues revealed comparative marginal cost advantage across the study areas for this type of biomass (Figure 15).

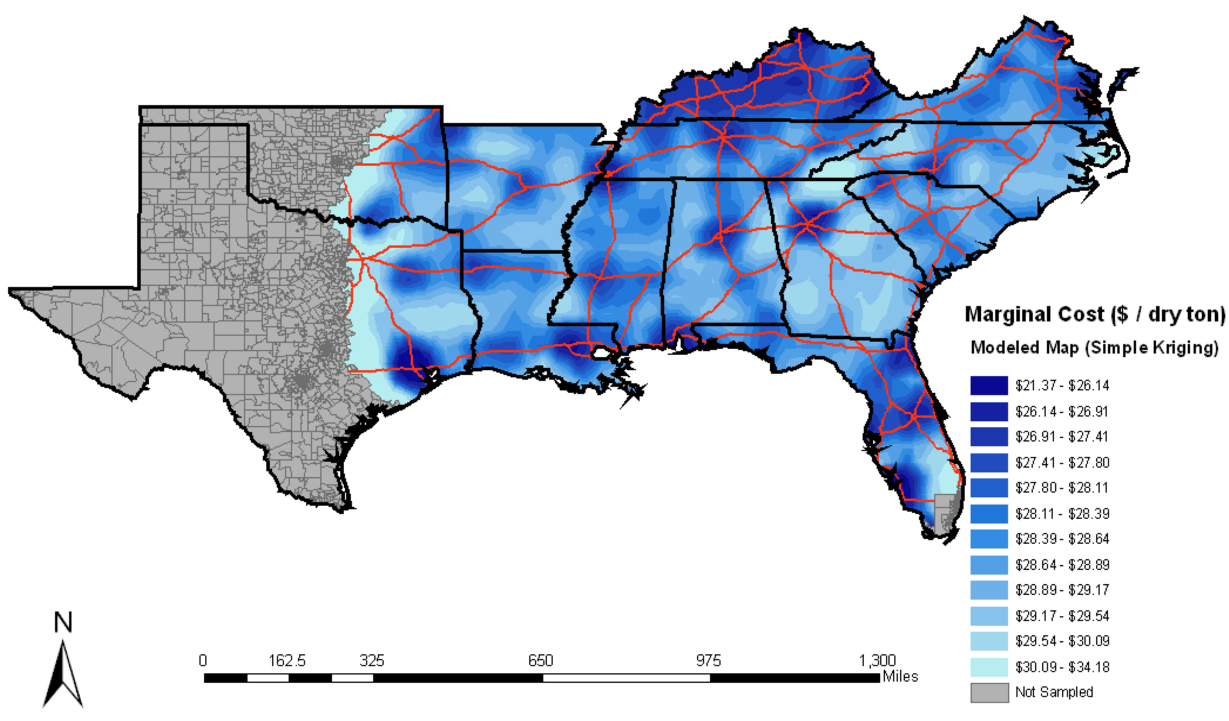

Figure 15. Kriged map of logging resides "at landing" for softwoods and hardwoods.

Logging Softwood Residues "At Landing." -- The top ten ZCTA locations in the southeast for bioenergy and biofuels plants that would use "softwood logging residues" harvested by chipping top and limbs "at the landing" of a merchantable harvest (assuming a maximum 160-mile one-way haul distance) were located in southeast MS, northern LA, southern AR, and central SC (Table 10). ATC varied from $27.34/dry ton to $28.68/dry ton. Median MC varied from $28.03/dry ton to $32.87/dry ton (Table 10). The model did not discriminate statistically (α = 0.05) between the top ten rankings for this biomass type based on ATC and the MC curves (Figure 16).

Table 10. Top ten locations for softwood logging residues "at landing" based on average total cost.

Rank	ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	39441	Jones	MS	Laurel	505,931	$14,030,506	$27.34	$28.34
2	39442	Jones	MS	Laurel	505,931	$14,030,506	$27.34	$28.34
3	71080	Bienville	LA	Taylor	506,585	$14,132,892	$27.47	$27.24
4	71003	Claiborne	LA	Athens	507,213	$14,175,060	$27.63	$28.23
5	71021	Webster	LA	Cullen	507,055	$14,125,730	$27.68	$32.87
6	71260	Union	LA	Marion	503,969	$14,276,848	$28.07	$28.40
7	71857	Nevada	AR	Prescott	517,926	$14,337,294	$28.38	$28.03
8	29002	Richland	SC	Ballentine	507,045	$14,265,453	$28.39	$28.96
9	29203	Richland	SC	Columbia	509,918	$14,296,599	$28.50	$28.75
10	29205	Richland	SC	Columbia	514,517	$14,404,652	$28.68	$28.16

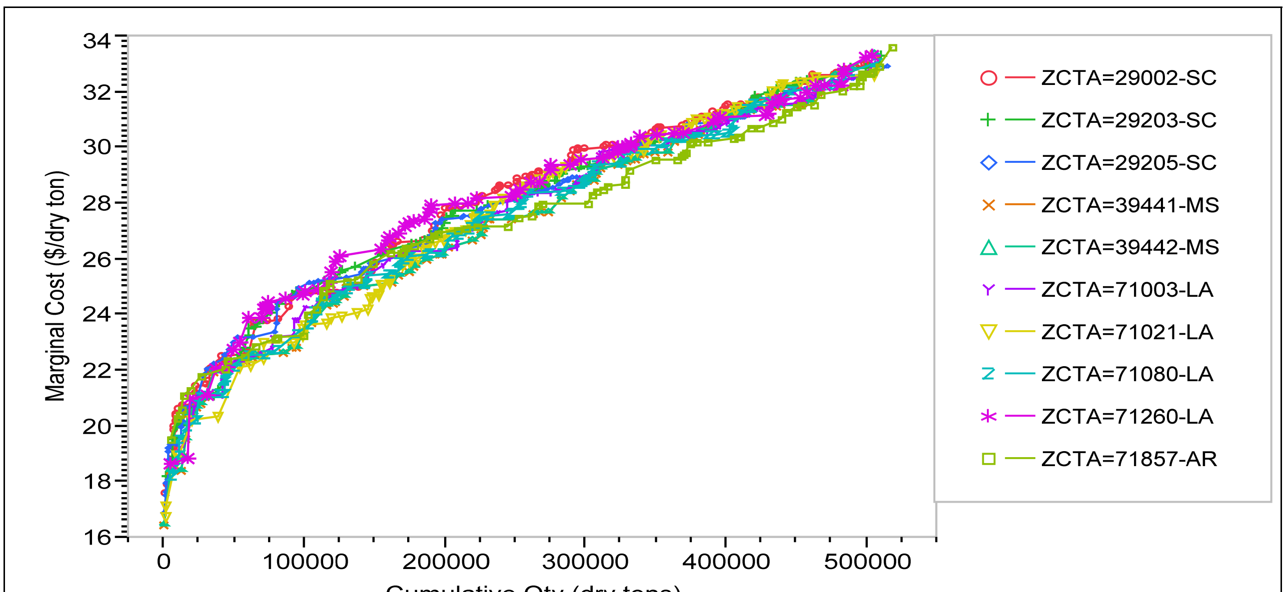

Figure 16. MC curves for top ten sites by ZCTA for softwood logging residues "at landing."

Logging Hardwood Residues "At Landing." -- The top ten ZCTA locations for hardwood logging residues "at landing" (assuming a maximum 160-mile one-way haul distance) were located in northeast NC, southeast VA, and east-central MS (Table 11). ATC varied from $26.24/dry ton to $27.64/dry ton. Median MC varied from $26.91/dry ton to $29.67/dry ton (Table 11). The model did not discriminate statistically between the ATC of top three rankings ($\alpha = 0.05$). ZCTAs 27969 and 27986 had cost advantages for MC for harvest levels below 150,000 dry tons/year (Figure 17).

Table 11. Top ten locations for hardwood logging residues "at landing" based on average total cost.

Rank	ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	27967	Hertford	NC	Powellsville	508,999	$13,330,071	$26.24	$28.95
2	27969	Gates	NC	Roduco	524,253	$13,433,807	$26.65	$27.57
3	27910	Hertford	NC	Ahoskie	522,784	$13,510,197	$26.68	$28.40
4	27855	Hertford	NC	Murfreesboro	525,457	$13,568,593	$27.06	$28.23
5	27924	Bertie	NC	Colerain	501,448	$13,680,397	$27.18	$29.67
6	23827	Southampton	VA	Boykins	511,792	$13,735,089	$27.24	$28.38
7	27805	Bertie	NC	Aulander	520,915	$13,802,021	$27.26	$29.18
8	39302	Lauderdale	MS	Meridian	502,252	$13,837,225	$27.40	$26.91
9	27986	Hertford	NC	Winton	535,028	$13,730,325	$27.45	$28.15
10	23828	Southampton	VA	Branchville	513,526	$13,831,839	$27.64	$28.41

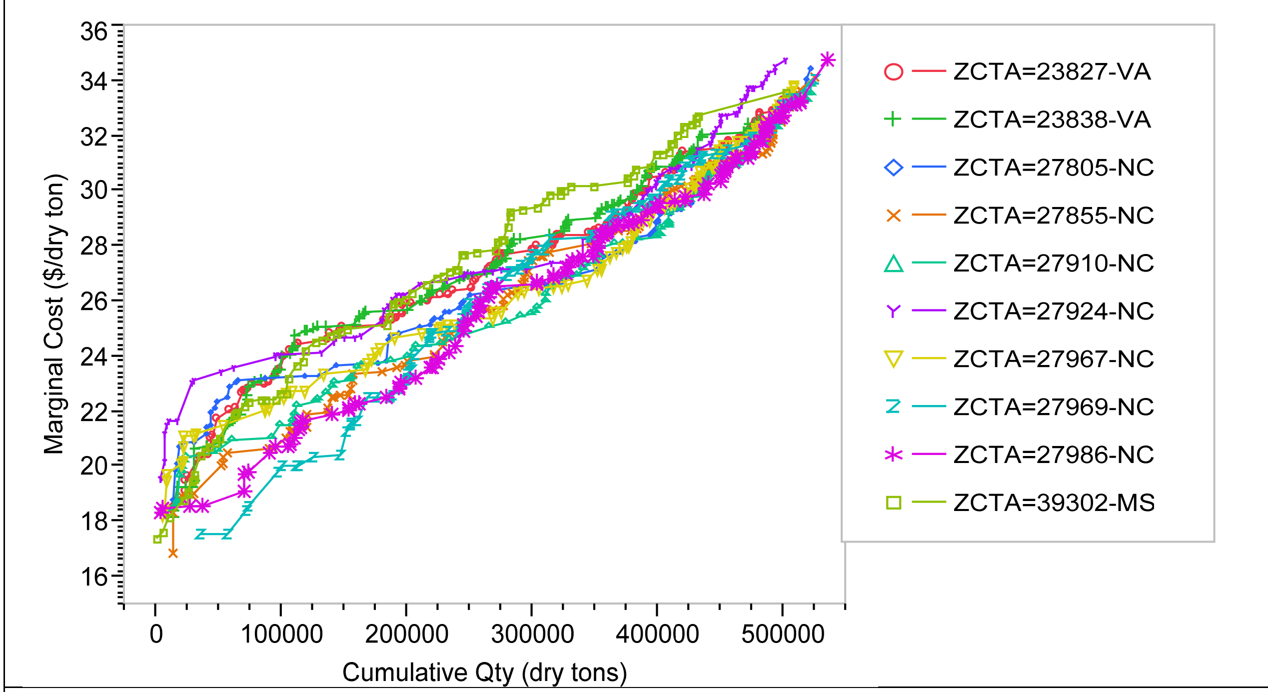

Figure 17. MC curves for top ten sites by ZCTA for total hardwood logging residues "at landing."

<u>Total Logging Residues "In Woods."</u> -- The top ten ZCTA locations in the southeast for bioenergy and biofuels plants that would use all types (softwood and hardwood, clean and unclean) of logging residues harvesting small trees and logging debris "in the woods" (assuming a maximum 160-mile one-way haul distance by truck) were located in northeast GA (Table 12). ATC varied from $169.47/dry ton to $179.79/dry ton. Median MC varied from $168.27/dry ton to $183.39/dry ton (Table 12). The model did not discriminate statistically between the top ten rankings for this biomass type based on ATC. There was no comparable advantage for the MC curves for the top ten sites (Figure 18). See GIS maps in Appendices F and G.

Table 12. Top ten locations for total "in woods" logging residues based on average total cost.

Rank	ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	31636	Lowndes	GA	LARe Park	1,508,464	$257,769,437	$169.47	$168.27
2	31648	Echols	GA	Statenville	1,503,001	$256,495,423	$170.22	$170.97
3	31525	Glynn	GA	Brunswick	1,511,098	$260,849,639	$173.35	$169.54
4	31631	Echols	GA	Fargo	1,543,578	$262,612,006	$174.22	$168.89
5	31778	Thomas	GA	Pavo	1,504,400	$263,082,933	$174.96	$170.26
6	31568	Camden	GA	White OAR	1,540,318	$270,216,219	$175.02	$170.29
7	31331	McIntosh	GA	Townsend	1,519,054	$264,079,498	$176.04	$175.27
8	31305	McIntosh	GA	Darien	1,540,998	$267,272,628	$177.74	$171.77
9	31537	Charlton	GA	Folkston	1,572,056	$268,987,024	$179.31	$169.36
10	31404	Chatham	GA	Savannah	1,527,829	$270,658,985	$179.79	$183.39

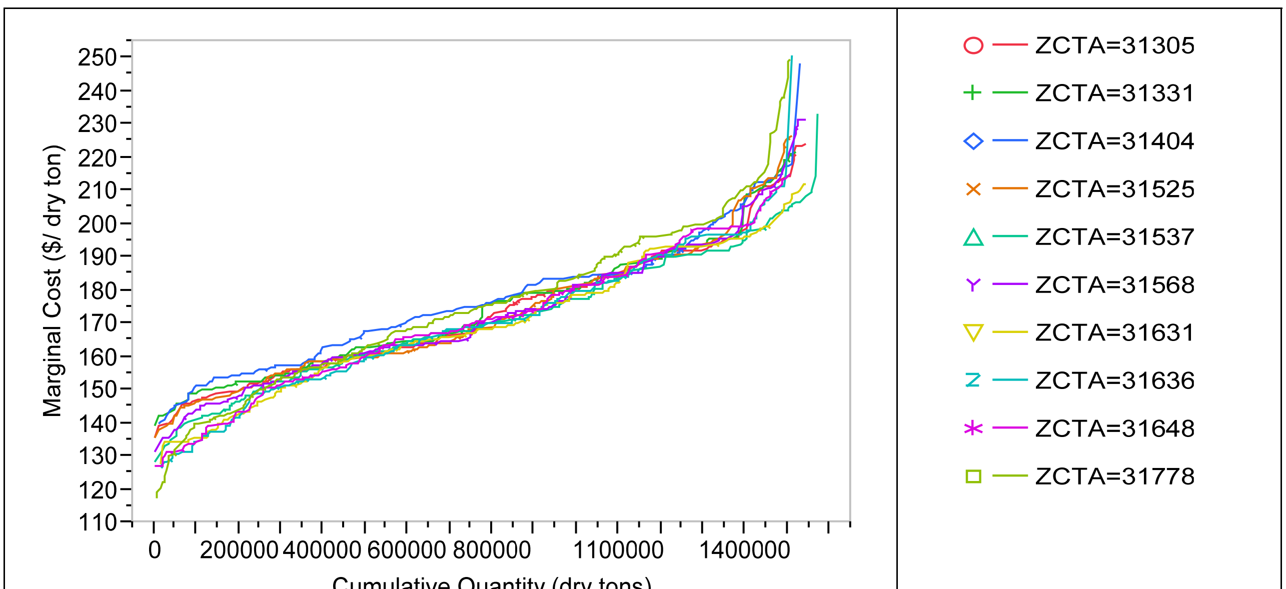

Figure 18. MC curves for top ten sites by ZCTA for total "in woods" logging residues.

Logging Softwood Residues "In Woods." -- The top ten ZCTA locations for "in woods" softwood logging residues (assuming a maximum 160-mile one-way haul distance) were located in northeast GA and SC (Table 13). ATC varied from $187.67/dry ton to $196.56/dry ton. Median MC varied from $191.08/dry ton to $198.52/dry ton (Table 13). The model did not discriminate statistically between the top four rankings (α = 0.05) given a significant increase in ATC due to an increase in available quantity in certain bio-basins (Table 13). There were crossings of MC curves below 800,000 dry tons per year (Figure 19).

Table 13. Top ten locations for "in woods" softwood logging residues based on average total cost.

Rank	ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	30477	Jefferson	GA	Wadley	1,503,518	$282,138,244	$187.67	$192.20
2	30441	Burke	GA	Midville	1,501,555	$283,065,345	$188.22	$191.08
3	29831	Aiken	SC	Jackson	1,501,160	$290,463,143	$193.27	$198.52
4	29071	Lexington	SC	Lexington	1,502,697	$290,909,857	$193.75	$193.91
5	29073	Lexington	SC	Lexington	1,500,556	$291,147,854	$193.93	$194.57
6	29211	Richland	SC	Columbia	1,506,109	$291,972,548	$194.34	$192.75
7	29228	Richland	SC	Columbia	1,511,666	$292,704,764	$195.08	$192.72
8	29292	Richland	SC	Columbia	1,512,766	$292,889,555	$195.26	$192.68
9	29053	Lexington	SC	Gaston	1,508,892	$293,320,061	$195.47	$195.19
10	29072	Lexington	SC	Lexington	1,514,897	$294,325,587	$195.56	$194.20

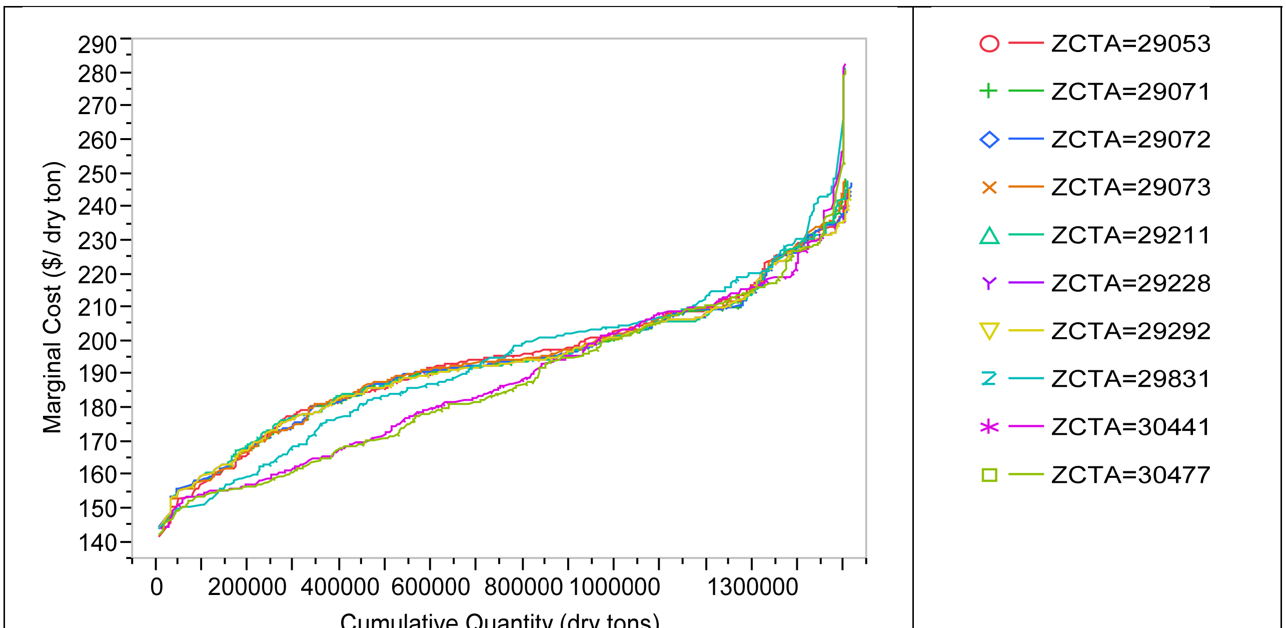

Figure 19. MC curves for top ten sites by ZCTA for "in woods" softwood logging residues.

Logging Hardwood Residues "In Woods." -- The top ten ZCTA locations in the southeast for bioenergy and biofuels plants that would use "in woods" hardwood logging residues (assuming a maximum 160-mile one-way haul distance by truck) were located in MS and LA (Table 14). ATC varied from $194.77/dry ton to $198.95/dry ton. Median MC varied from $192.80/dry ton to $199.41/dry ton (Table 14). The model did not discriminate statistically between the top ten rankings (α = 0.05), Table 14. There was no comparable advantage in the MC curves for softwood logging residues for harvesting levels less than 1,300,000 dry tons per year (Figure 20).

Table 14. Top ten locations for "in woods" hardwood logging residues based on average total cost.

Rank	ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	39175	Hinds	MS	Utica	1501253	$292,704,172	$194.77	$196.60
2	39074	Scott	MS	Forest	1506912	$297,373,843	$196.21	$194.63
3	39092	Scott	MS	LARe	1512401	$299,921,463	$197.57	$194.58
4	39051	LeARe	MS	Carthage	1508793	$299,821,110	$197.69	$199.41
5	39156	Warren	MS	Redwood	1501033	$297,086,205	$197.76	$196.46
6	39183	Warren	MS	Vicksburg	1508408	$297,284,514	$198.02	$197.00
7	39182	Warren	MS	Vicksburg	1523079	$300,266,460	$198.35	$196.28
8	71233	Madison	LA	Delta	1525649	$299,124,952	$198.63	$195.93
9	39338	Jasper	MS	Louin	1514221	$298,400,312	$198.69	$192.81
10	39327	Newton	MS	Decatur	1511122	$299,594,673	$198.95	$195.93

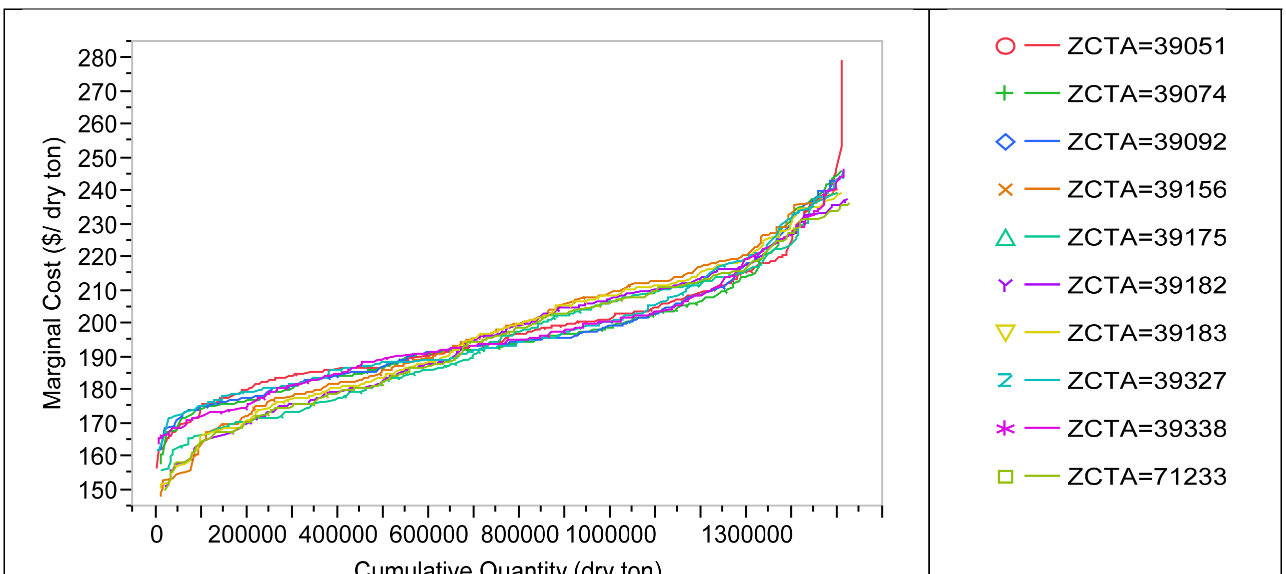

Figure 20. MC curves for top ten sites by ZCTA for "in woods" hardwood logging residues.

Total Logging Residues "At Landings" and "In Woods"

The top ten ZCTA locations in the southeast for bioenergy and biofuels plants that would use total logging residues (assuming a maximum 160-mile one-way haul distance by truck) were located predominately in KY (Table 15). ATC varied from $87.71/dry ton to $95.41/dry ton. Median MC varied from $37.66/dry ton to $83.43/dry ton (Table 15). The model did discriminate statistically between the top three rankings relative to the other demand ZCTAs (α = 0.05), Figure 21.

Table 15. Top ten locations for total logging residues based on average total cost.

Rank	ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	41267	Martin	KY	Warfield	1,516,193	$133,698,221	$87.71	$39.42
2	41214	Martin	KY	Debord	1,518,613	$135,086,289	$89.03	$38.13
3	41602	Floyd	KY	Auxier	1,501,702	$134,373,530	$89.32	$38.08
4	41265	Johnson	KY	Van Lear	1,527,705	$139,120,688	$90.78	$37.66
5	41607	Floyd	KY	Blue River	1,528,733	$138,849,006	$91.79	$38.84
6	41465	Magoffin	KY	Salyersville	1,509,485	$139,169,490	$91.99	$41.05
7	41231	Martin	KY	Lovely	1,578,571	$140,828,353	$93.60	$39.59
8	41653	Floyd	KY	Prestonsburg	1,561,222	$142,192,209	$94.08	$38.08
9	41408	Wolfe	KY	Cannel City	1,529,985	$143,517,359	$94.86	$76.30
10	22625	Frederick	VA	Cross Junct.	1,502,277	$143,661,143	$95.41	$83.43

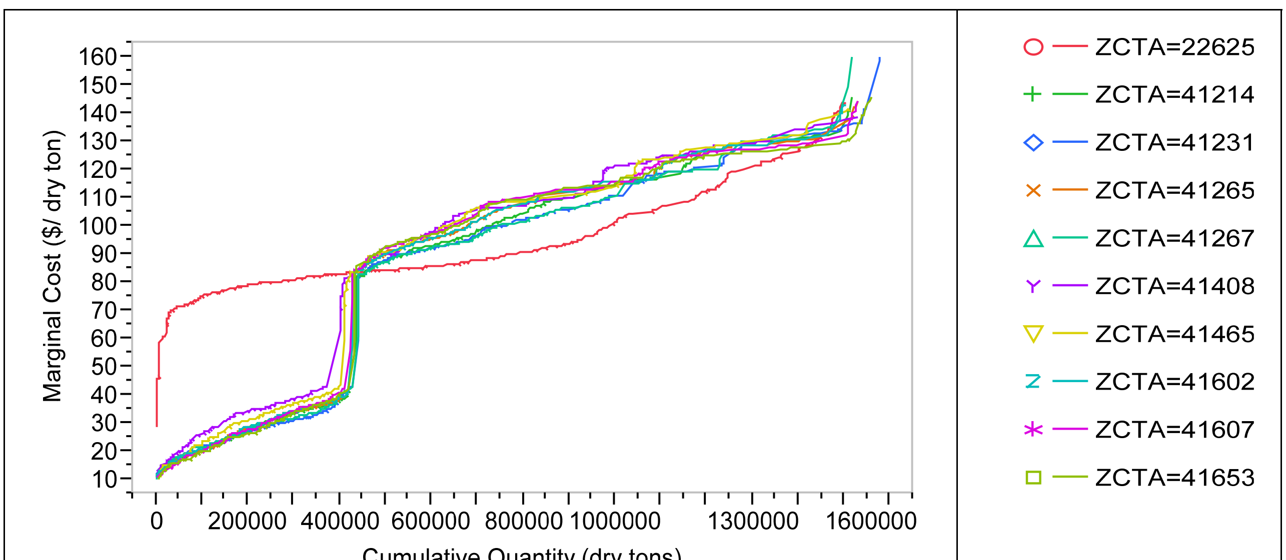

Figure 21. MC curves for top ten sites by ZCTA for total logging residues.

SRTS Model Projections of Logging Residues from Growing Stock and Non-growing Stock

SRTS model projections to the year 2050 were given by state for both softwood and hardwood logging residues (growing stock and non-growing stock).[9] GA and MS have the largest and most economically sustainable supply of growing and non-growing stock softwood logging residues. GA has projected economically sustainable softwood growing stock logging residues of approximately 550,000 dry tons per year until 2050 and additional softwood non-growing stock logging residue supplies of approximately 1,000,000 dry tons per year until 2050 (Figures 22 and 23).

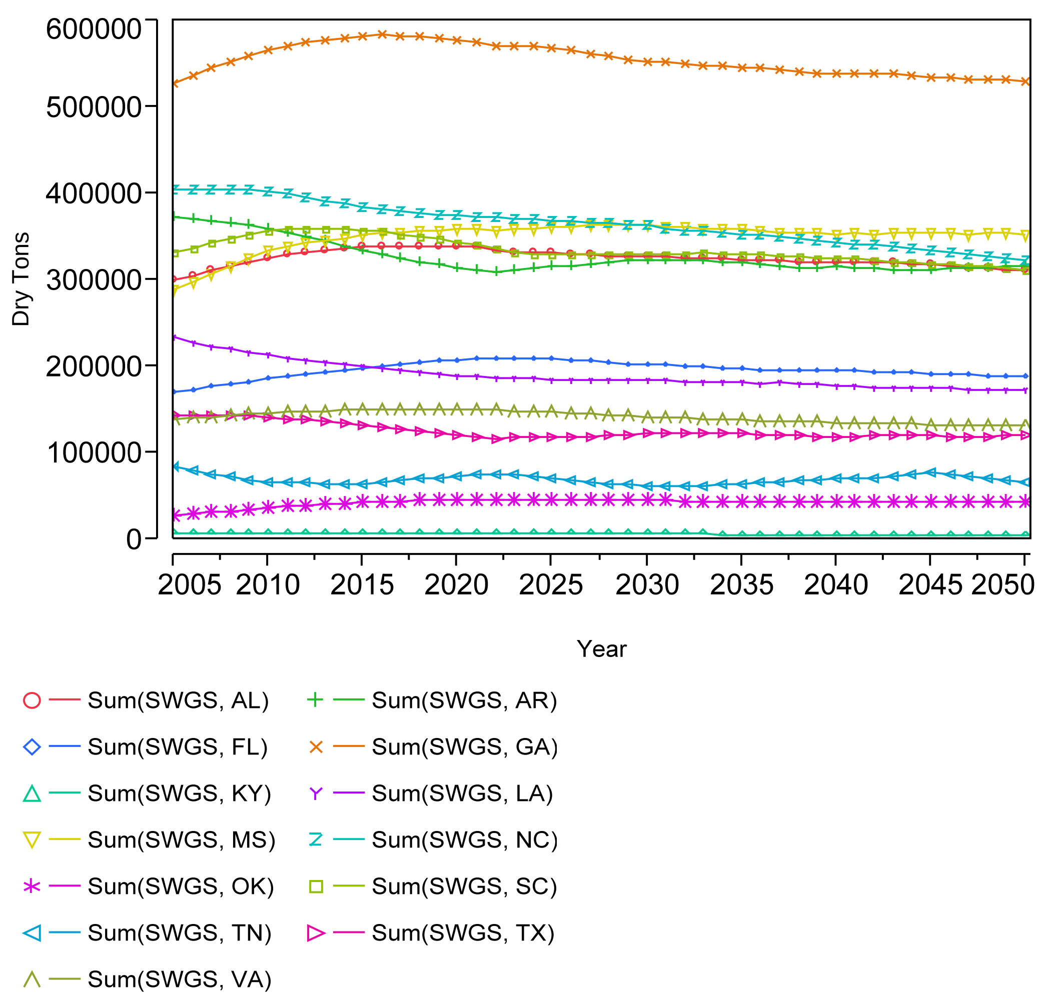

Figure 22. SRTS model projections of logging residues from softwood growing stock by state.

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[9] SRTS uses U.S. Forest Service FIA data to project timber supply trends based on current conditions and the economic responses in timber markets (Abt et al. 2000). Abt et al. (2000) note SRTS is a partial equilibrium market simulation model that can be used to analyze various forest resource and timber supply situations.

MS has projected economically sustainable softwood growing stock logging residues of approximately 350,000 dry tons per year until 2050 and additional softwood non-growing stock logging residue supplies of approximately 850,000 dry tons per year until 2050 (Figure 23). Recall that GA and MS also had some of the least cost bio-basins for logging residues harvested "in woods" and "at the landing."

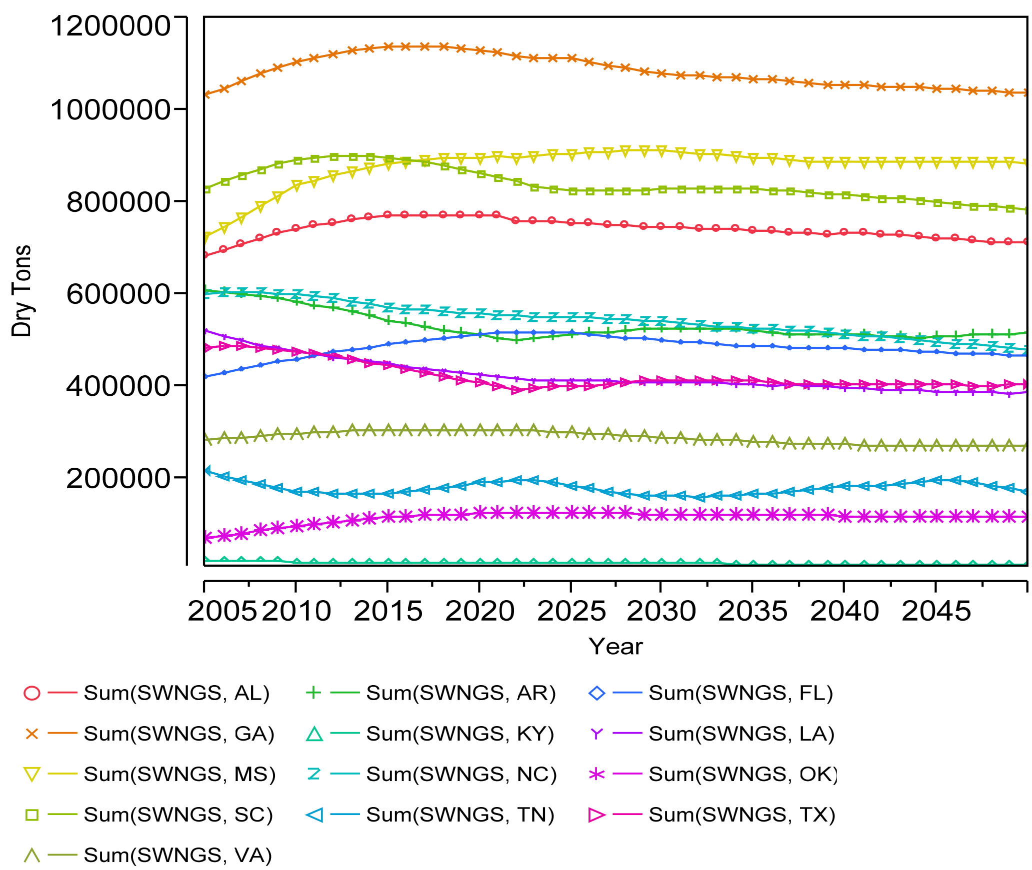

Figure 23. SRTS model projections of logging residues from softwood non-growing stock by state.

MS, GA, and AL have the largest and most economically sustainable supply of hardwood growing stock logging residues (Figure 23). MS has increasing projected economically sustainable hardwood growing stock logging residues of approximately 650,000 dry tons per year until 2050. GA has the steepest projected increases in hardwood growing stock from approximately 500,000 dry tons per year in 2005 to approximately 600,000 dry tons per year in 2050 (Figure 24). AL has economically sustainable hardwood growing stock logging residues of approximately 550,000 dry tons per year to 2050 (Figure 24). Recall that MS had the least cost bio-basins for "in woods" hardwood logging residues.

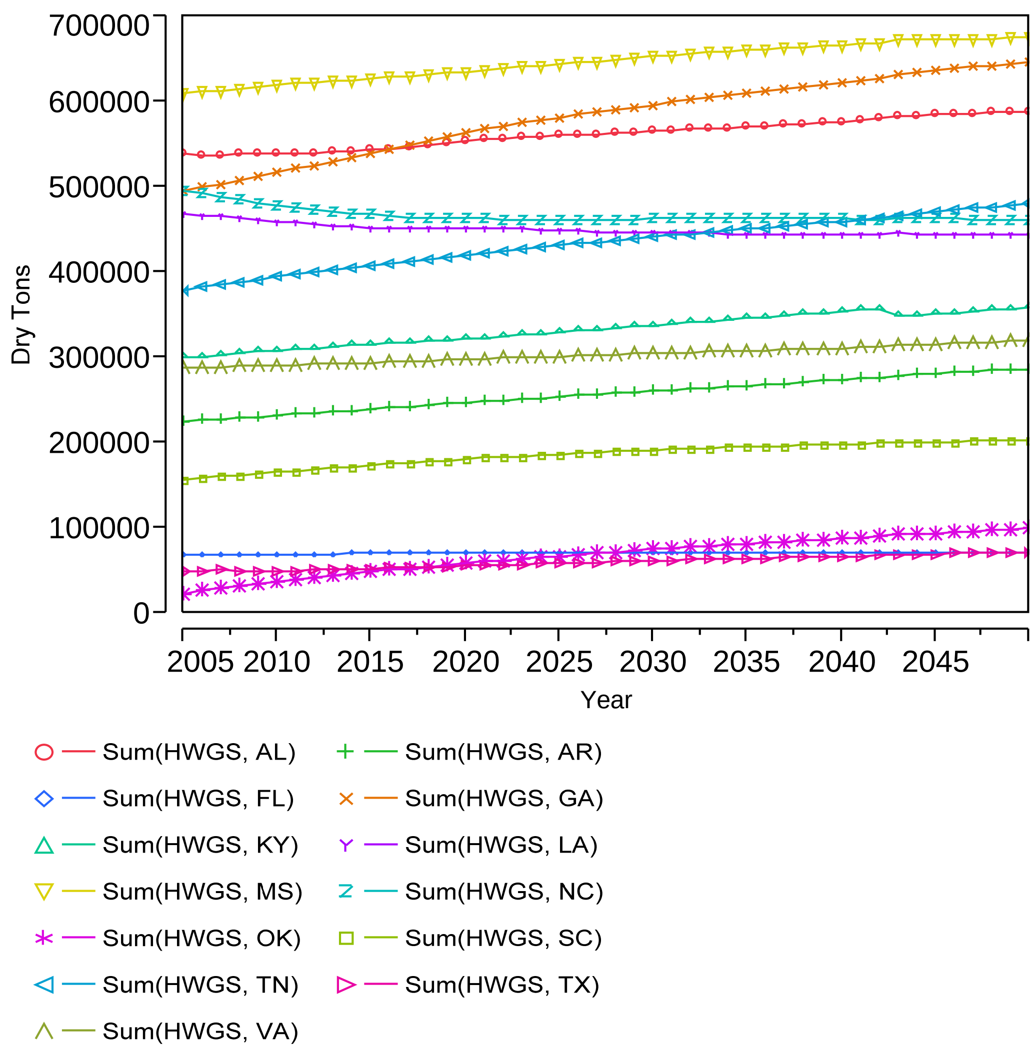

Figure 24. SRTS model projections of logging residues from hardwood growing stock by state.

TN and MS have the steepest projected increases in hardwood non-growing stock economically sustainable supplies from 2005 to 2050 (Figure 25). TN's economically sustainable hardwood non-growing stock logging residues was projected to consistently increase from approximately 900,000 dry tons per year in 2005 to 1,200,000 dry tons per year in 2050. MS's economically sustainable hardwood non-growing stock logging residues was projected to increase slightly from approximately 900,000 dry tons per year in 2005 to 1,000,000 dry tons per year in 2050.

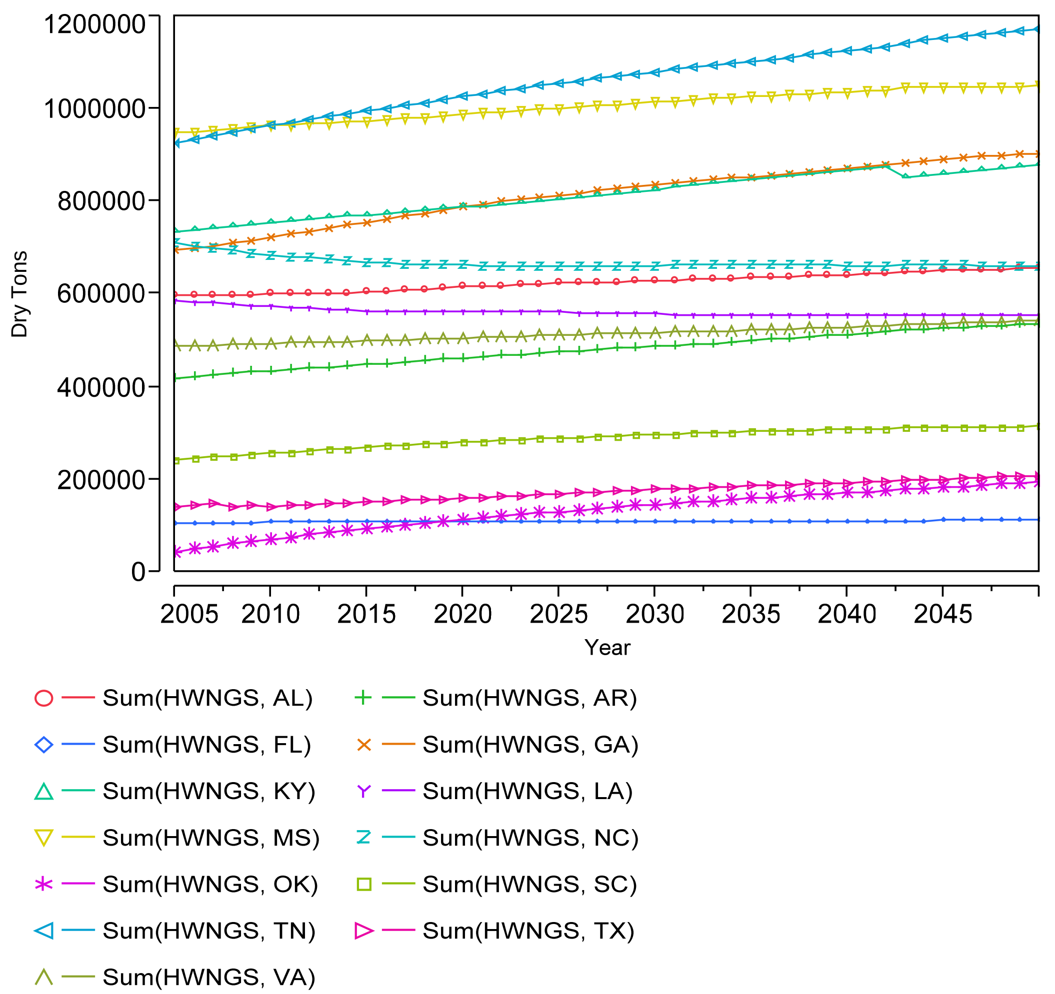

Figure 25. SRTS model projections of logging residues from hardwood non-growing stock by state.

The SRTS model projections for softwood and hardwood (for both pulpwood and sawtimber) removals and inventory from 2005 to 2050 are given in Appendix H. These projections assumed both a 0.5% increase per year demand increase for pulpwood and no demand increase for sawtimber. These commercial product projections form part of the basis of the growing stock and non-growing stock logging residue projections.

Conclusions

The rationale for this research was driven by the world's continued dependence on oil for energy which is projected to increase by 40% by 2020. The U.S. economy remains vulnerable to economic shocks from disrupted imported oil supplies and the subsequent real price increases that would occur from such shocks. In 2008 the U.S. imported 59% of its oil, of which 20% came from the sensitive Persian Gulf region.

Assessing the economic capability and stability of the bioenergy supply chain infrastructure is an essential first-step for market organization of this emerging industry, and is the key question addressed by this study. The overall goal of the research was to improve the understanding of costs for mill and logging residues that make-up the woody biomass supply chain which is deemed an essential first-step for market organization of this emerging industry. Geo-referenced economic supply curves (marginal cost curves) for woody biomass producers' for the 13 southern states were developed using the BioSAT Model (Biomass Site Assessment Tool, www.biosat.net). The project had three objectives that were aggregated to provide spatially explicit economic data for potential producers of bioenergy and biofuels: 1) use the SubRegional Timber Supply (SRTS) model with USDA Forest Service inventory data in an economic supply and demand framework to project timber inventory, supply, and price into the future for estimating logging residues; 2) develop a cost model for mill residues; and 3) develop a trucking transportation cost model for woody biomass. The three objectives of the research study were met which led to regional geo-referenced comparisons of the economic supply of woody biomass for the southeastern U.S.

Least cost bio-basins for "clean softwood" mill residues were located in west-central GA. Average total costs (ATC) in these bio-basins ranged from $39.88 to $42.47 per dry ton and marginal costs (MC) ranged from $40.98 to $43.45 per dry ton. Least cost bio-basins for "clean hardwood" mill residues were located in southern and central VA. ATC ranged from $46.30 to $47.65 per dry ton with MC ranging from $42.25 to $43.79 per dry ton.

Least cost bio-basins for softwood logging residues from chipped top and limbs "at the landing" from a merchantable harvest were located in southeast MS, northern LA, southern AR, and central SC. ATC ranged from $27.34 to $28.68 per dry ton and MC ranged from $28.03 to $32.87 per dry ton. Least cost bio-basins for hardwood logging residues "at the landing" were located in northeast NC, southeast VA, and east-central MS. ATC ranged from $26.24 to $27.64 per dry ton and MC ranged from $26.91 to $29.67 per dry ton.

Projections from the Southern Regional Timber Supply (SRTS) model indicated that GA has the largest and most economically sustainable supply of softwood logging residues from growing and non-growing stocks. GA has projected economically sustainable softwood logging residues from the growing stock of approximately 550,000 dry tons per year until the year 2050, with additional softwood logging residues from the non-growing stock of approximately 1,000,000 dry tons per year until the year 2050. MS, GA, and AL have the largest and most economically sustainable supply of hardwood logging residues from the growing stock. MS has economically sustainable hardwood logging residues from the growing stock of approximately 650,000 dry tons per year until the year 2050, GA has hardwood logging residues from the growing stock of approximately 600,000 dry tons per year until the year 2050, and AL has hardwood logging residues from the growing stock of approximately 550,000 dry tons per year until the year 2050. TN has the steepest projected increases in economically sustainable supplies of hardwood logging residues from non-growing stock. TN's economically sustainable hardwood logging residues from non-growing stock was projected to increase from approximately 900,000 dry tons per year in 2005 to 1,200,000 dry tons per year in the year 2050.

The research study provided an important geo-referenced economic framework for woody biomass resources. The development of statistical-based cost estimates for procuring woody biomass within potential bio-basins at the 5-digit Zip Code Tabulation Area (ZCTA) that include confidence bounds was a strength of the study. The SRTS model projections of logging residues from the growing and non-growing stocks provide important data for assessing the long-term economical sustainability of woody biomass supplies and were a key basis of the study.

Confidence bounds of the woody biomass supply in any given bio-basin which is a grouping of 5-digit ZCTAs did not offer any improvement over existing studies which aggregate county-level resource supply data. However, the use of the 5-digit ZCTA as the demand point for woody biomass, with the surrounding road network of the bio-basin, may offer some improvement of cost estimates when compared to studies which rely on estimates based on the centroid of the county. Counties can be large and have geographic barriers that impact transportation time and distance (e.g., bridges over large waterways, mountains, large metropolitan areas, etc.). The study also had low total cost estimates for larger quantities of logging residues that were located in close proximity to metropolitan areas. This may reflect "development harvests" rather than "forest management harvests" which have a long term implication of sustainability. The lower total cost estimates near metropolitan areas may also reflect the lower transportation costs associated with improved highway networks.

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Appendix A

Bio-basins maps for top ten ZCTA sites for
total (hardwood and softwood) mill residues categorized by marginal cost

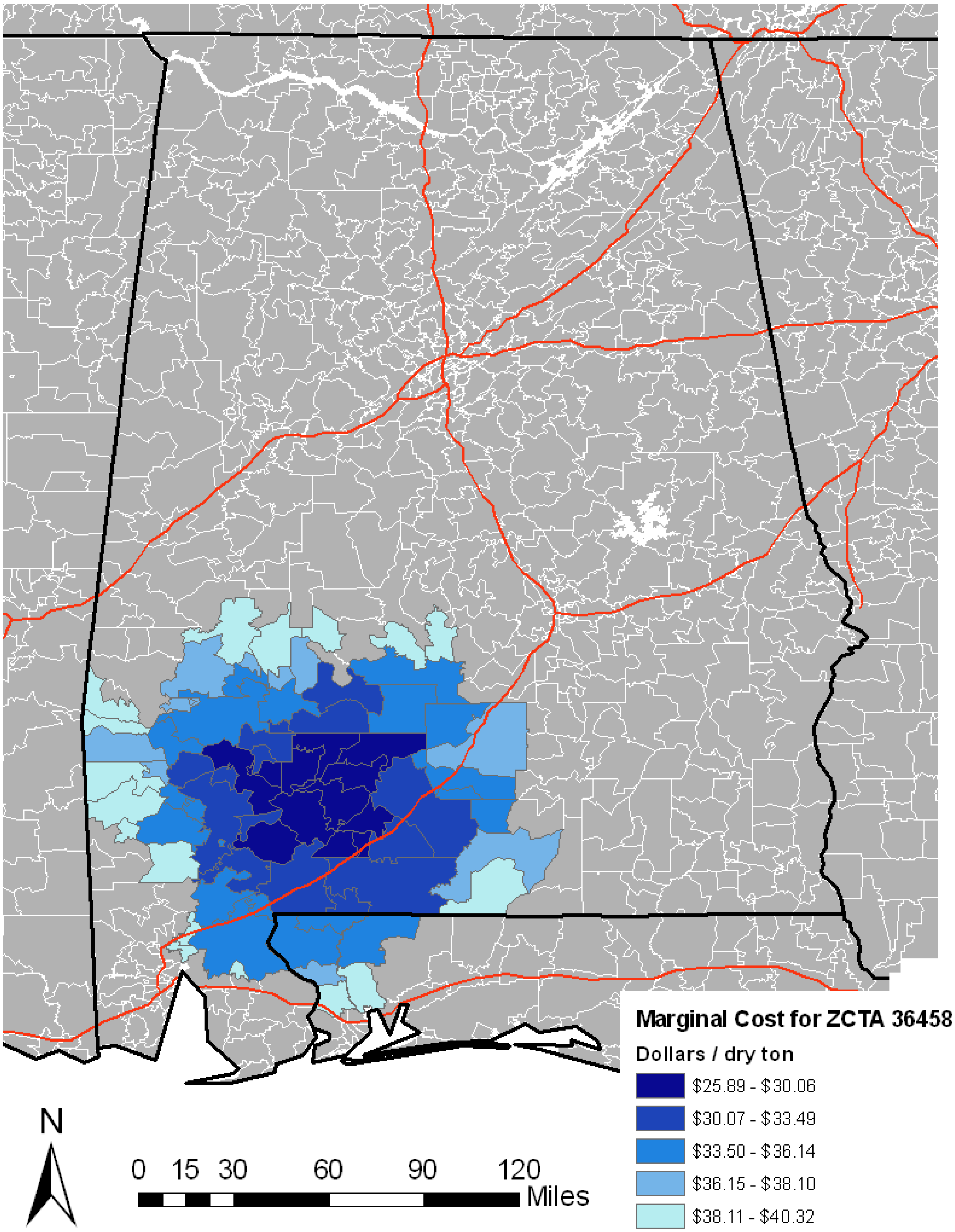

Figure A.1. Map of bio-basin for total mill residues for ZCTA 36458 (Mexia, AL, Monroe County, Ranked #1 site).

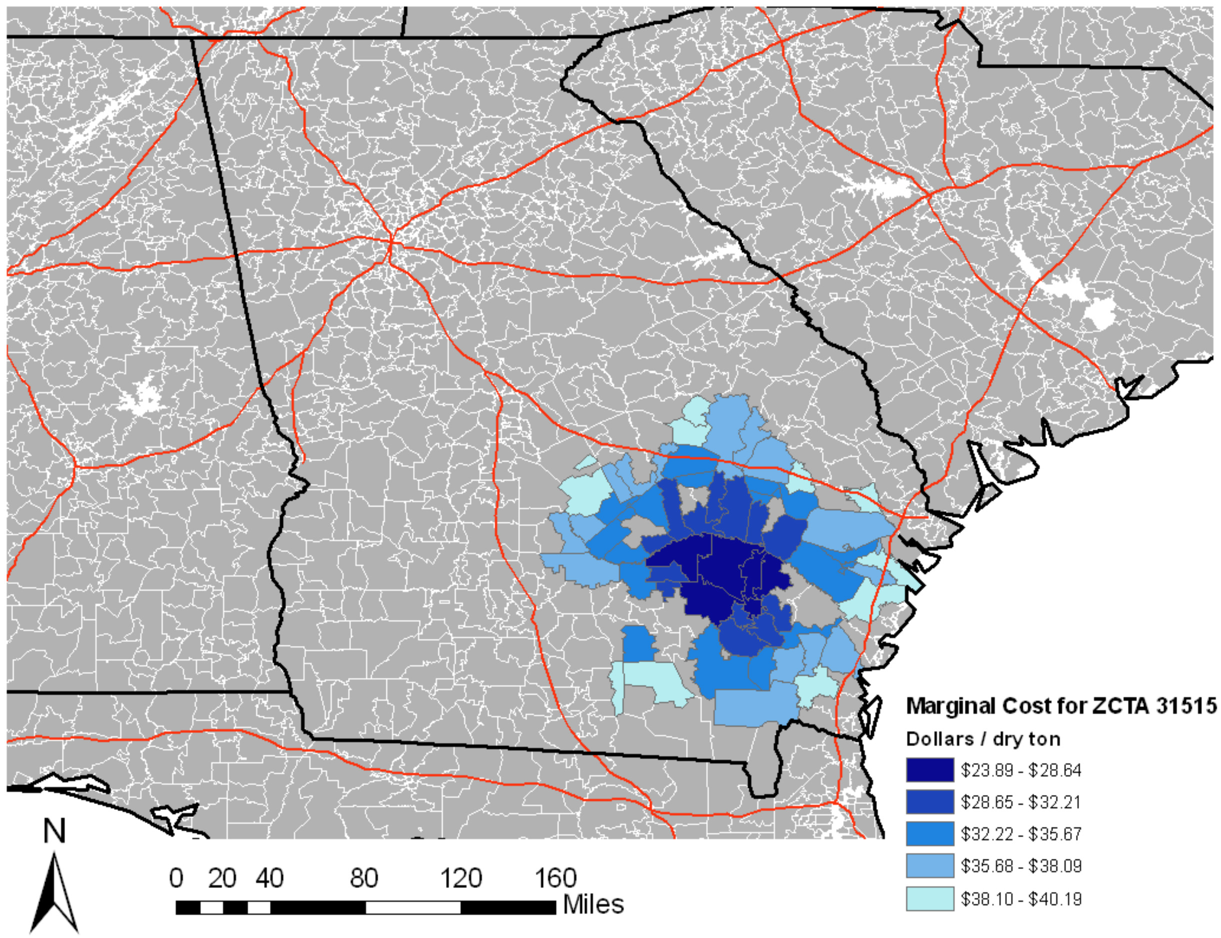

Figure A.2. Map of bio-basin for total mill residues for ZCTA 31515 (Baxley, GA, Appling County, Ranked #2 site).

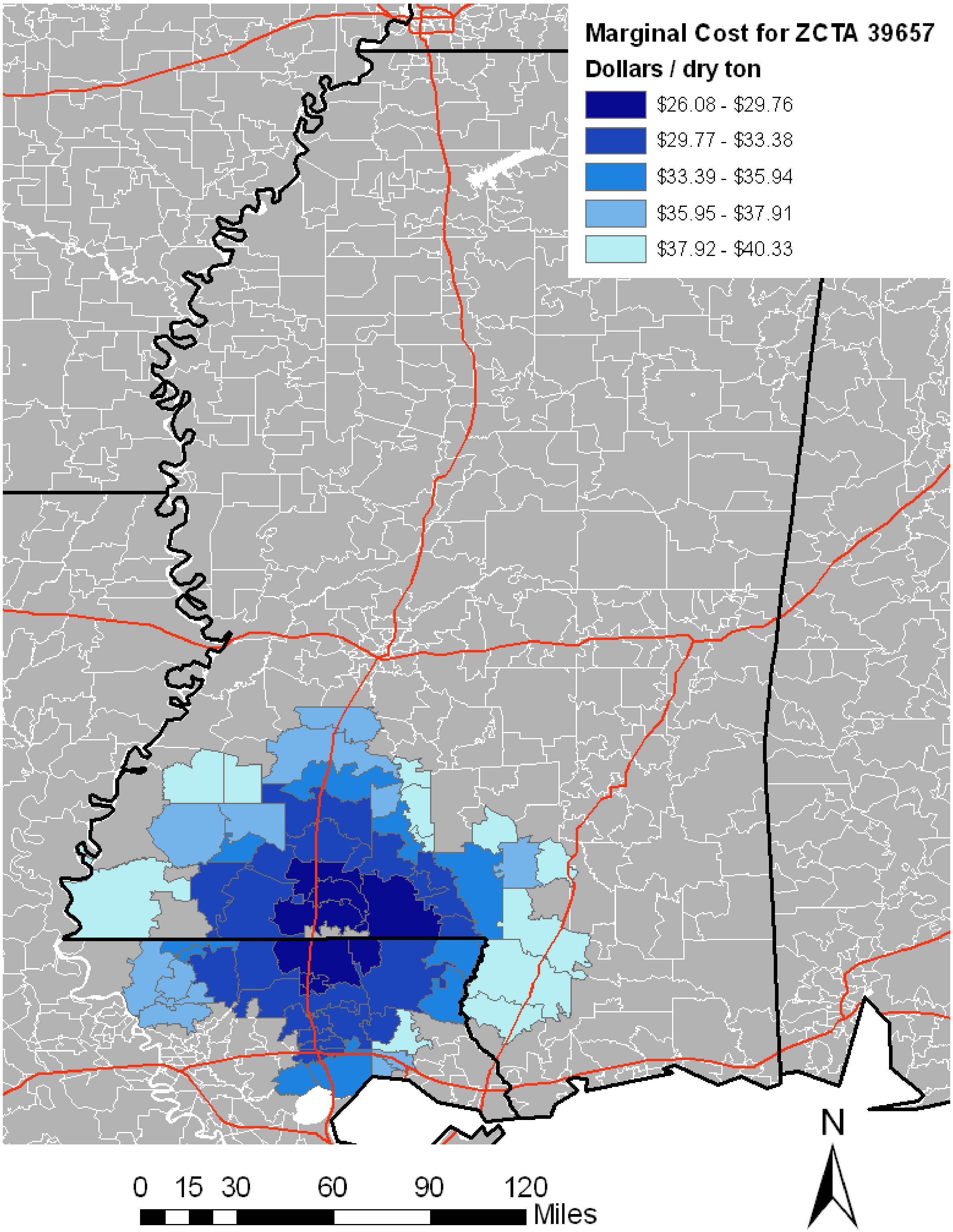

Figure A.3. Map of bio-basin for total mill residues for ZCTA 39657 (Osyka, MS, Pike County, Ranked #3 site).

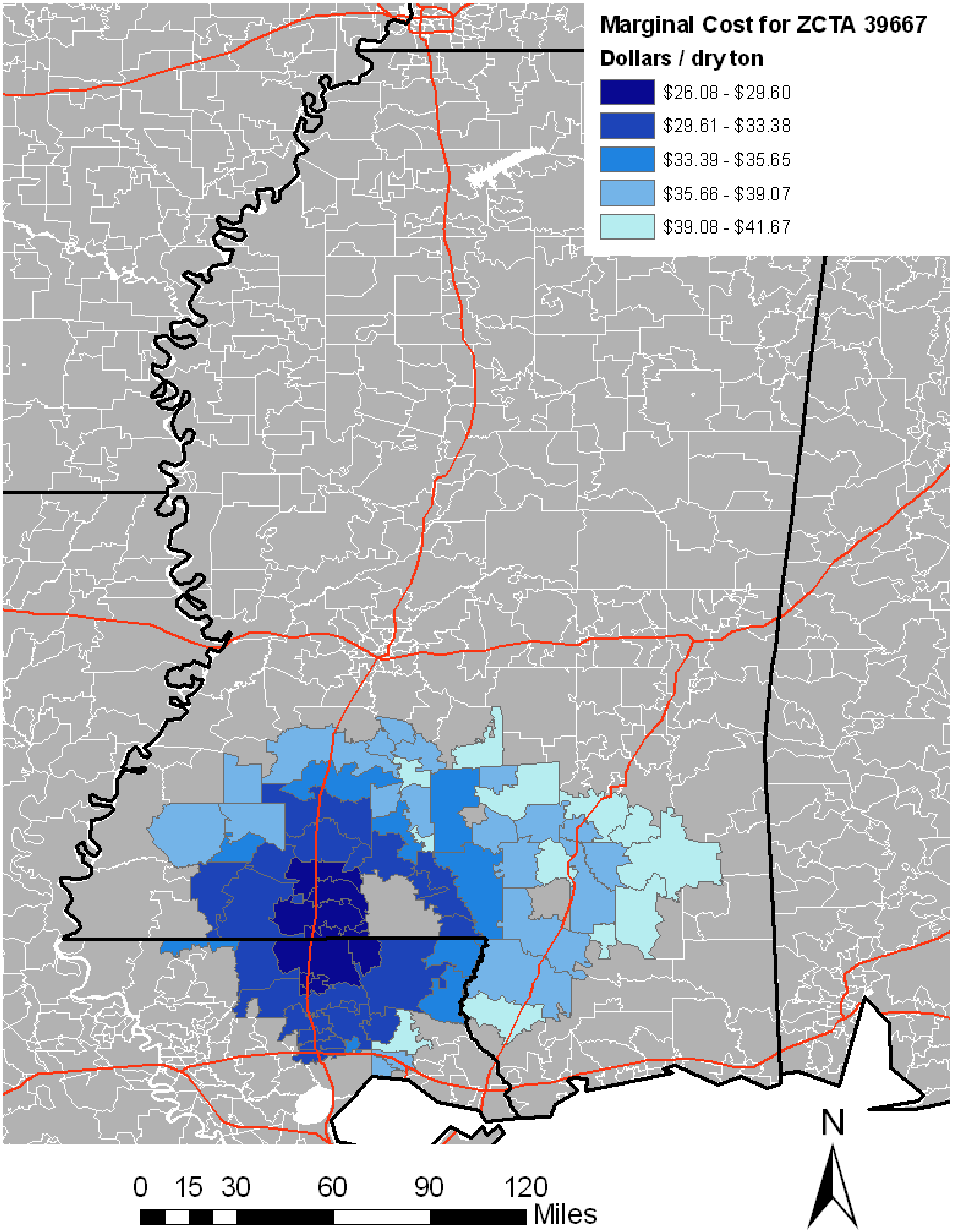

Figure A.4. Map of bio-basin for total mill residues for ZCTA 39667 (Tylertown, MS, Walthall County, Ranked #4 site).

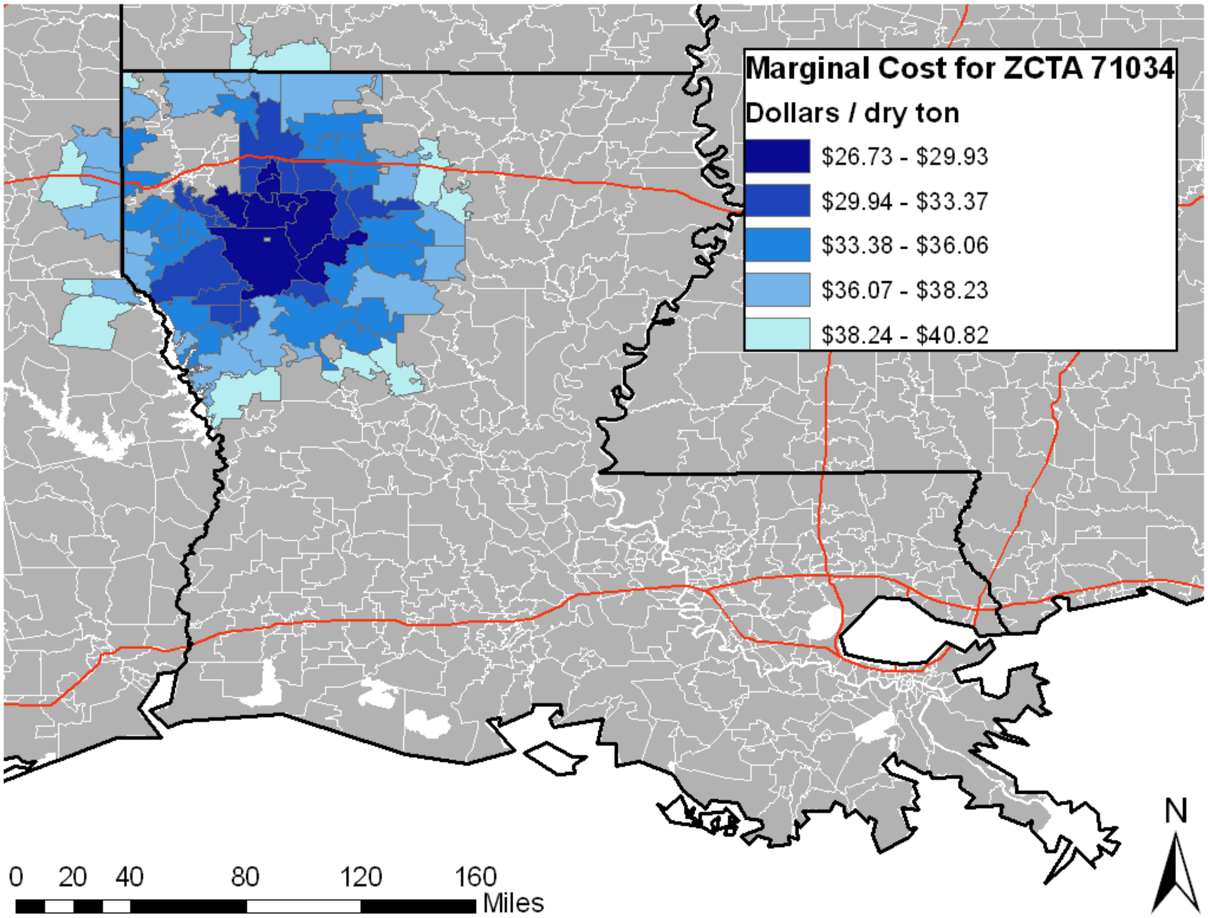

Figure A.5. Map of bio-basin for total mill residues for ZCTA 71034 (Hall Summit, LA, Red River County, Ranked #5 site).

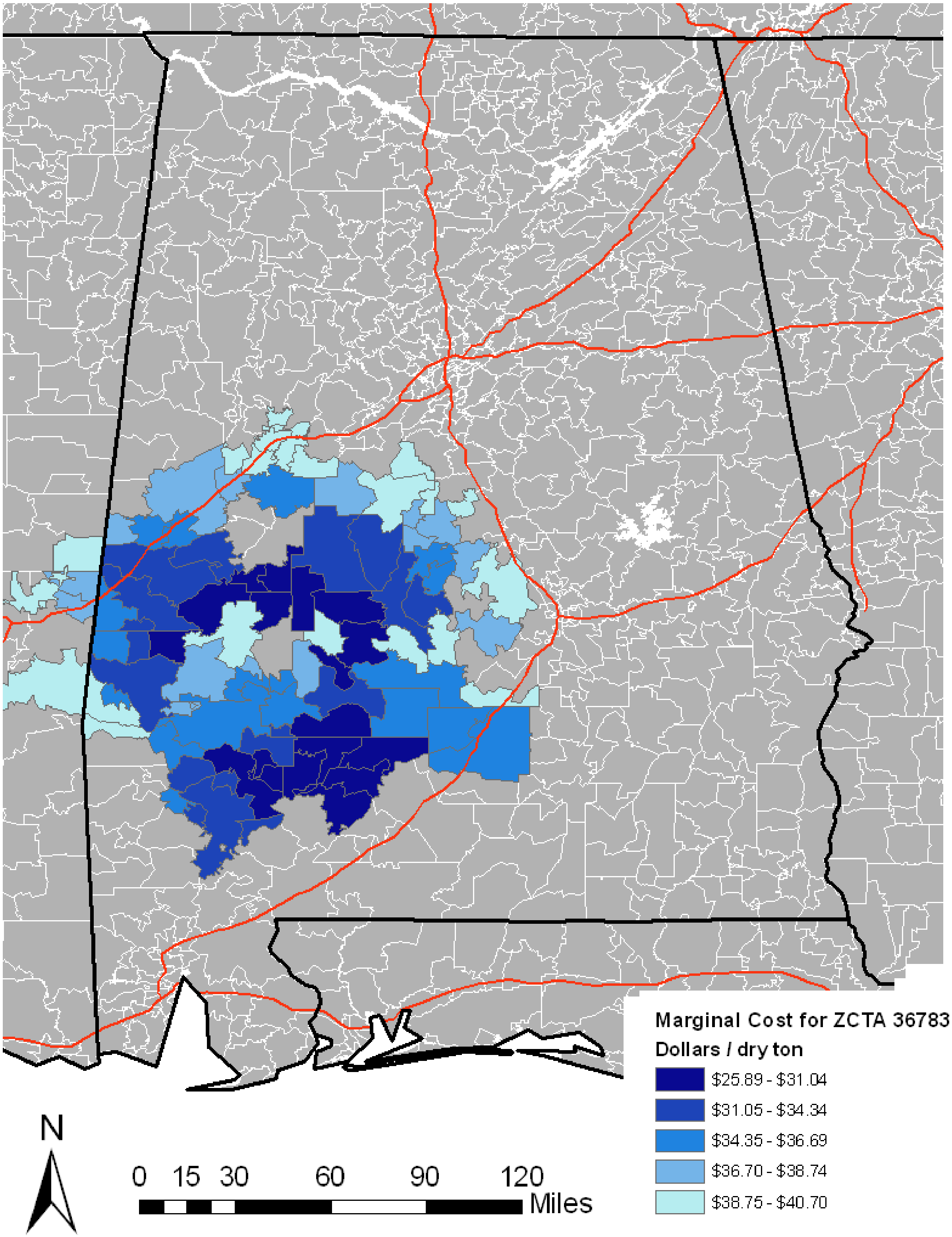

Figure A.6. Map of bio-basin for total mill residues for ZCTA 36783 (Thomaston, AL, Marengo County, Ranked #6 site).

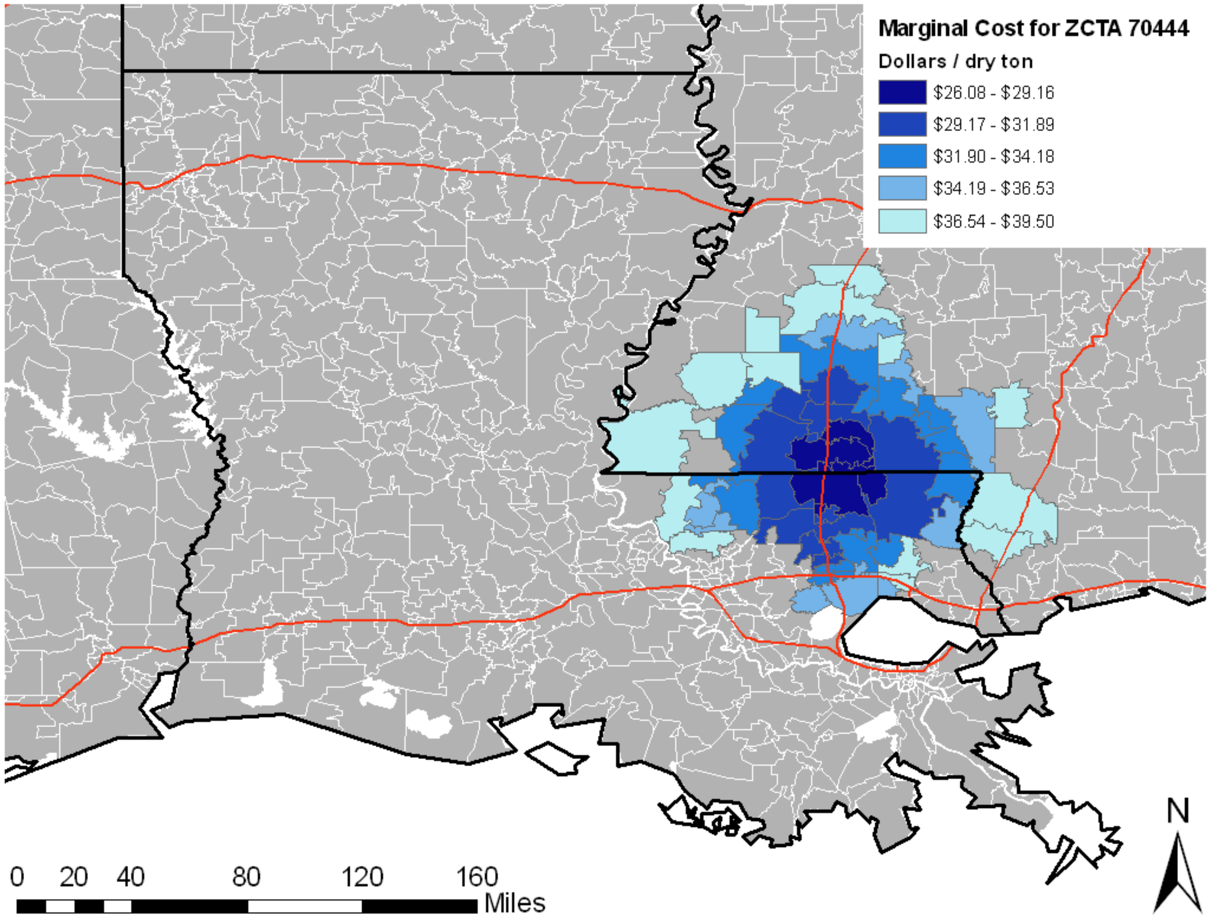

Figure A.7. Map of bio-basin for total mill residues for ZCTA 70444 (Kentwood, LA, Tangipahoa County, Ranked #7 site).

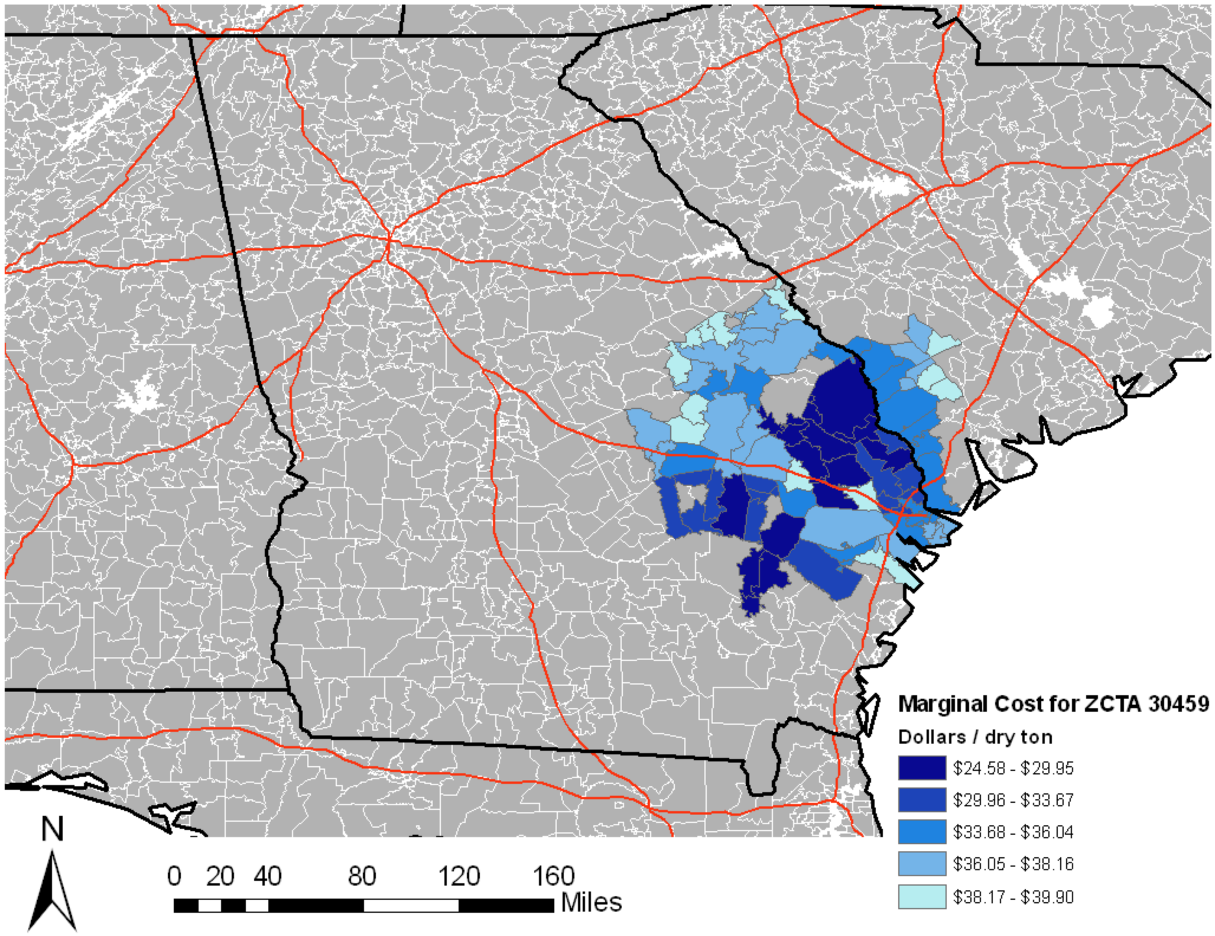

Figure A.8. Map of bio-basin for total mill residues for ZCTA 30459 (Statesboro, GA, Bulloch County, Ranked #8 site).

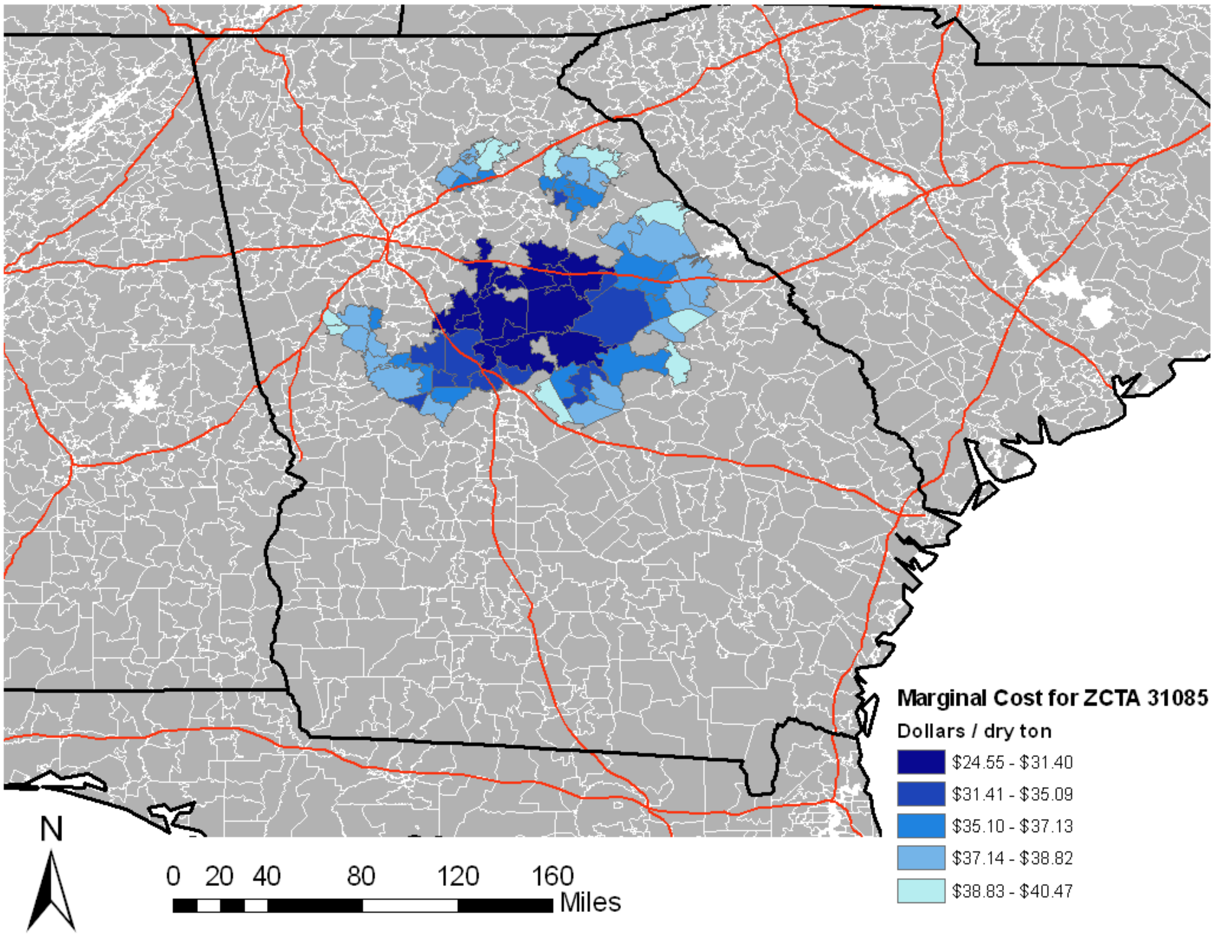

Figure A.9. Map of bio-basin for total mill residues for ZCTA 31085 (Shady Dale, GA, Jasper County, Ranked #9 site).

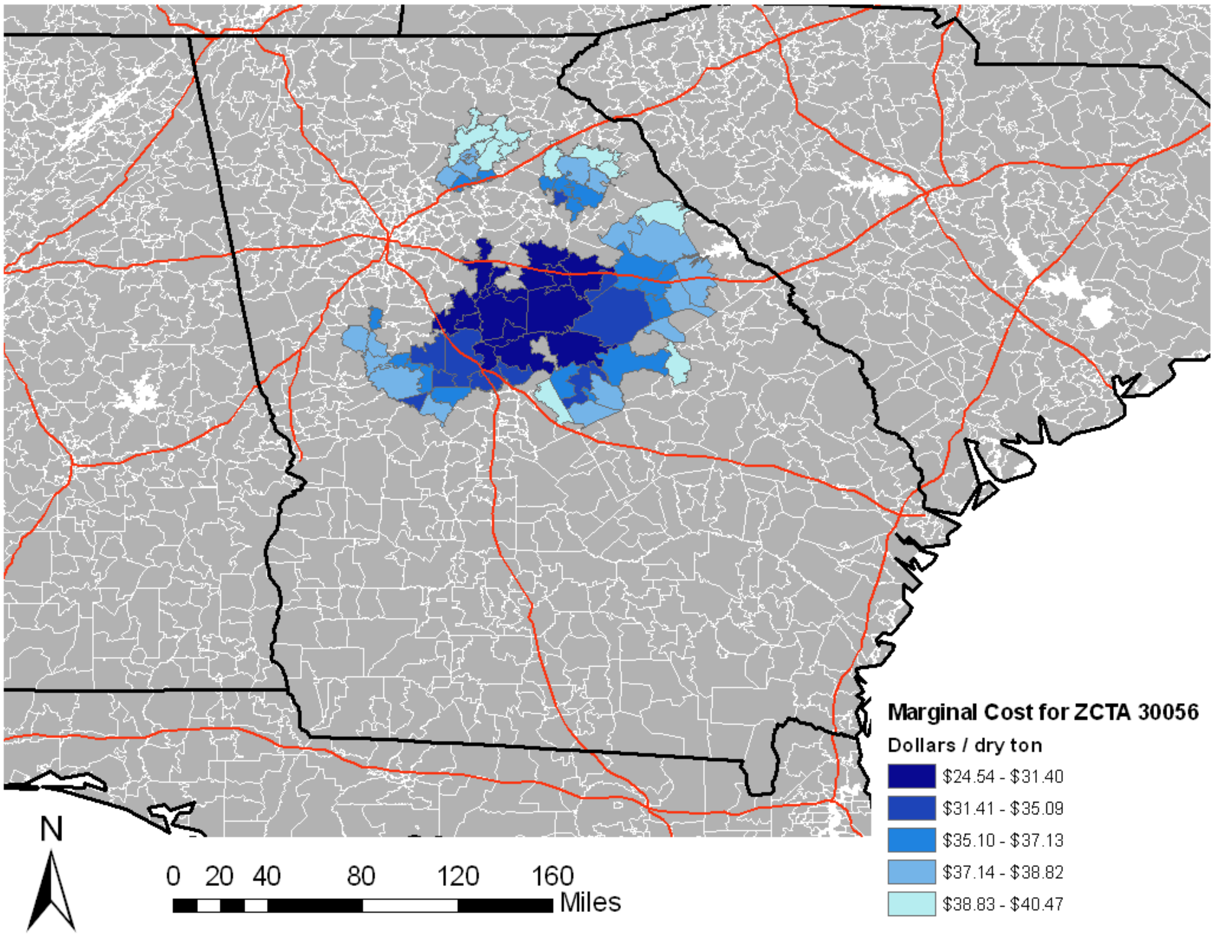

Figure A.10. Map of bio-basin for total mill residues for ZCTA 30056 (Newborn, GA, Jasper County, Ranked #10 site).

Appendix B

ZCTA maps for total (hardwood and softwood) mill residues categorized by marginal cost

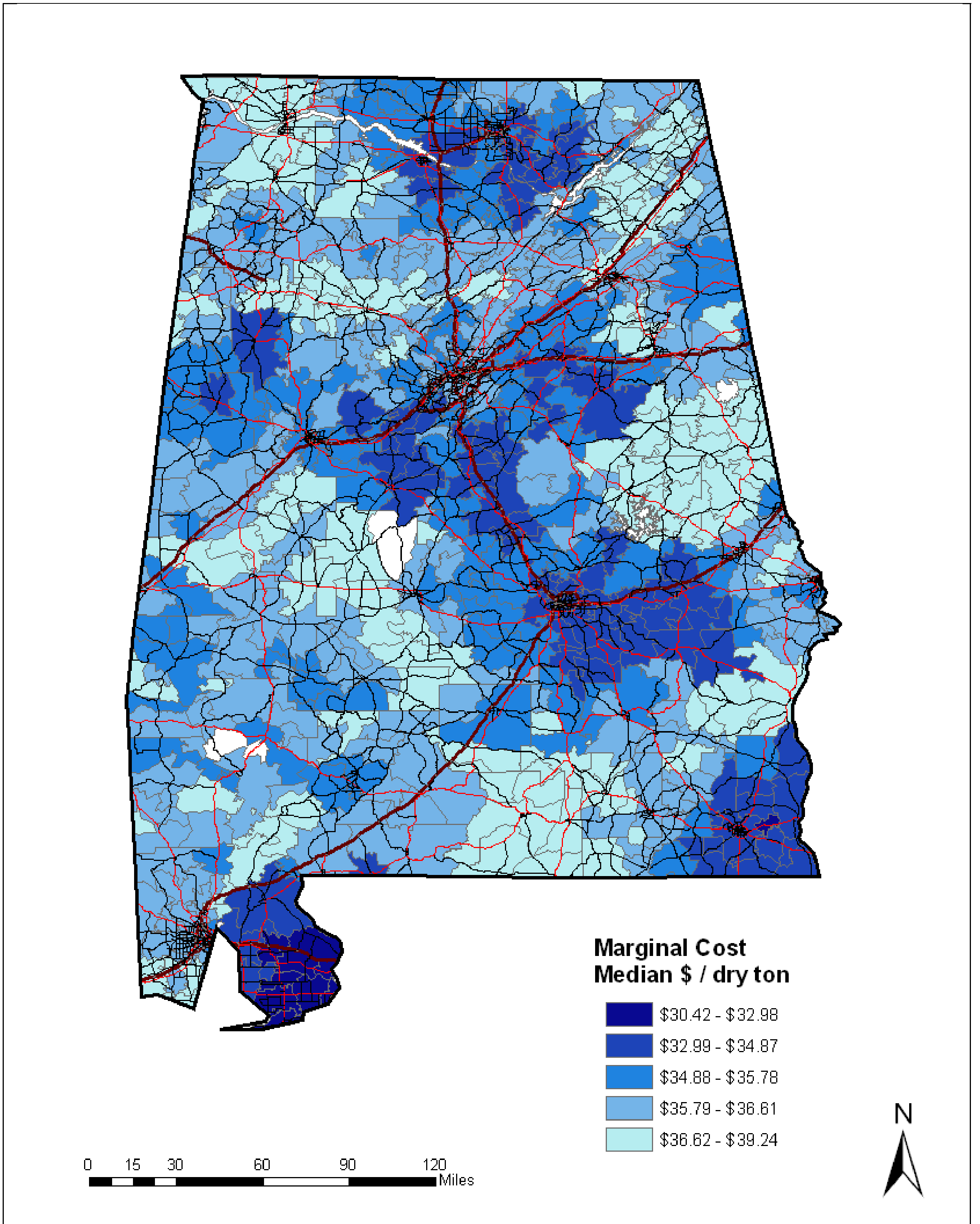

Figure B.1. Distribution of median marginal costs for total mill residues for Alabama.

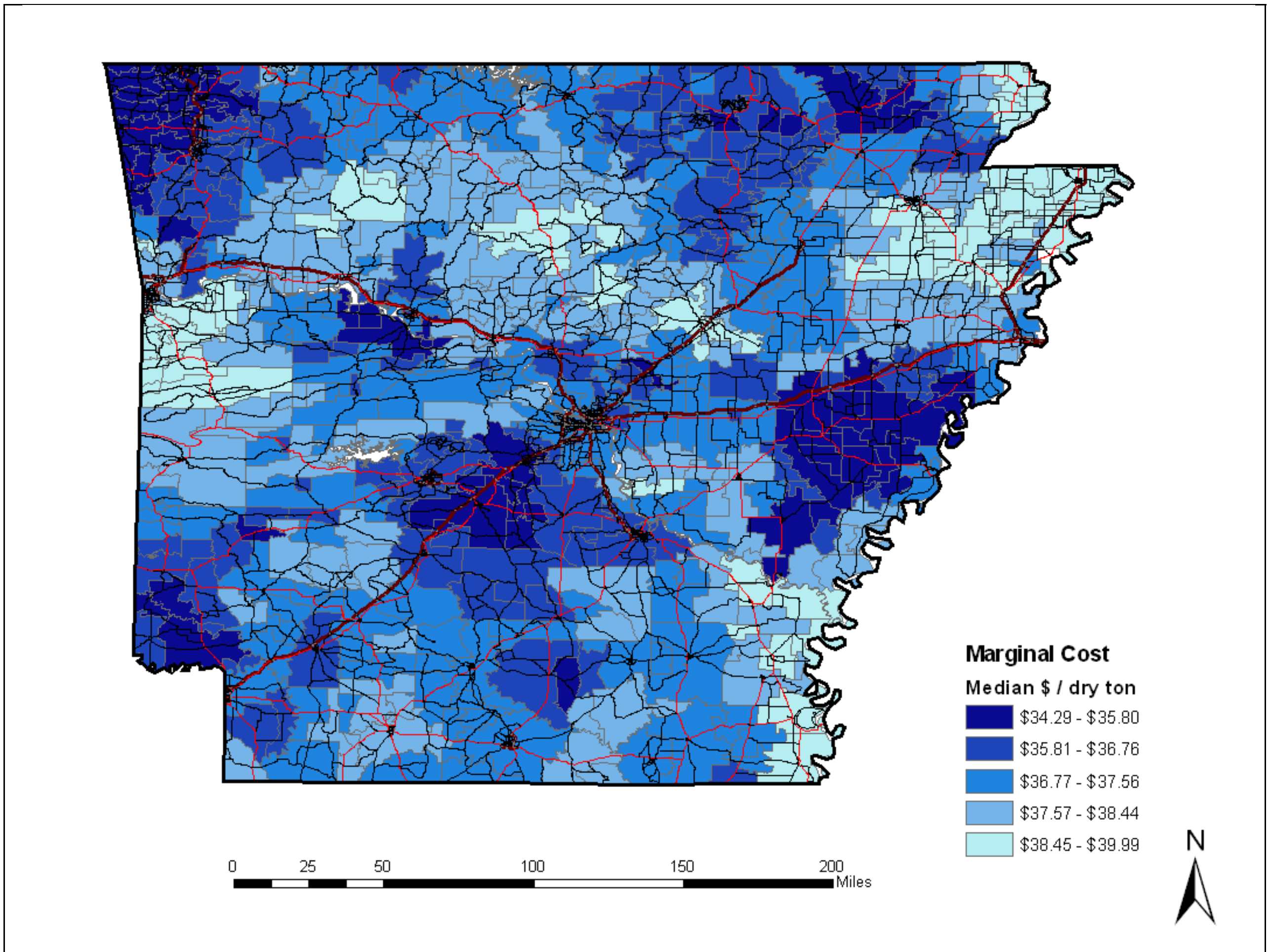

Figure B.2. Distribution of median marginal costs for total mill residues for Arkansas.

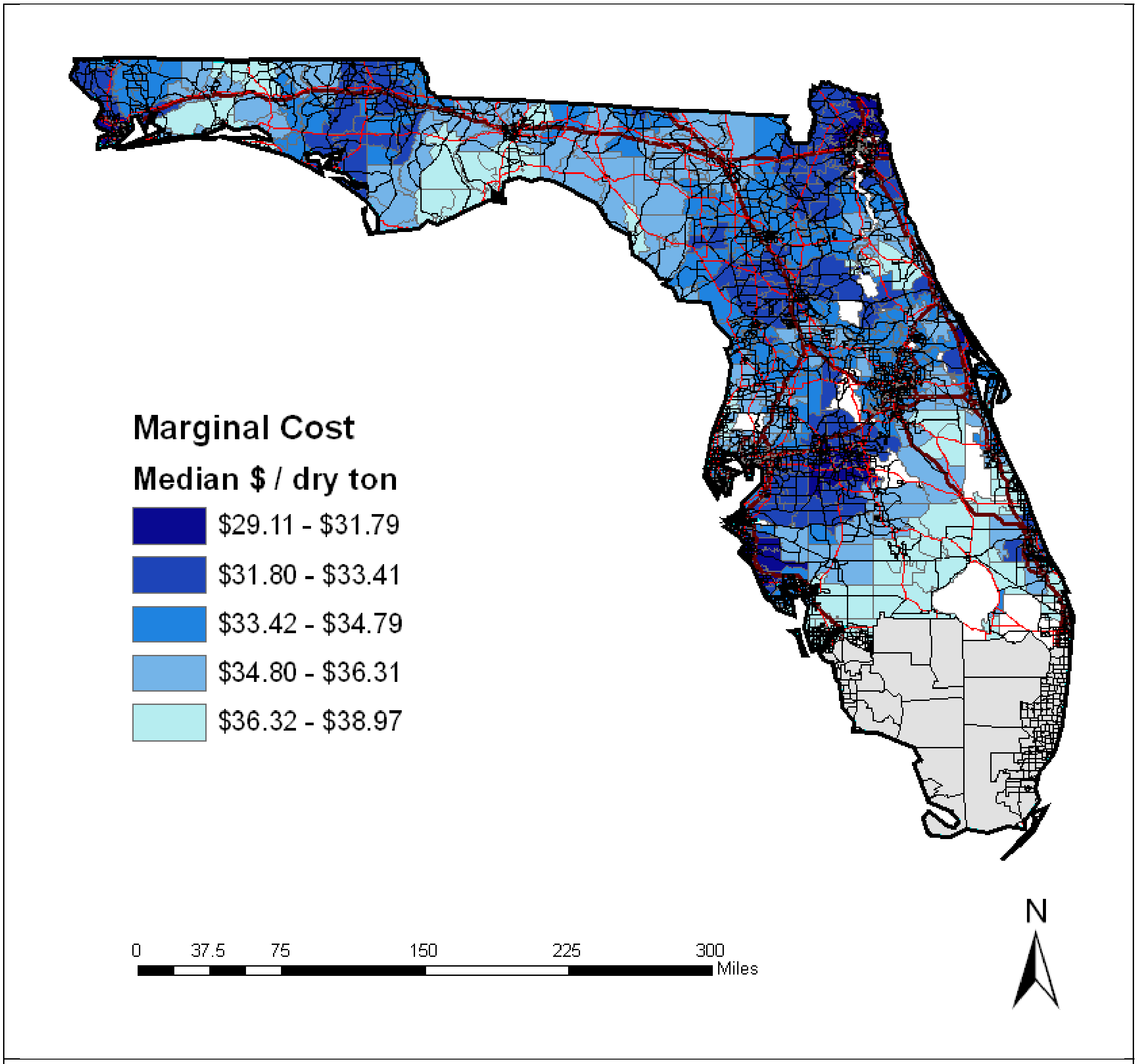

Figure B.3. Distribution of median marginal costs for total mill residues for Florida.

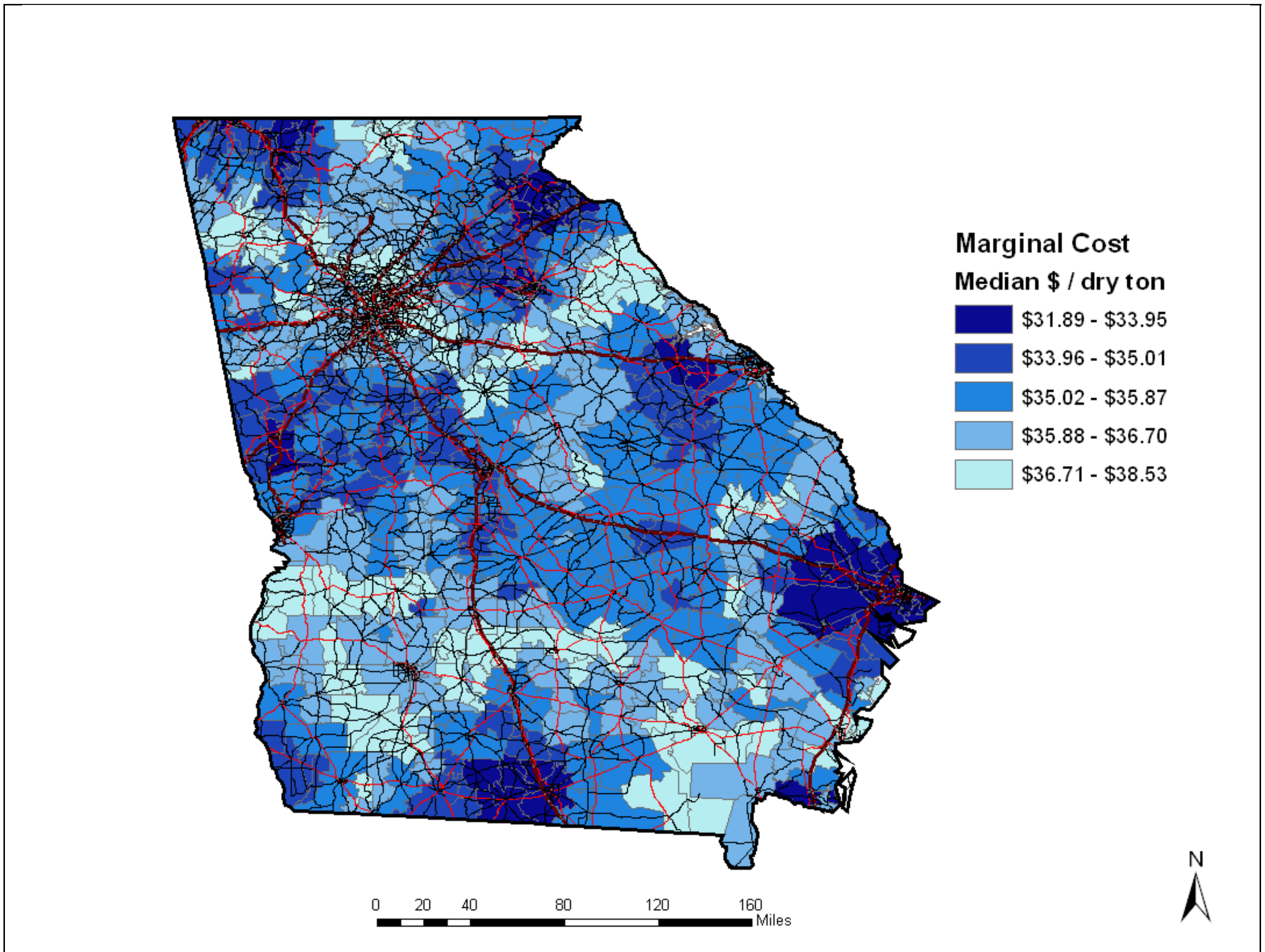

Figure B.4. Distribution of median marginal costs for total mill residues for Georgia.

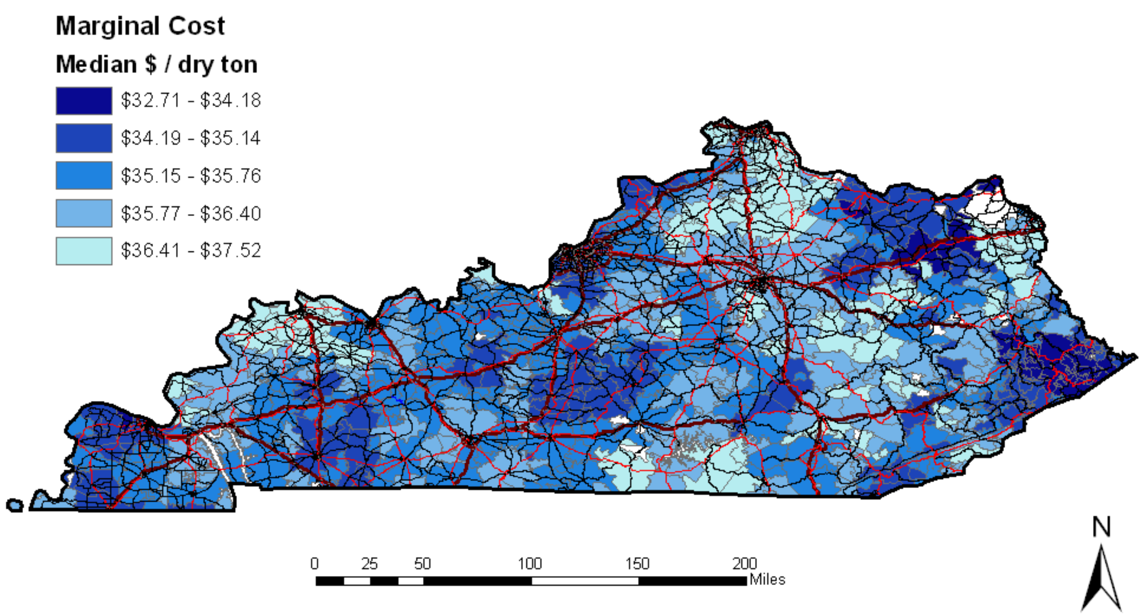

Figure B.5. Distribution of median marginal costs for total mill residues for Kentucky.

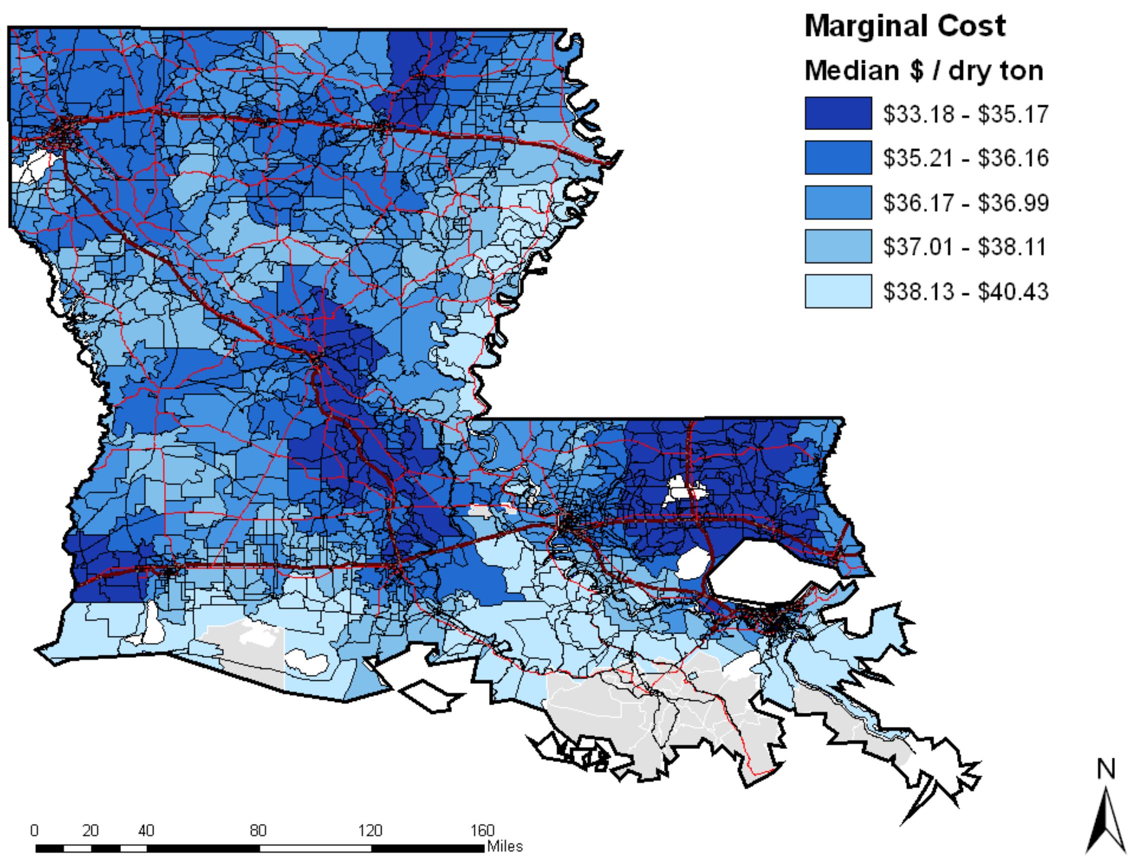

Figure B.6. Distribution of median marginal costs for total mill residues for Louisiana.

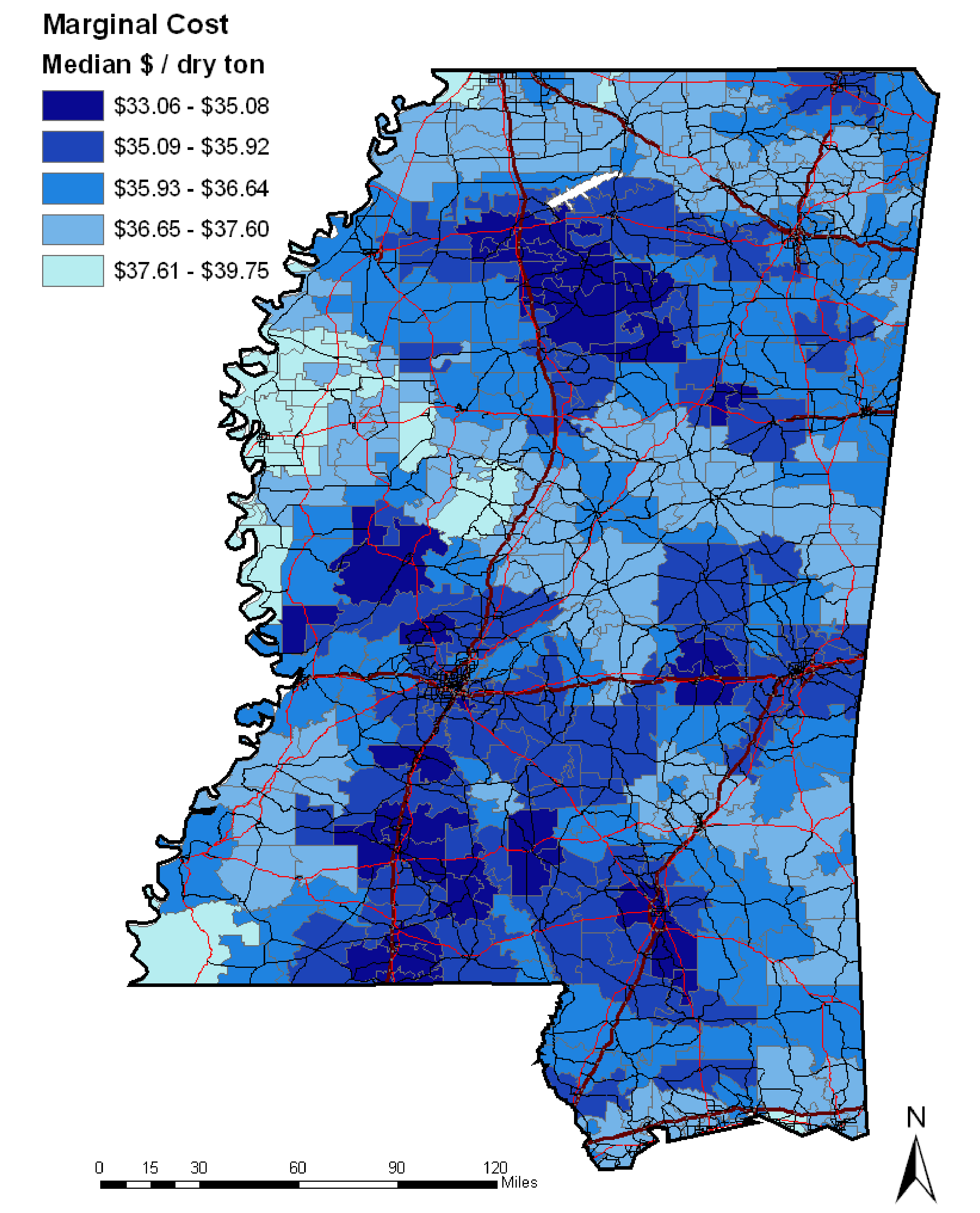

Figure B.7. Distribution of median marginal costs for total mill residues for Mississippi.

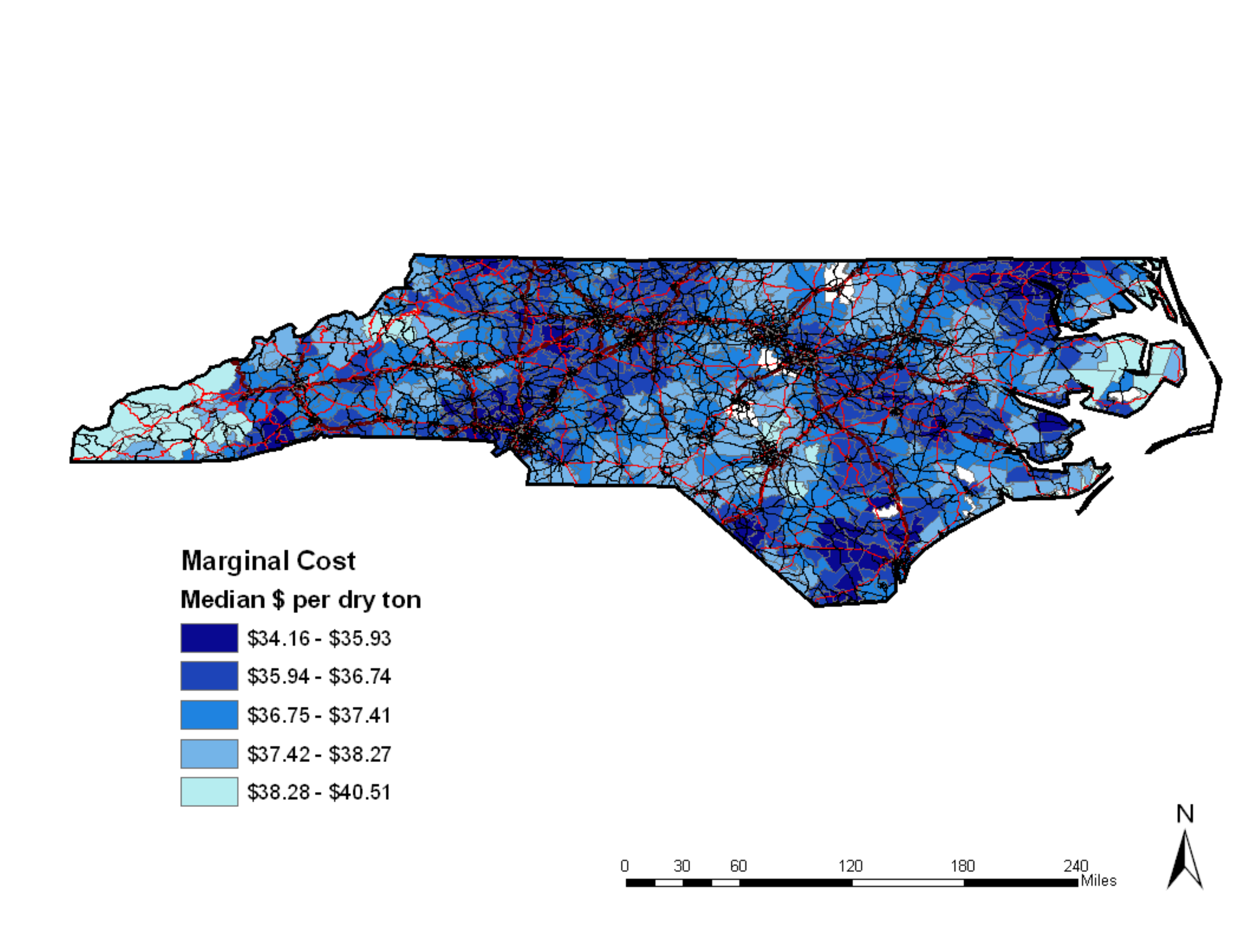

Figure B.8. Distribution of median marginal costs for total mill residues for North Carolina.

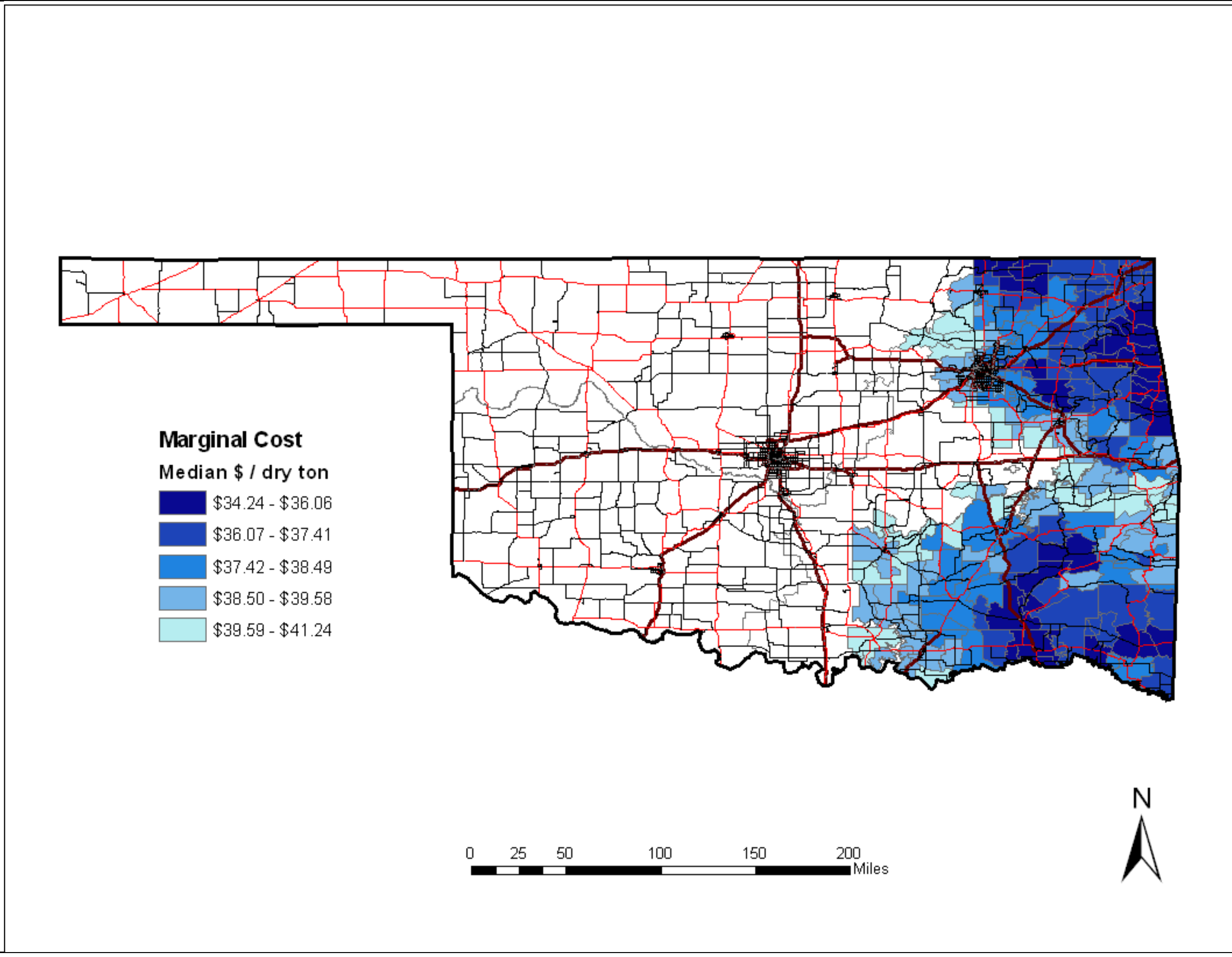

Figure B.9. Distribution of median marginal costs for total mill residues for Oklahoma.

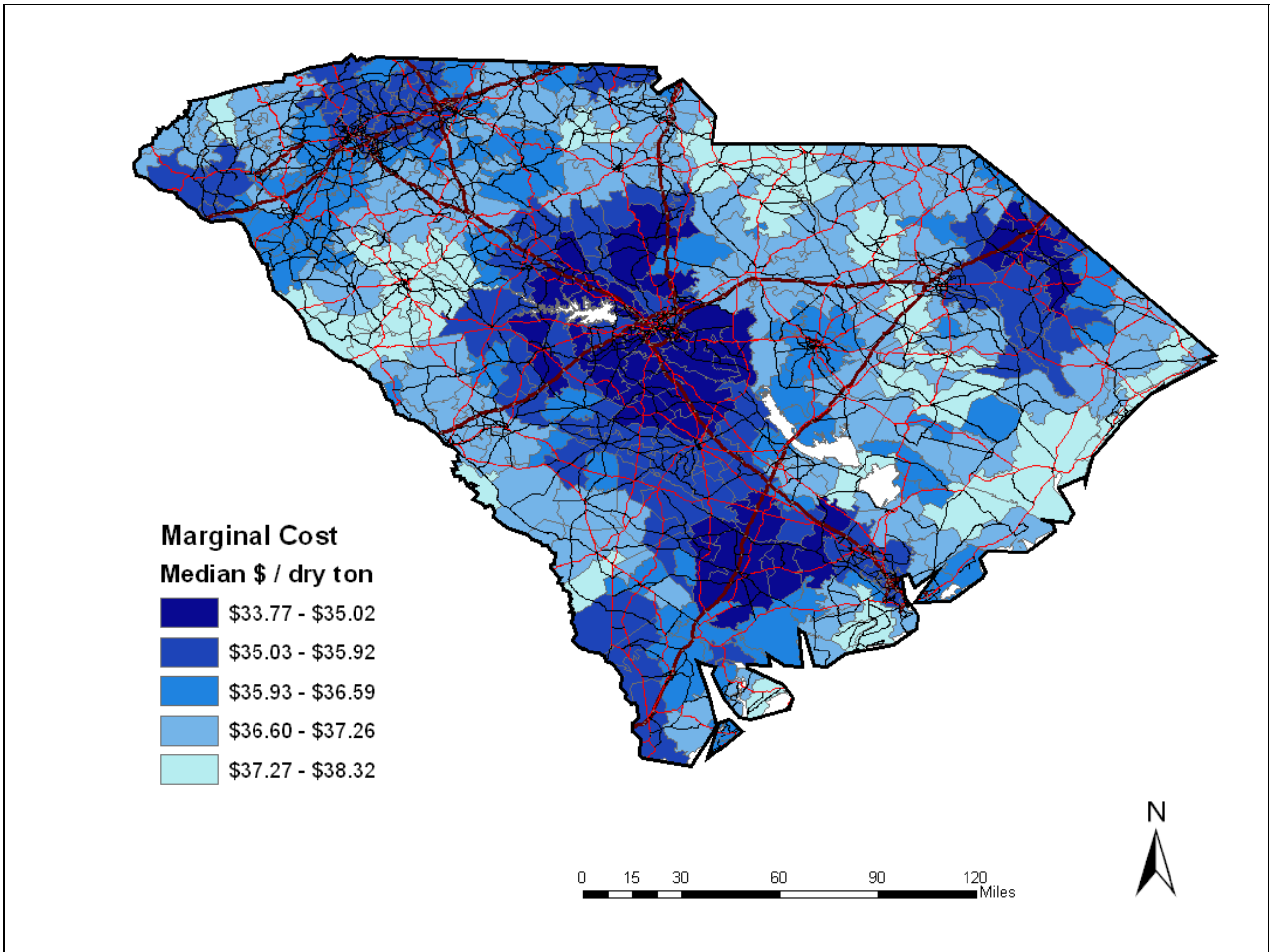

Figure B.10. Distribution of median marginal costs for total mill residues for South Carolina.

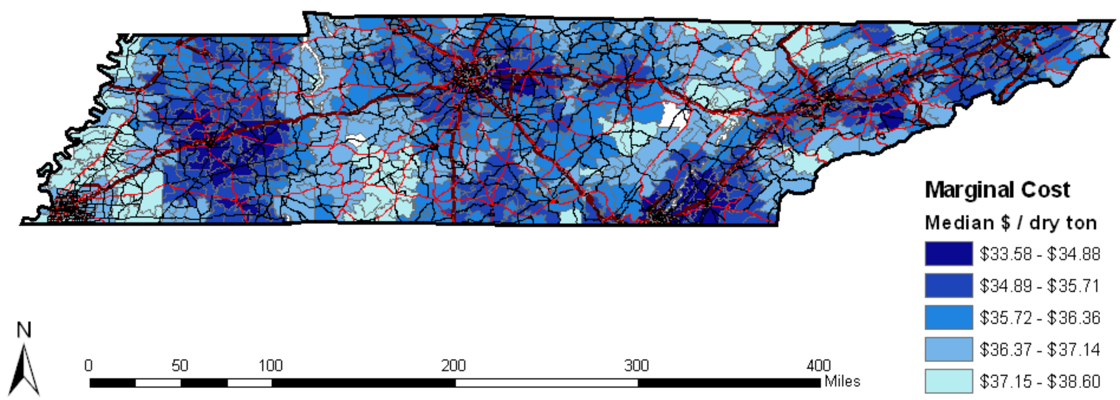

Figure B.11. Distribution of median marginal costs for total mill residues for Tennessee.

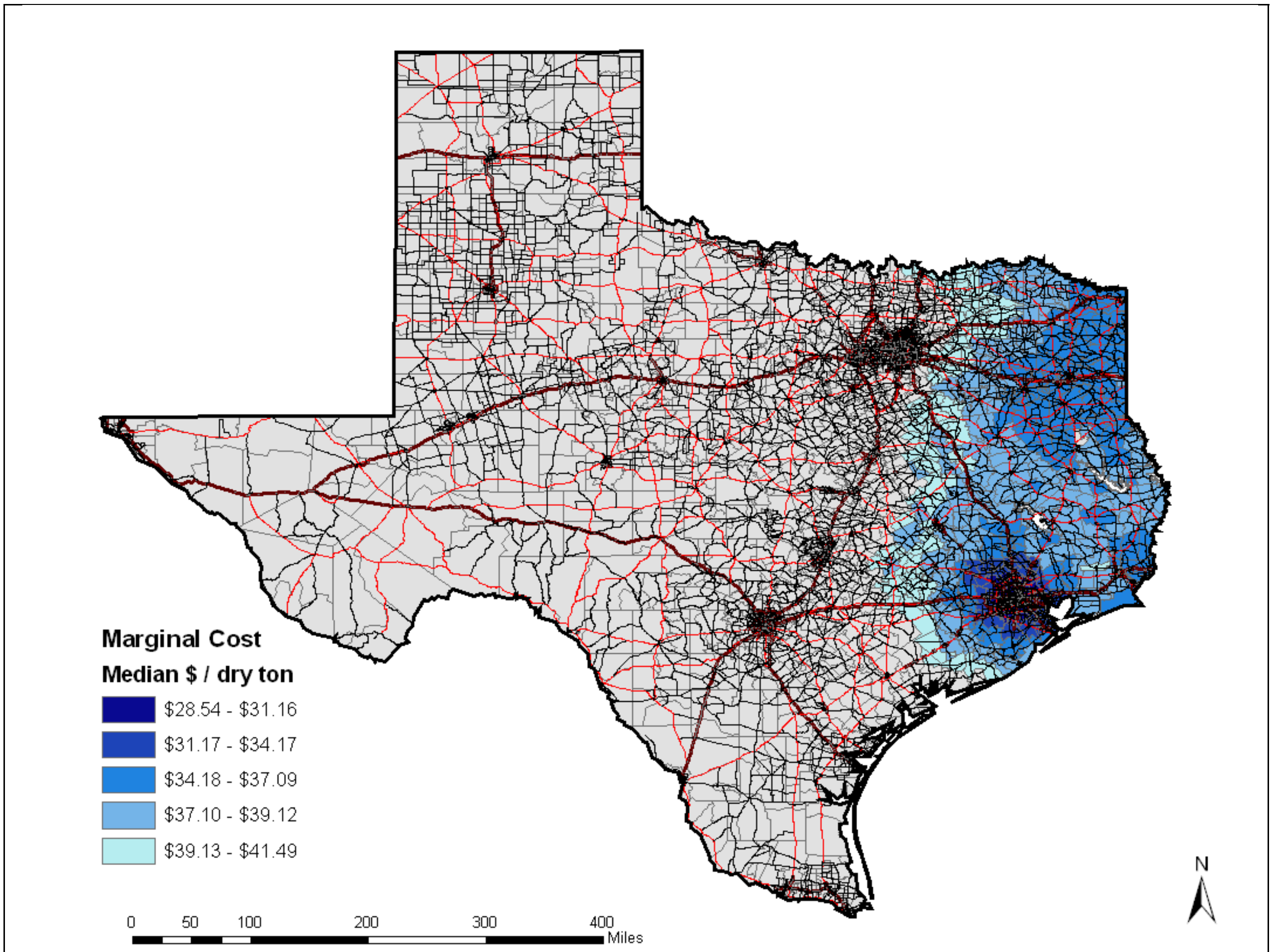

Figure B.12. Distribution of median marginal costs for total mill residues for Texas.

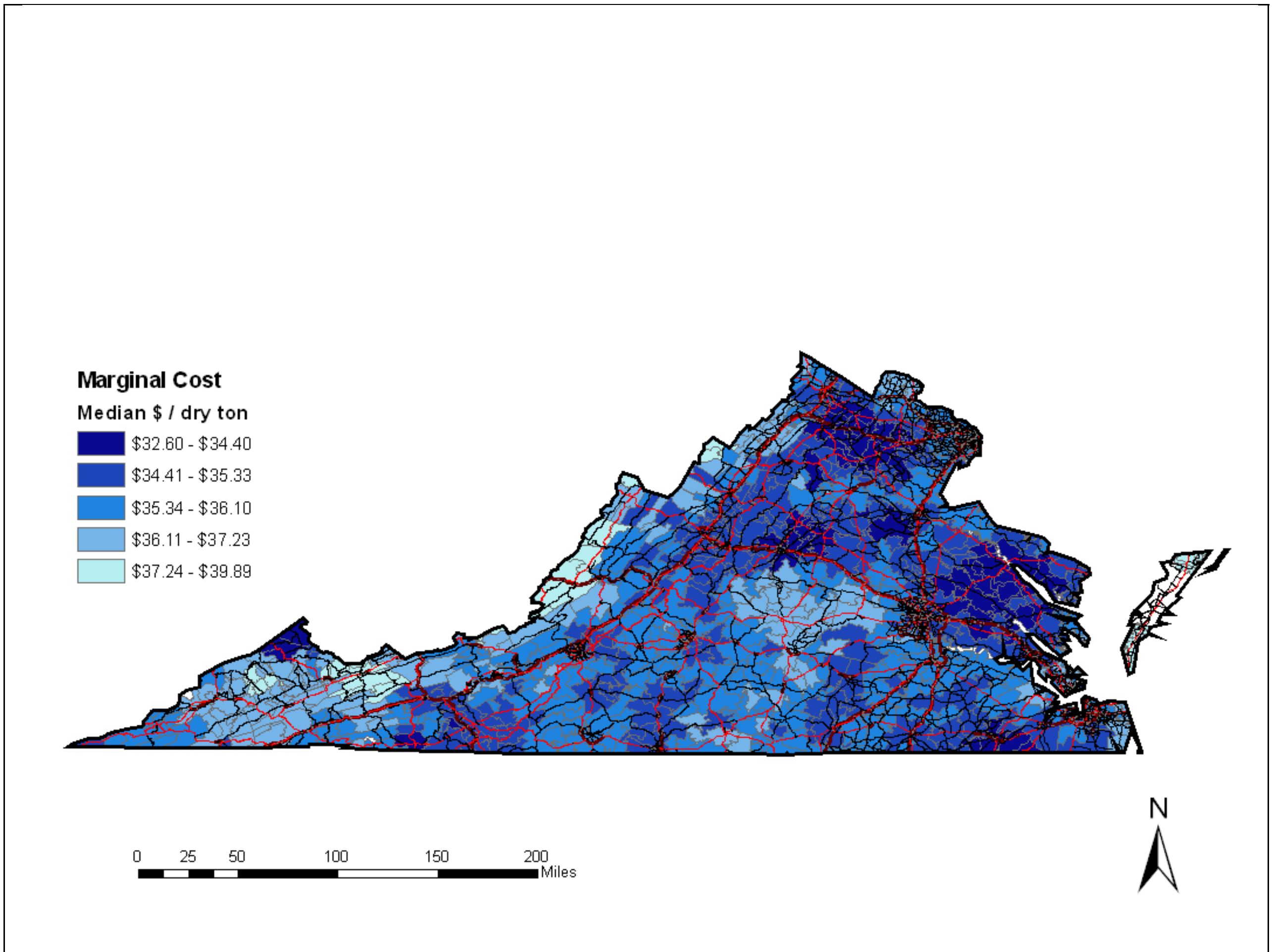

Figure B.13. Distribution of median marginal costs for total mill residues for Virginia.

Appendix C

"Kriged" ZCTA maps for total (hardwood and softwood) mill residues categorized by median marginal cost

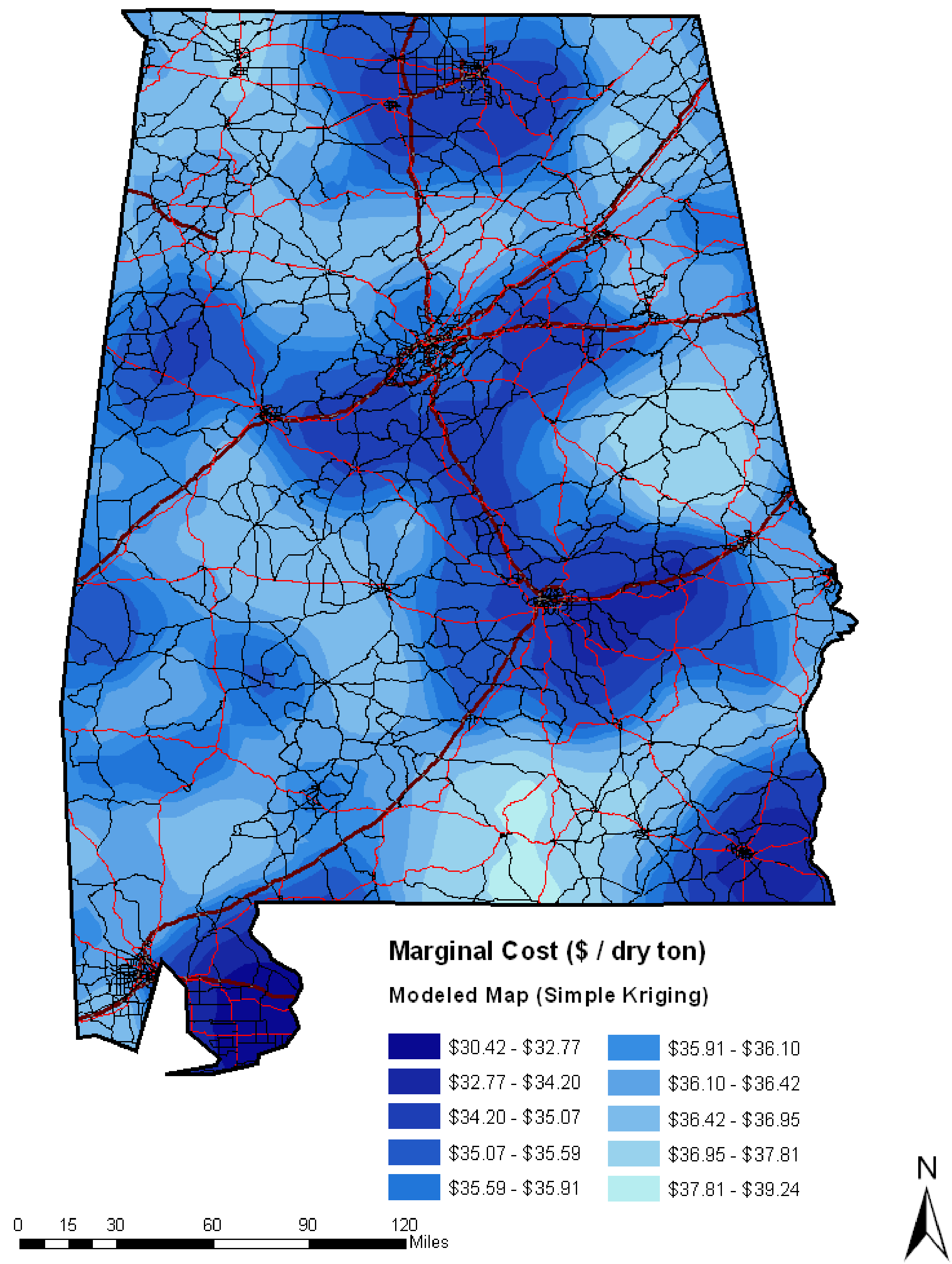

Figure C.1. "Kriged" distribution of median marginal costs for total mill residues for Alabama.

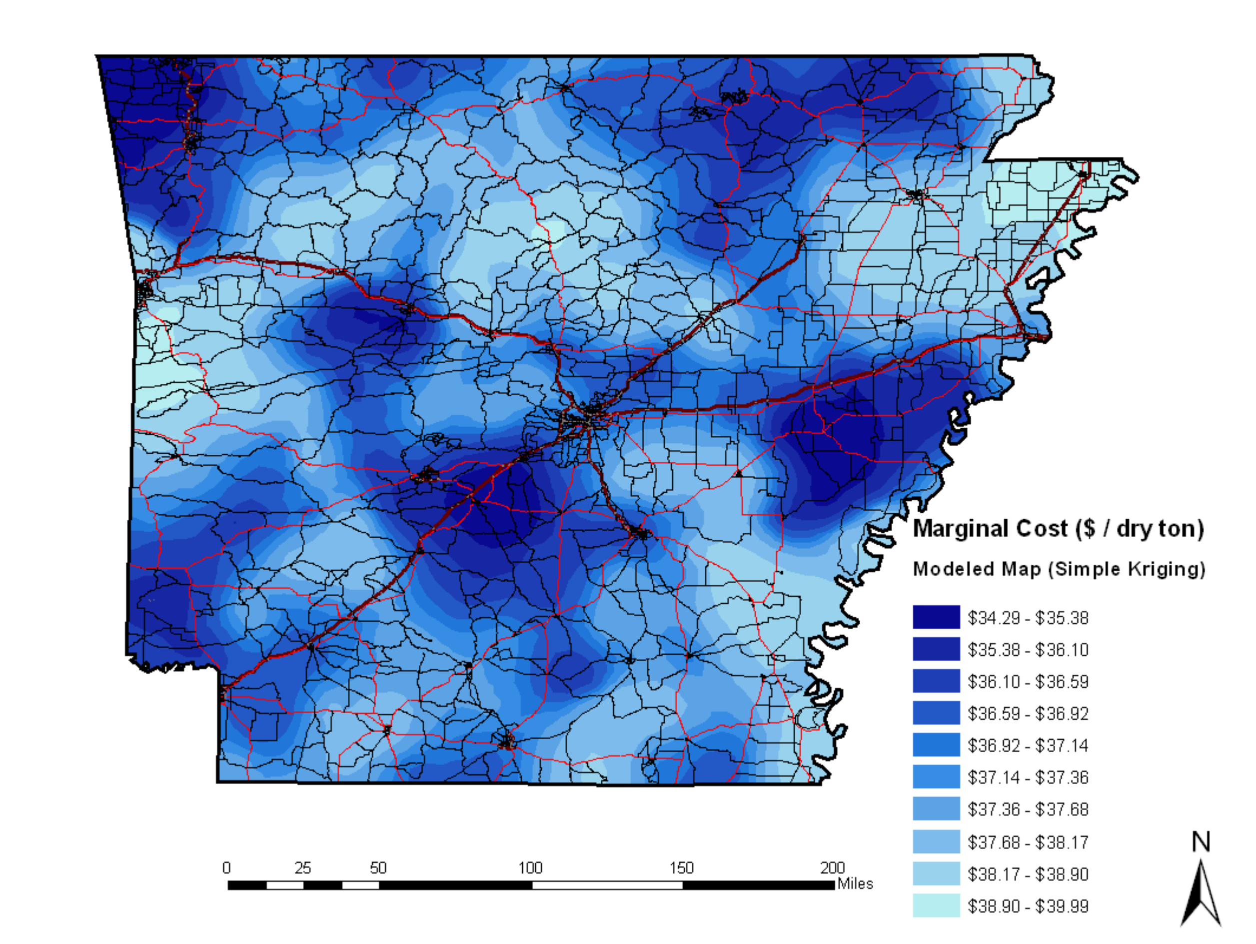

Figure C.2. "Kriged" distribution of median marginal costs for total mill residues for Arkansas.

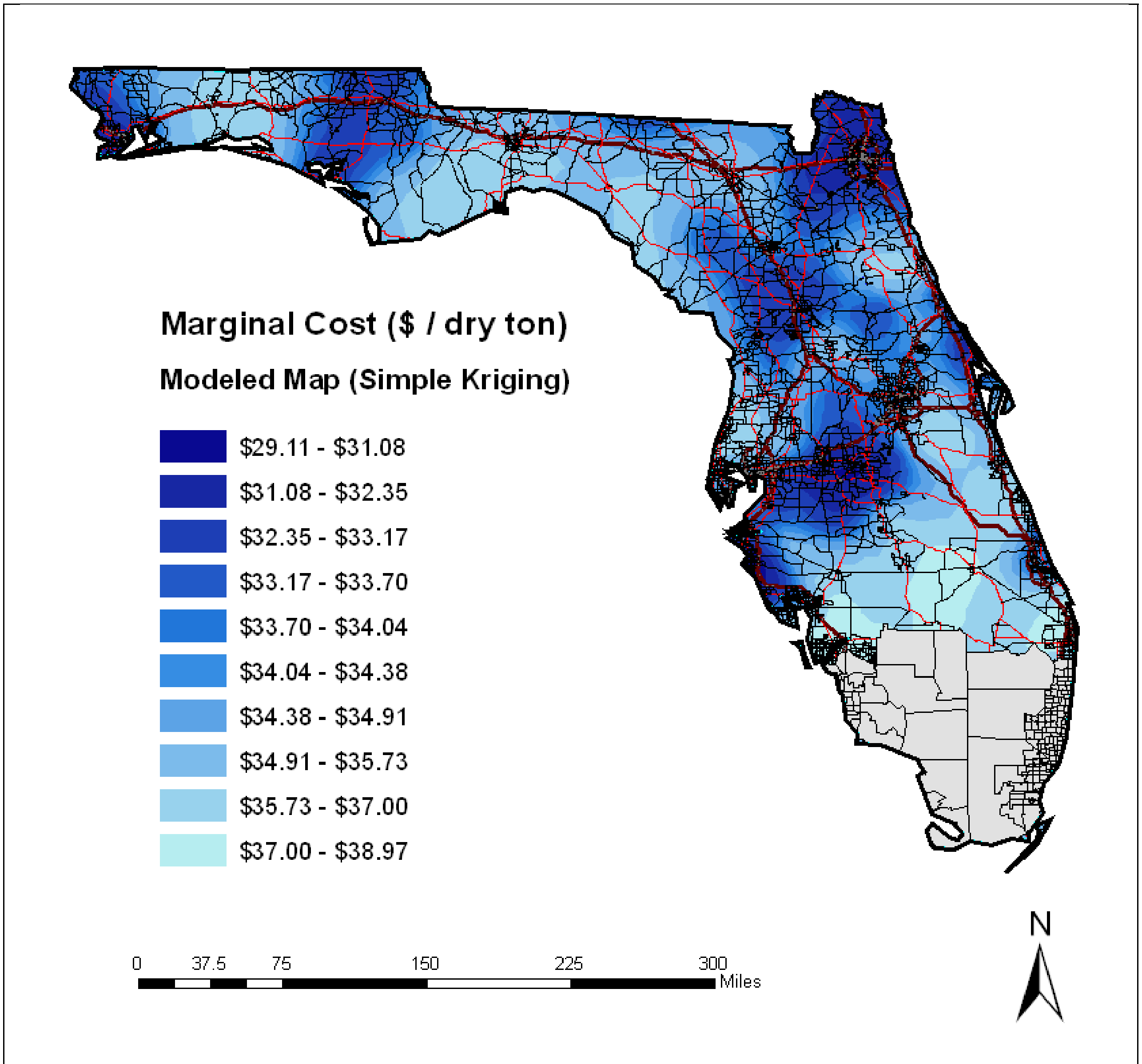

Figure C.3. "Kriged" distribution of median marginal costs for total mill residues for Florida.

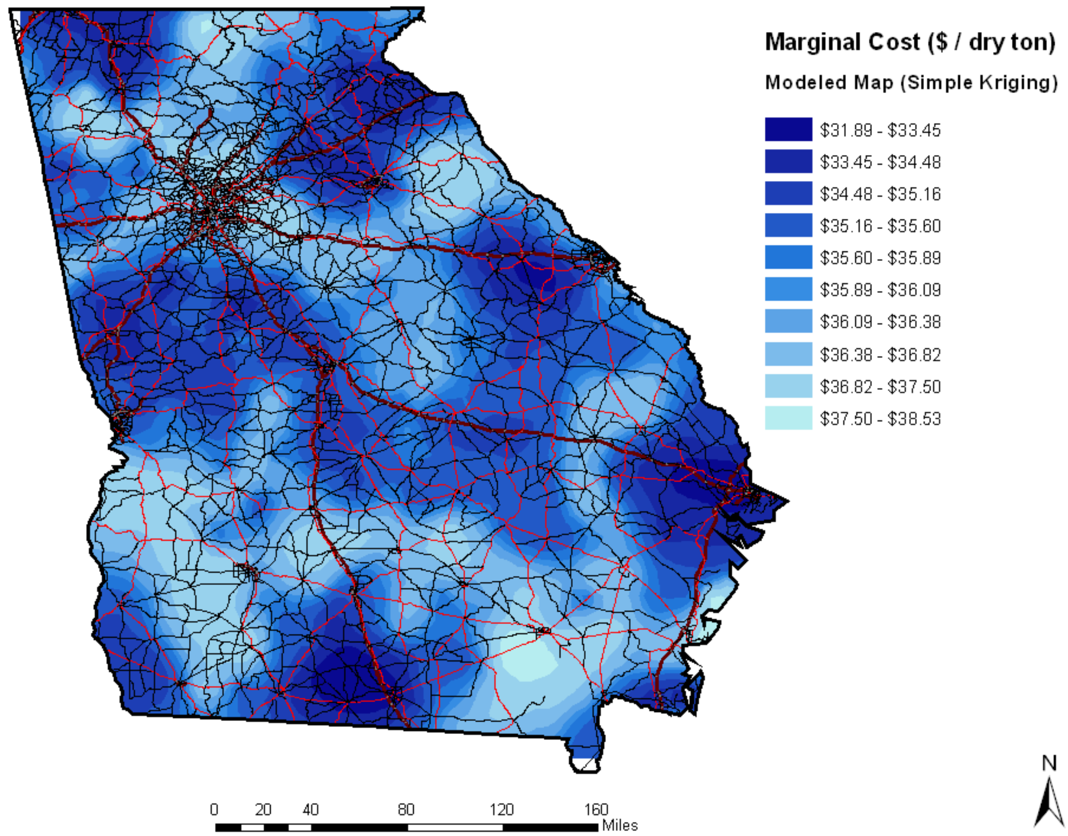

Figure C.4. "Kriged" distribution of median marginal costs for total mill residues for Georgia.

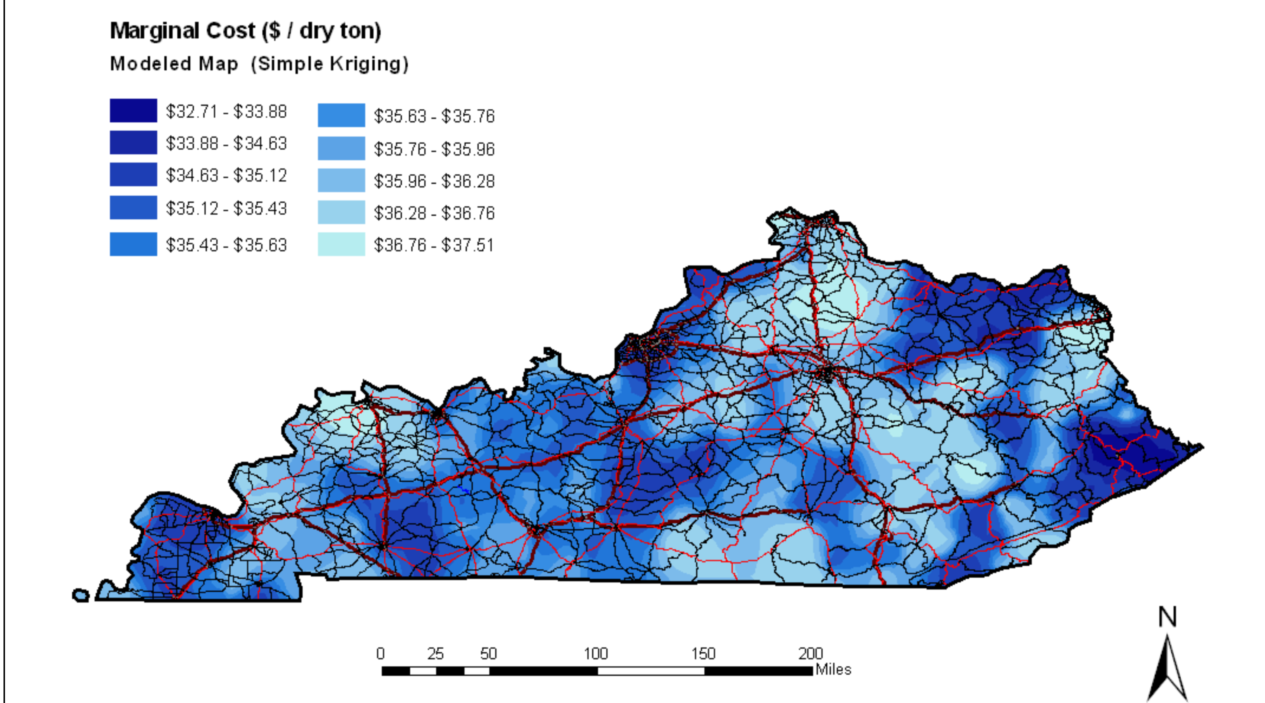

Figure C.5. "Kriged" distribution of median marginal costs for total mill residues for Kentucky.

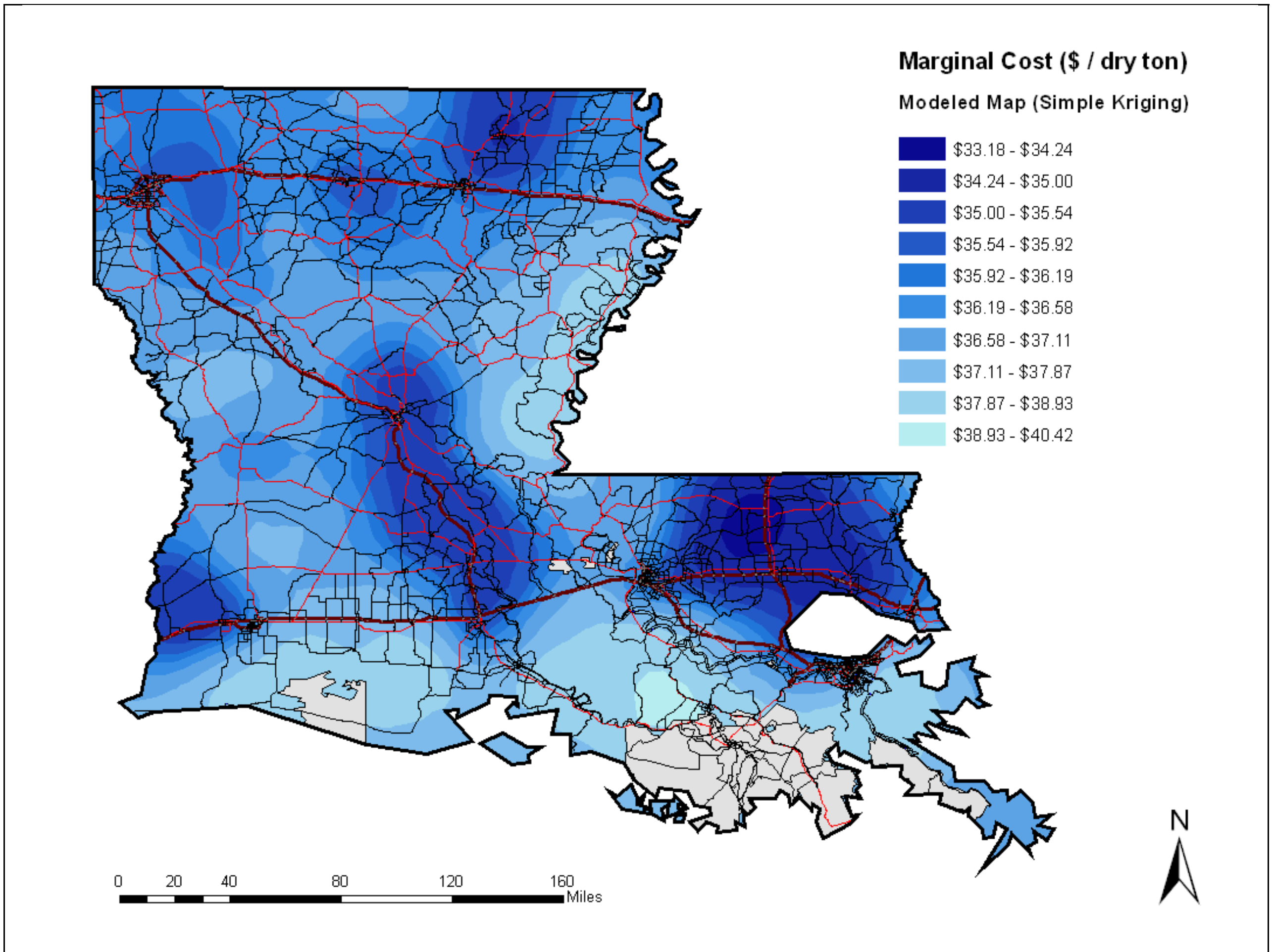

Figure C.6. “Kriged” distribution of median marginal costs for total mill residues for Louisiana.

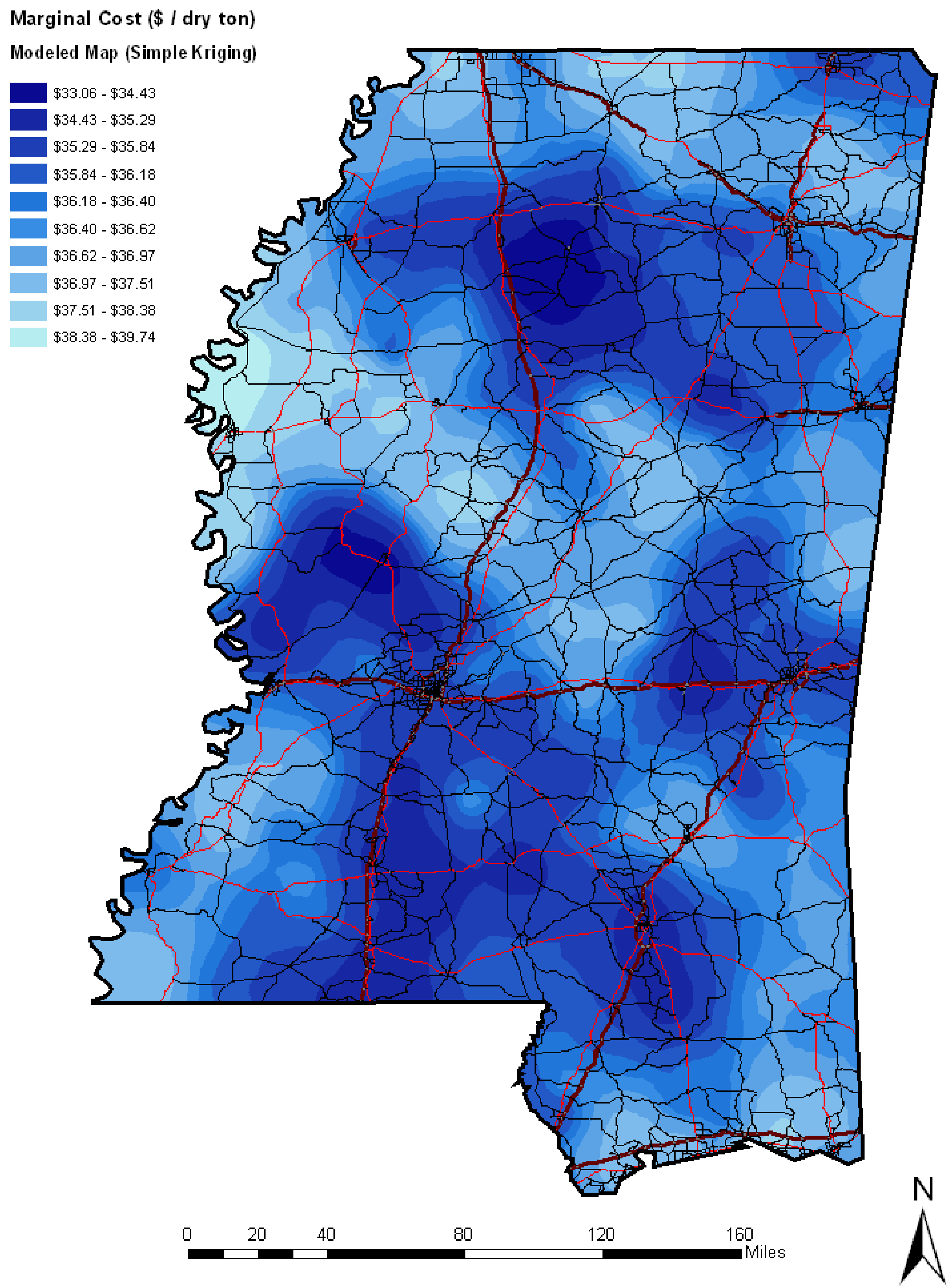

Figure C.7. "Kriged" distribution of median marginal costs for total mill residues for Mississippi.

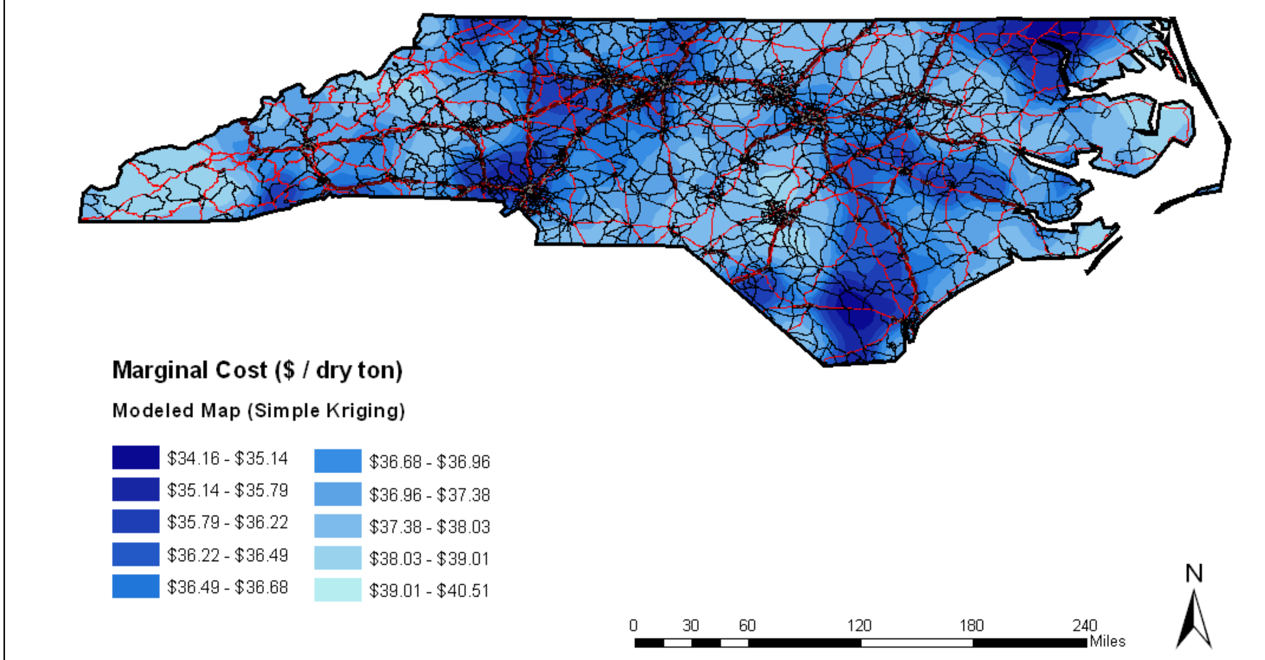

Figure C.8. "Kriged" distribution of median marginal costs for total mill residues for North Carolina.

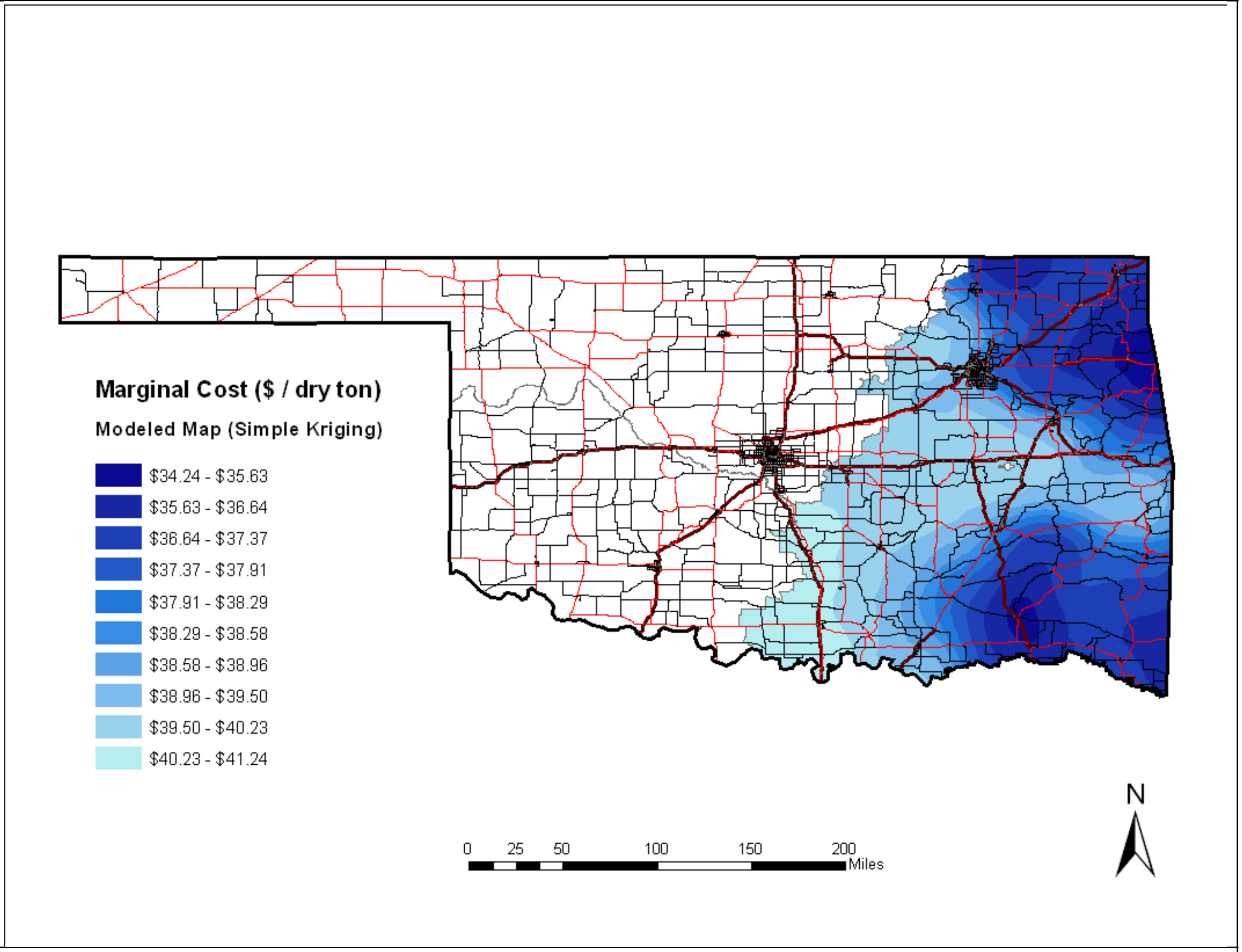

Figure C.9. "Kriged" distribution of median marginal costs for total mill residues for Oklahoma.

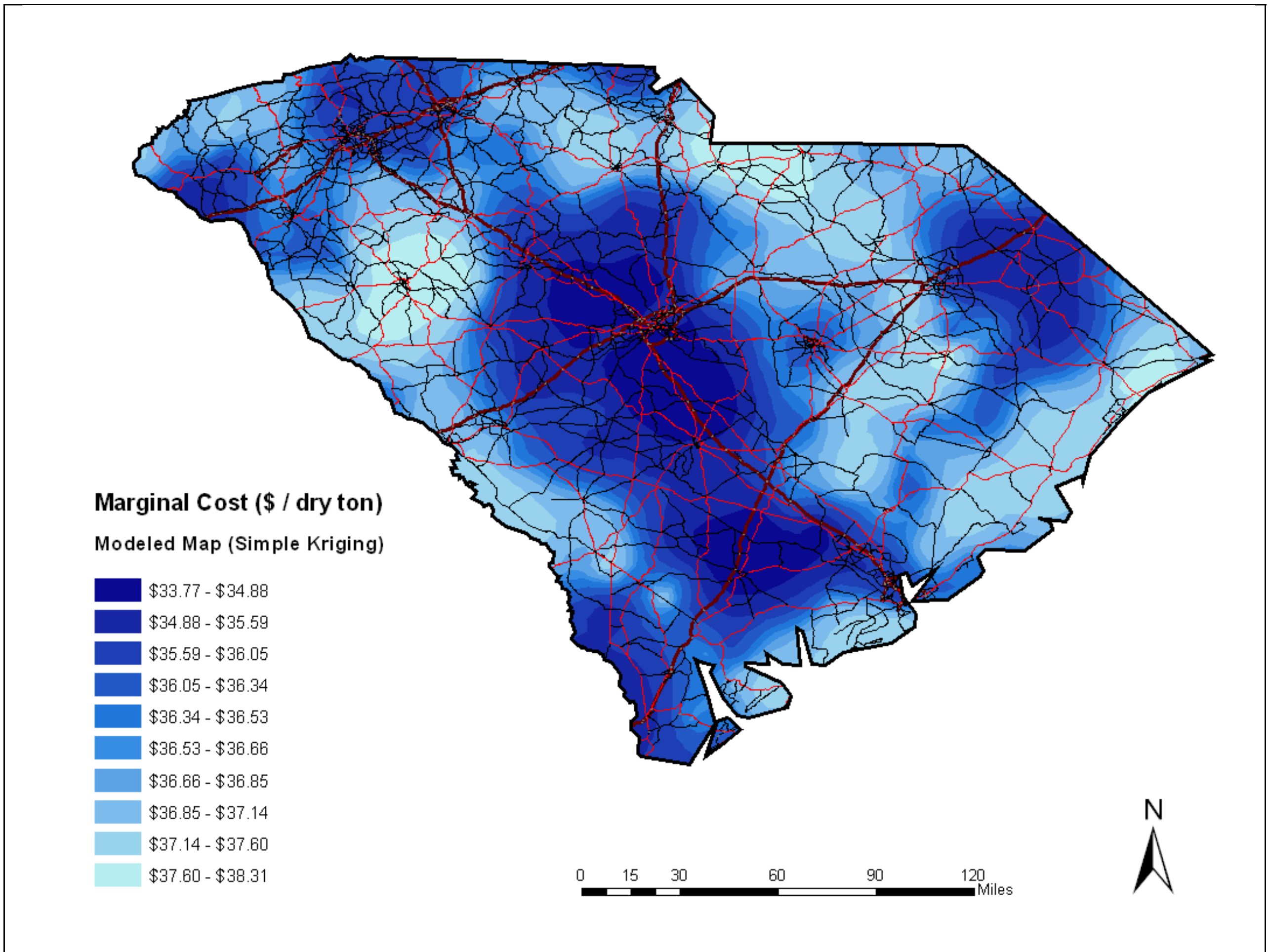

Figure C.10. "Kriged" distribution of median marginal costs for total mill residues for South Carolina.

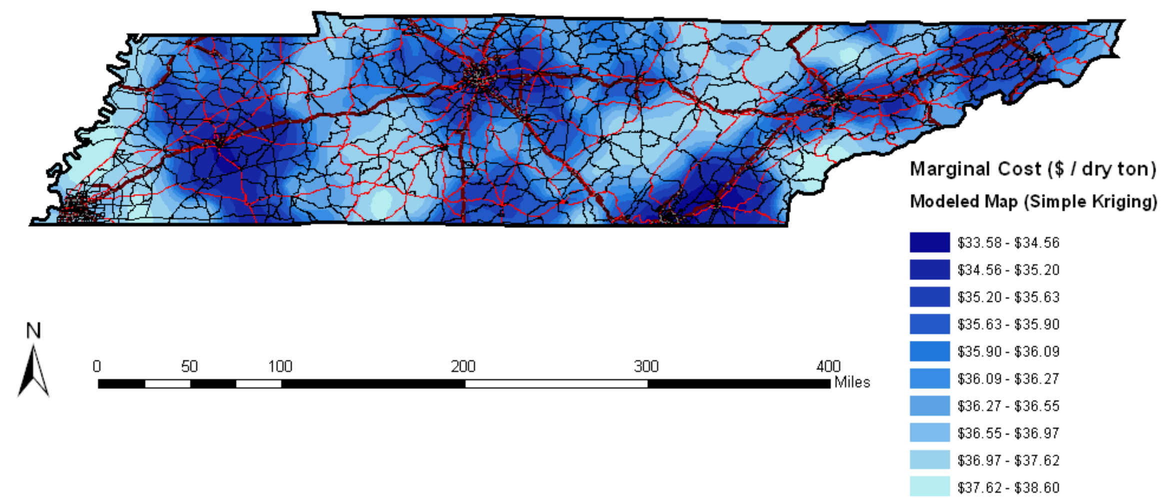

Figure C.11. "Kriged" distribution of median marginal costs for total mill residues for Tennessee.

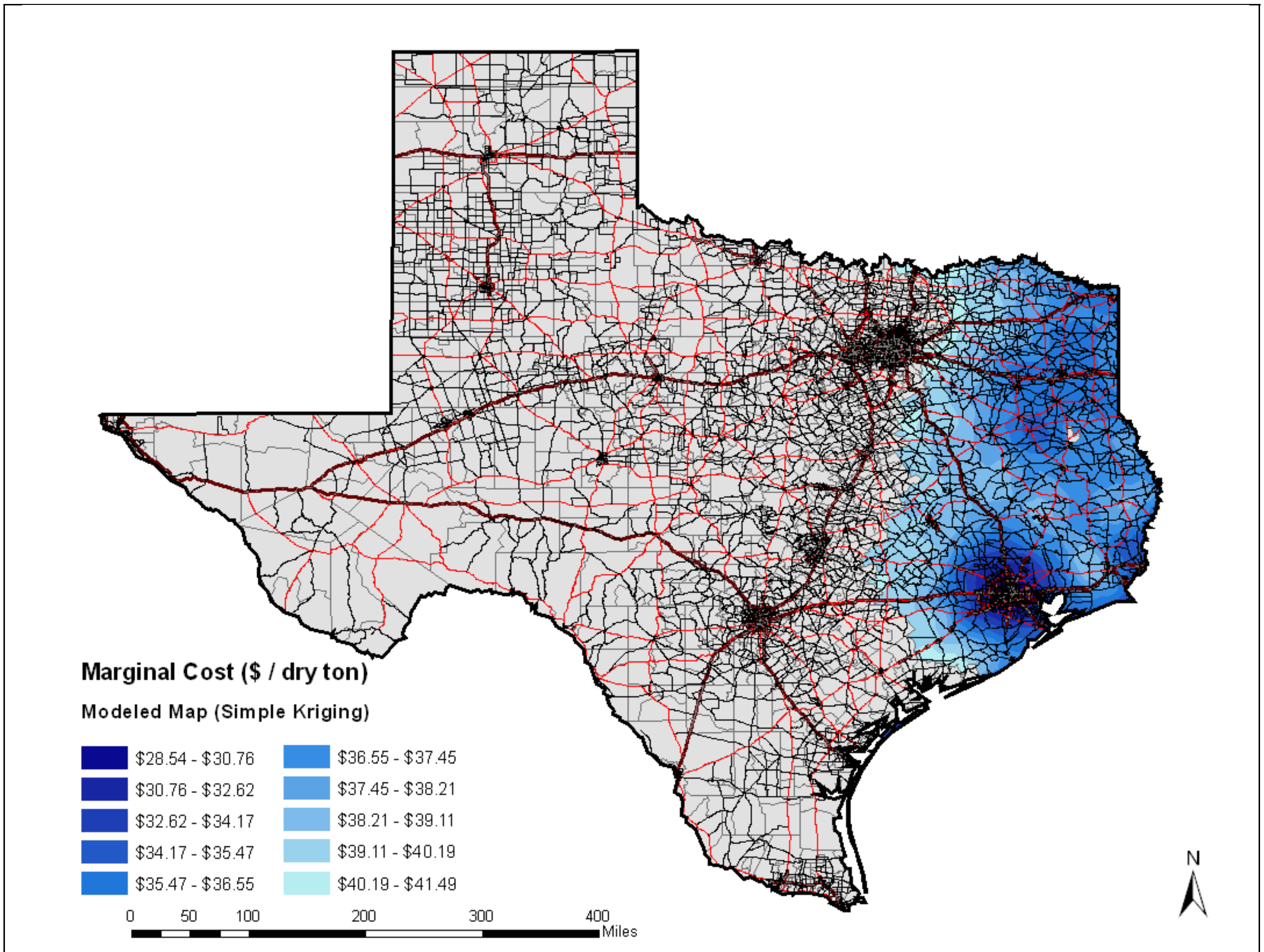

Figure C.12. "Kriged" distribution of median marginal costs for total mill residues for Texas.

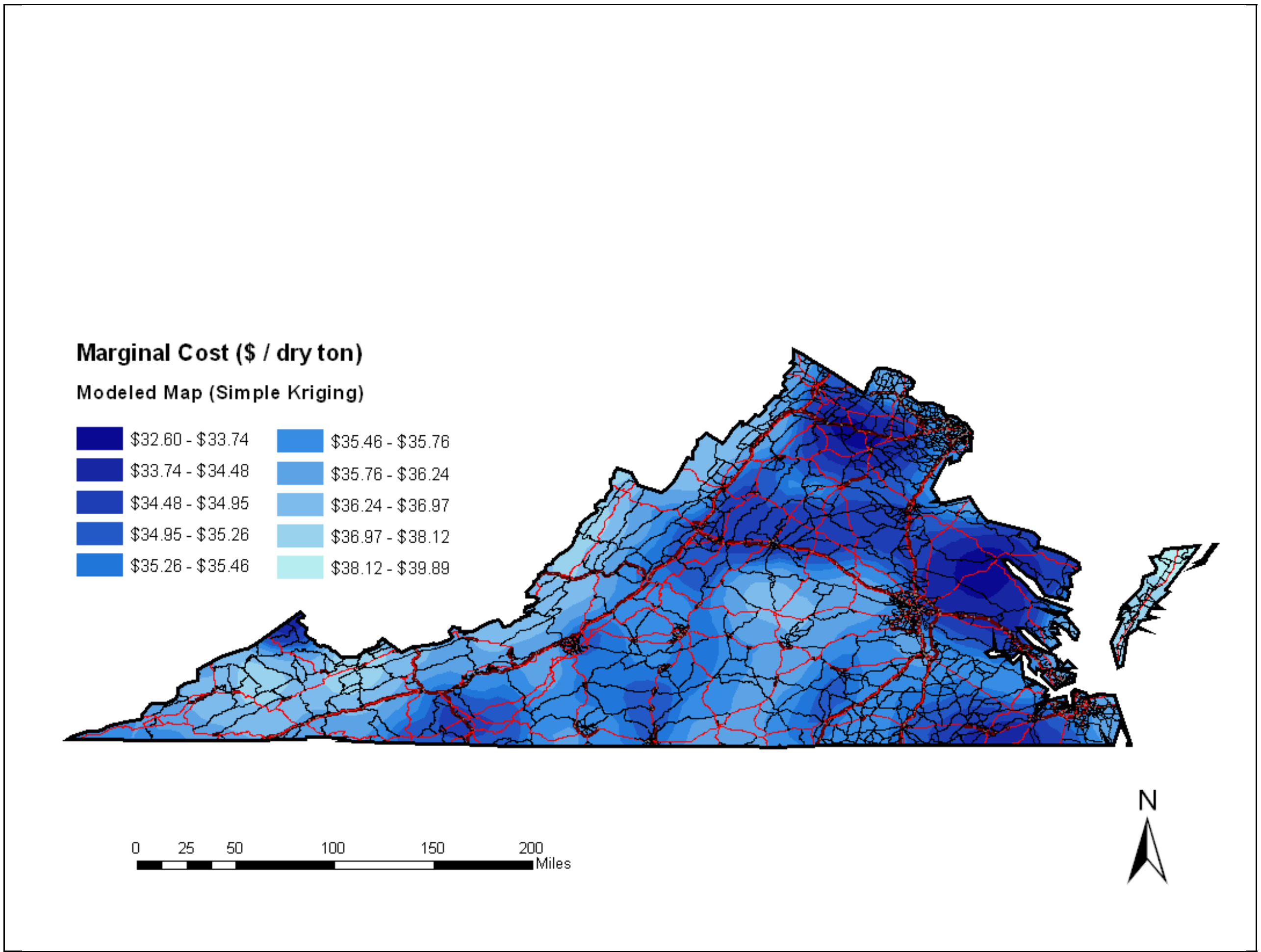

Figure C.13. "Kriged" distribution of median marginal costs for total mill residues for Virginia.

Appendix D

ZCTA maps for total (hardwood and softwood) "at landing" logging residues categorized by median marginal cost

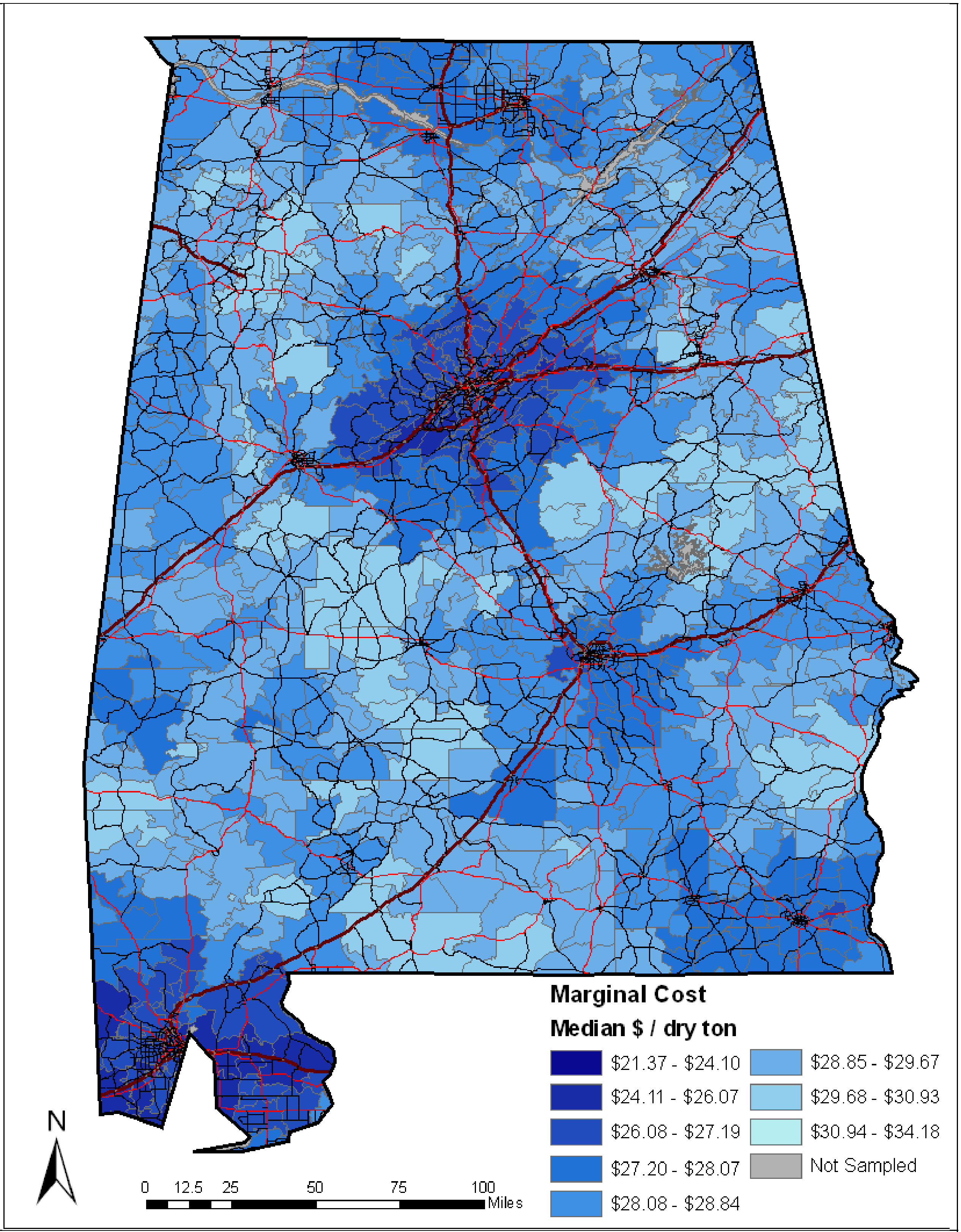

Figure D.1. Distribution of median marginal costs for "at landing" logging residues for Alabama.

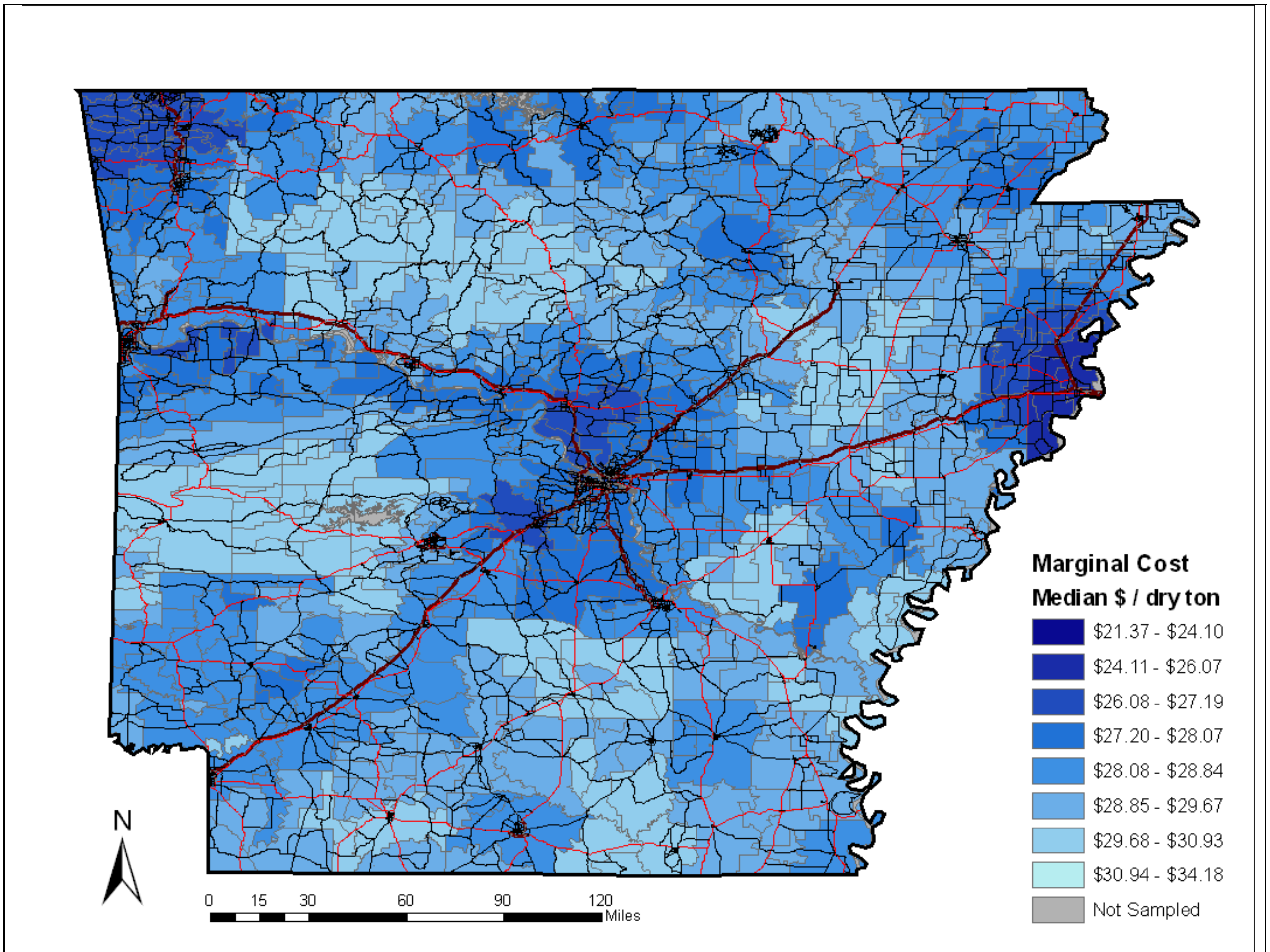

Figure D.2. Distribution of median marginal costs for "at landing" logging residues for Arkansas.

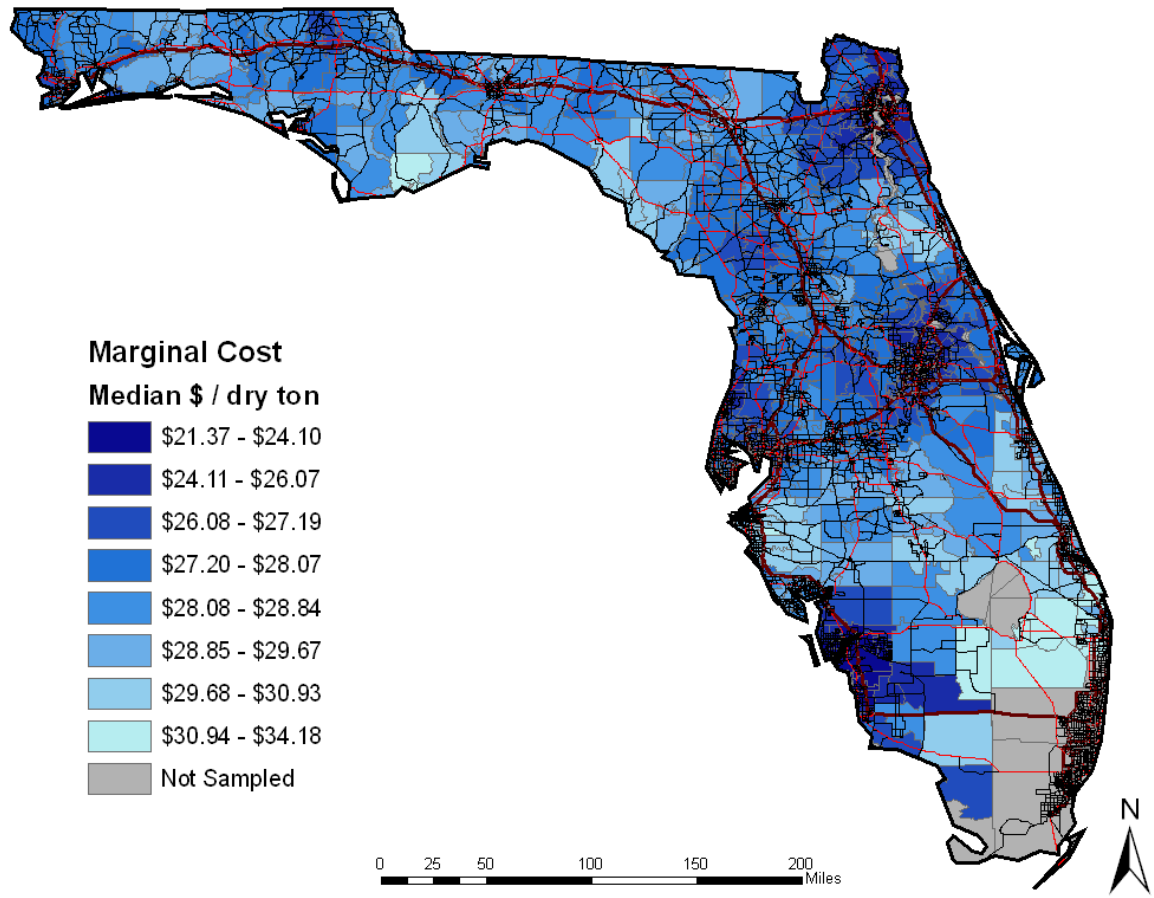

Figure D.3. Distribution of median marginal costs for "at landing" logging residues for Florida.

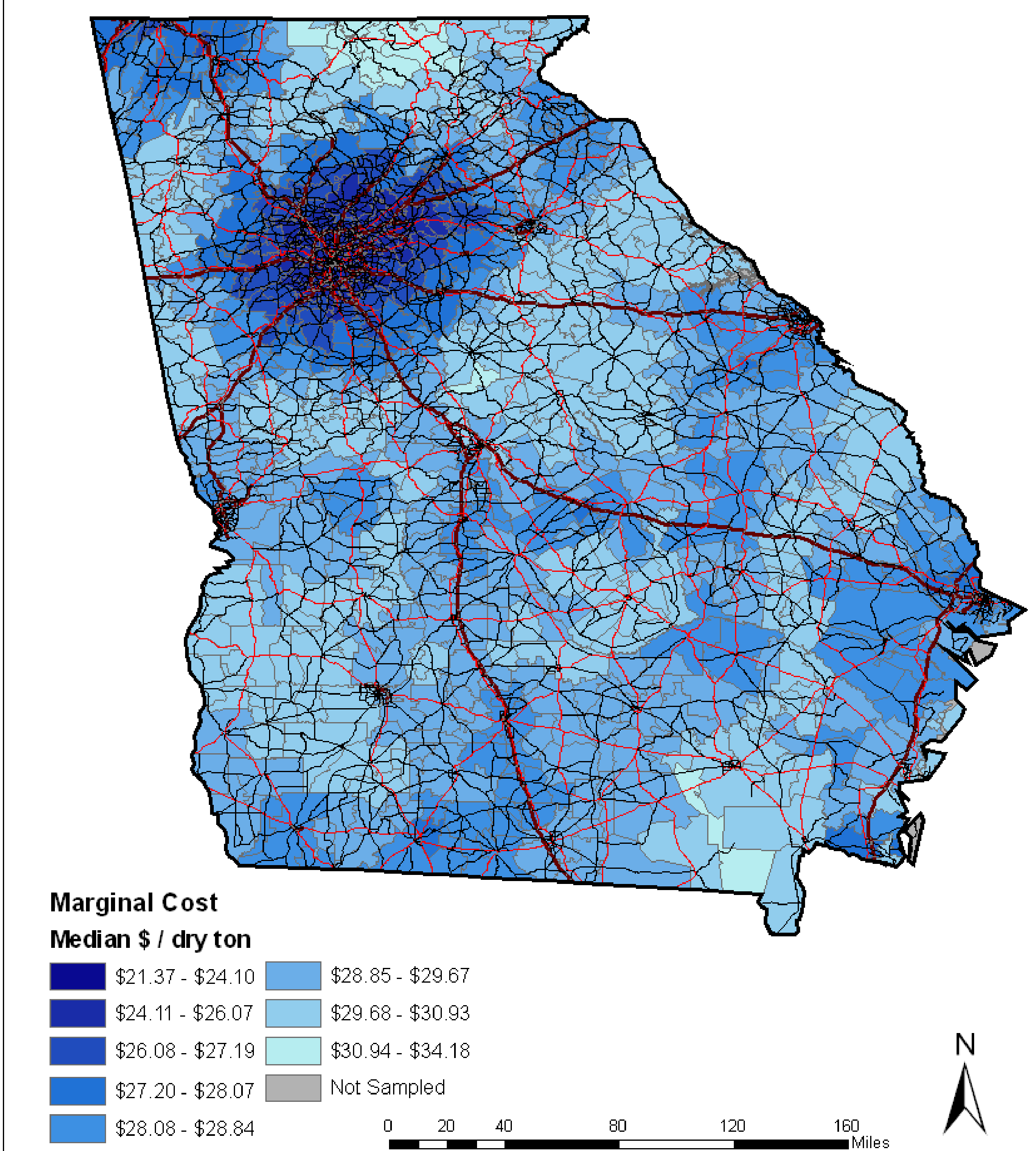

Figure D.4. Distribution of median marginal costs for "at landing" logging residues for Georgia.

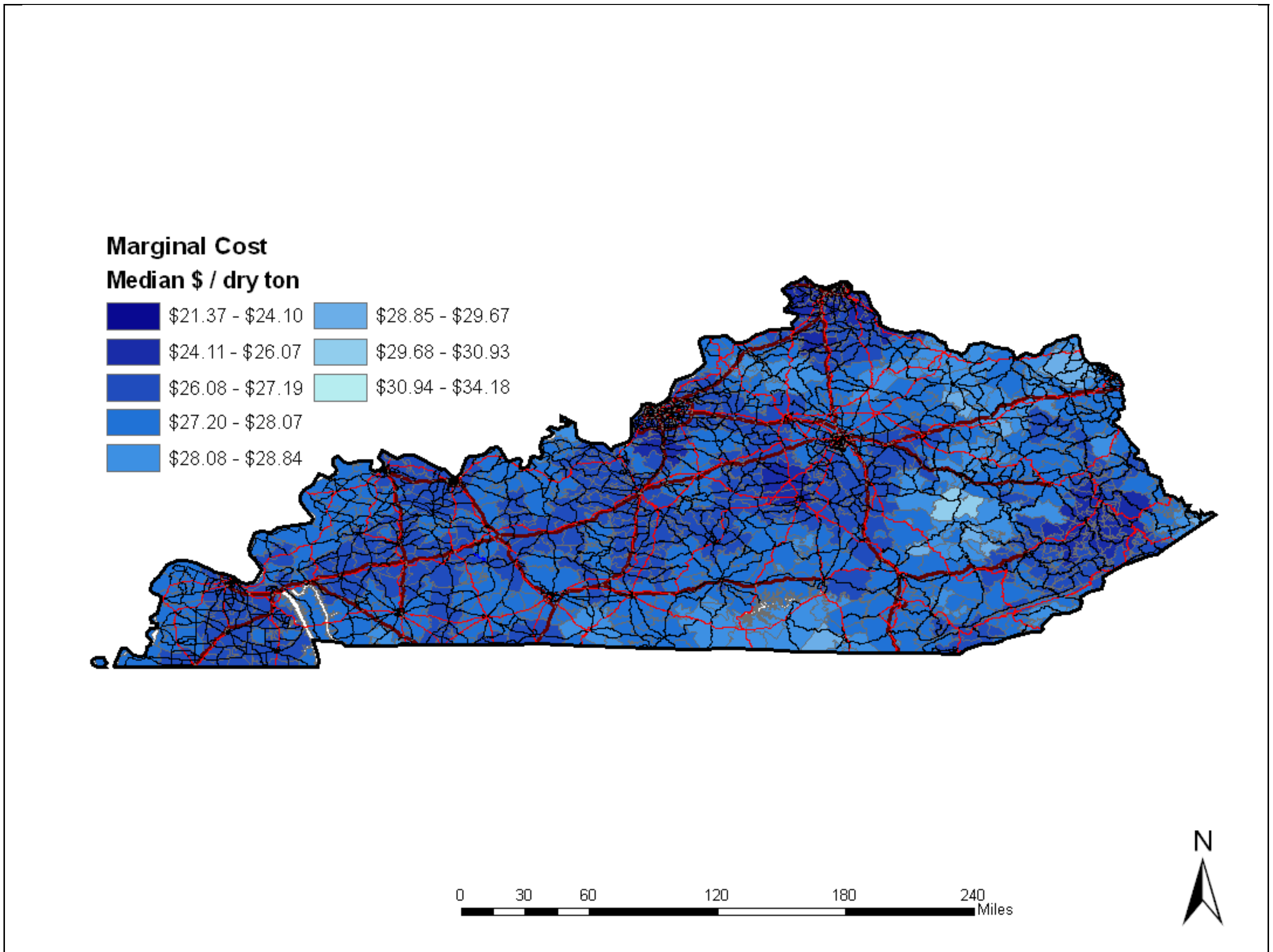

Figure D.5. Distribution of median marginal costs for "at landing" logging residues for Kentucky.

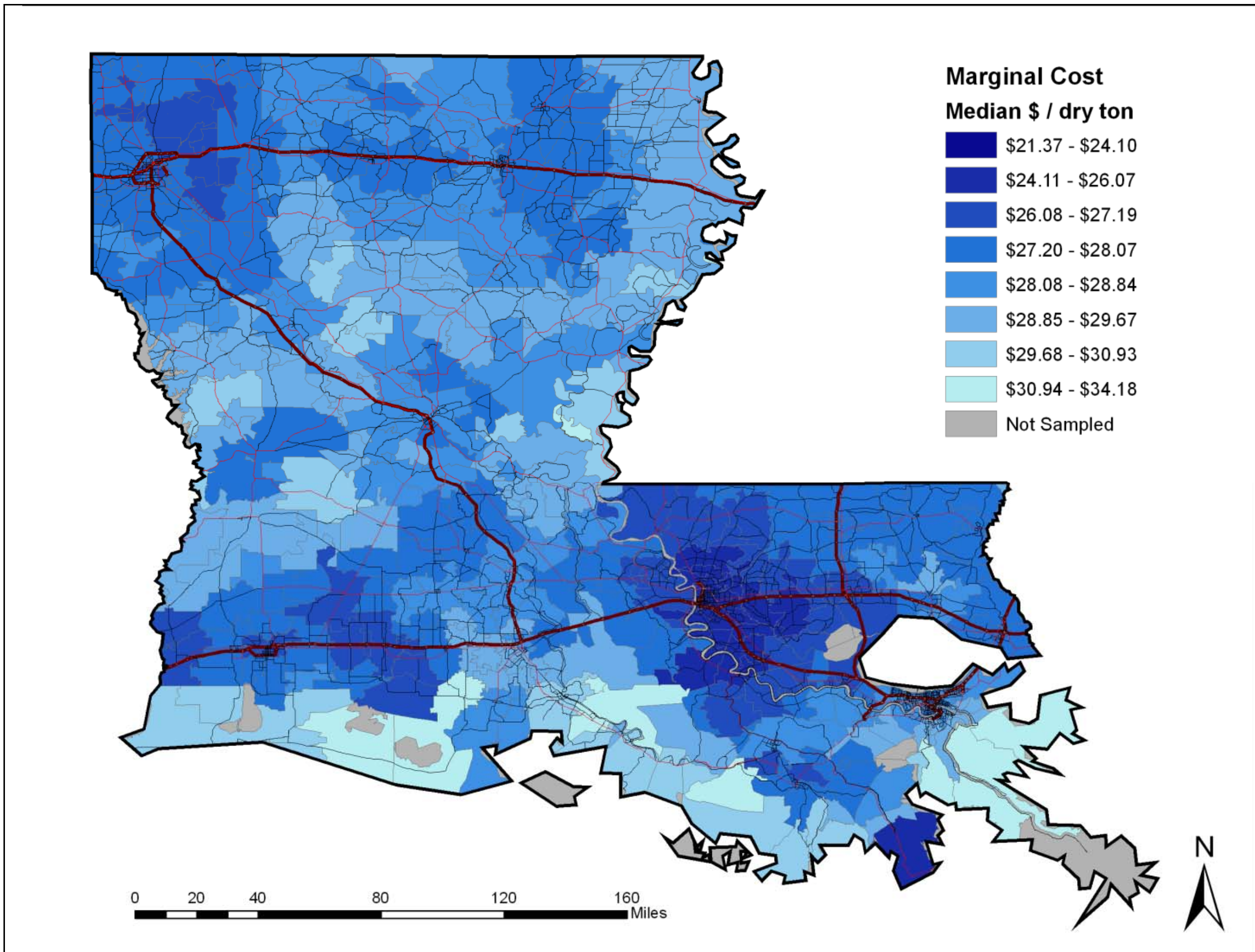

Figure D.6. Distribution of median marginal costs for "at landing" logging residues for Louisiana.

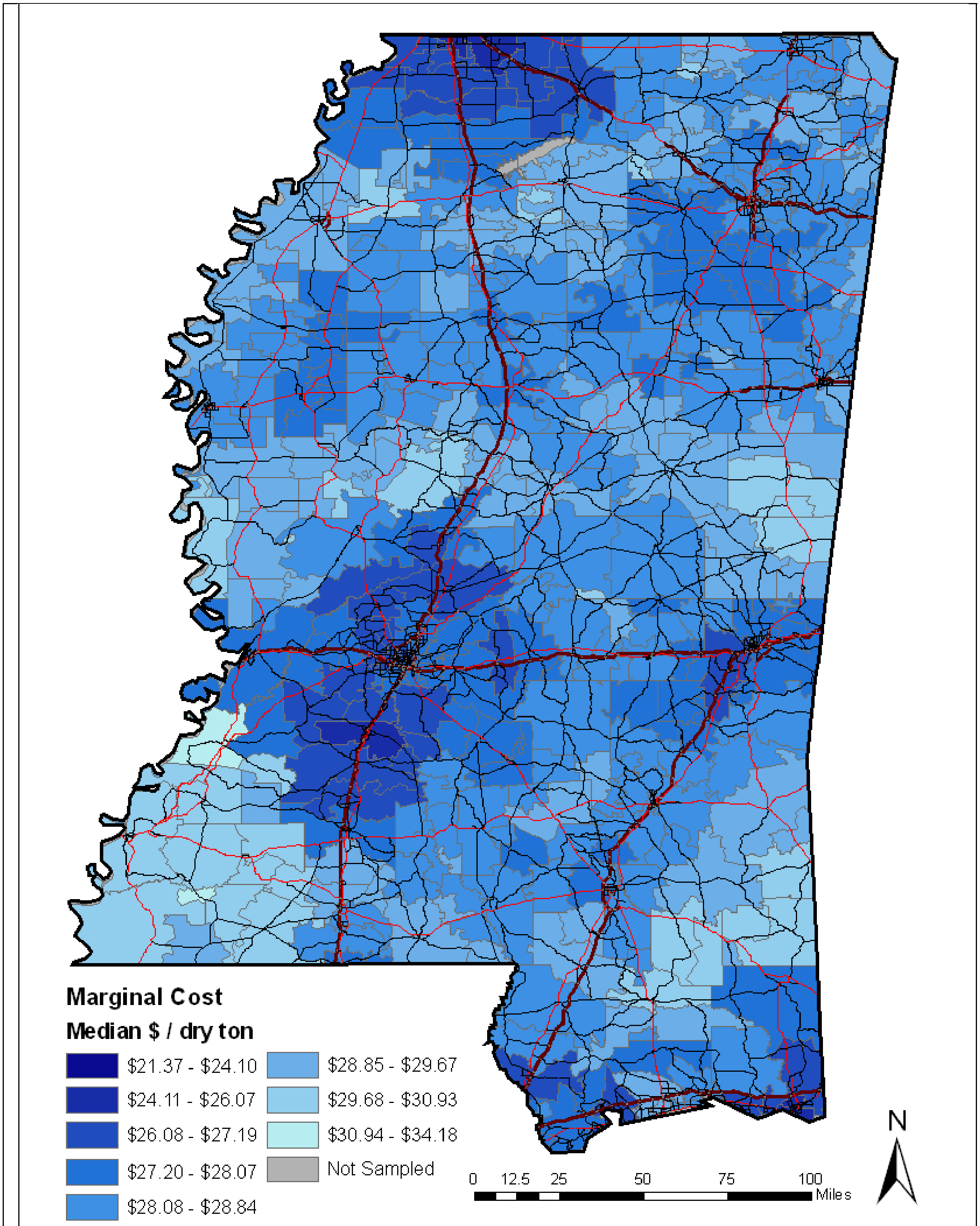

Figure D.7. Distribution of median marginal costs for "at landing" logging residues for Mississippi.

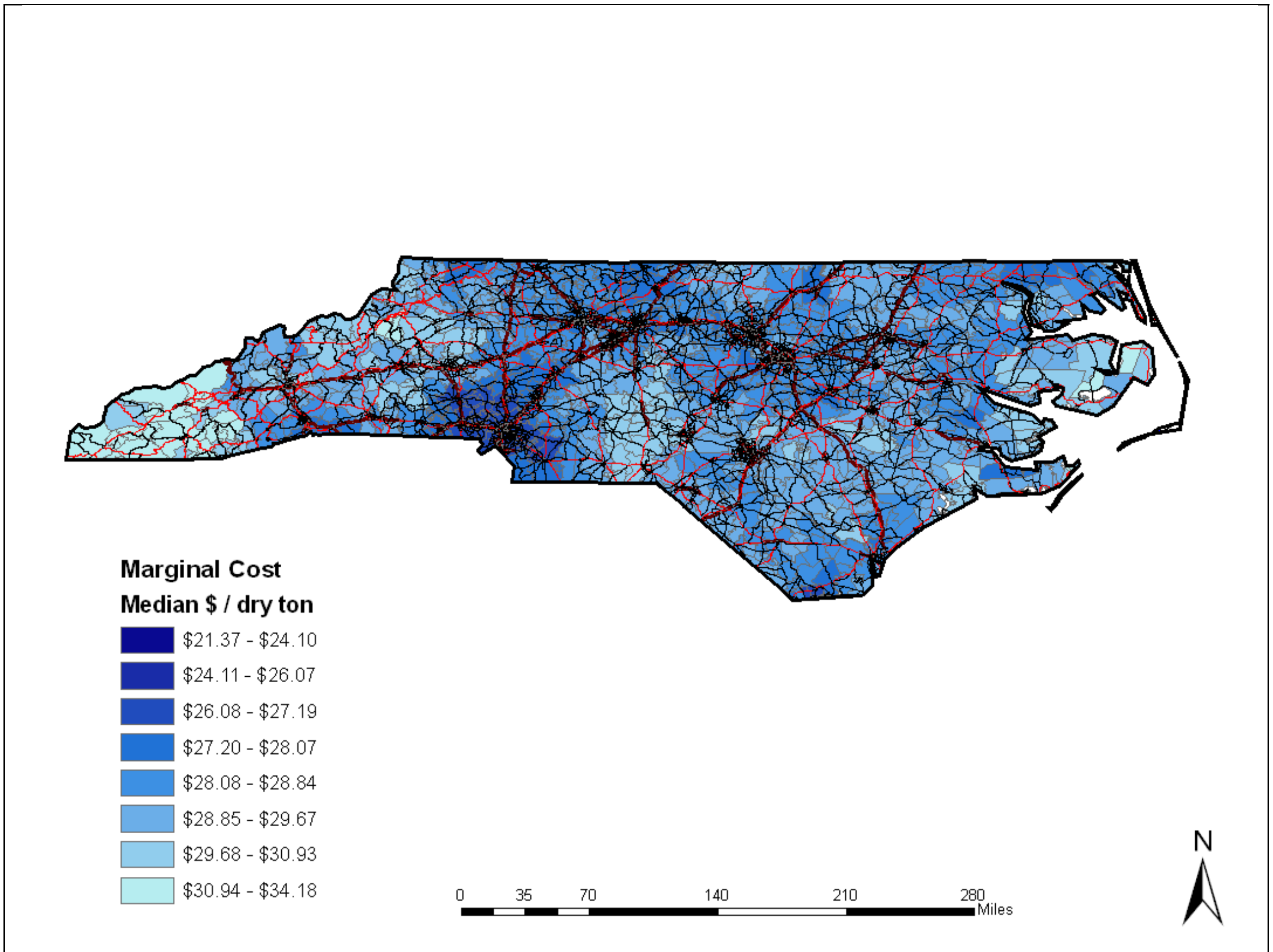

Figure D.8. Distribution of median marginal costs for "at landing" logging residues for North Carolina.

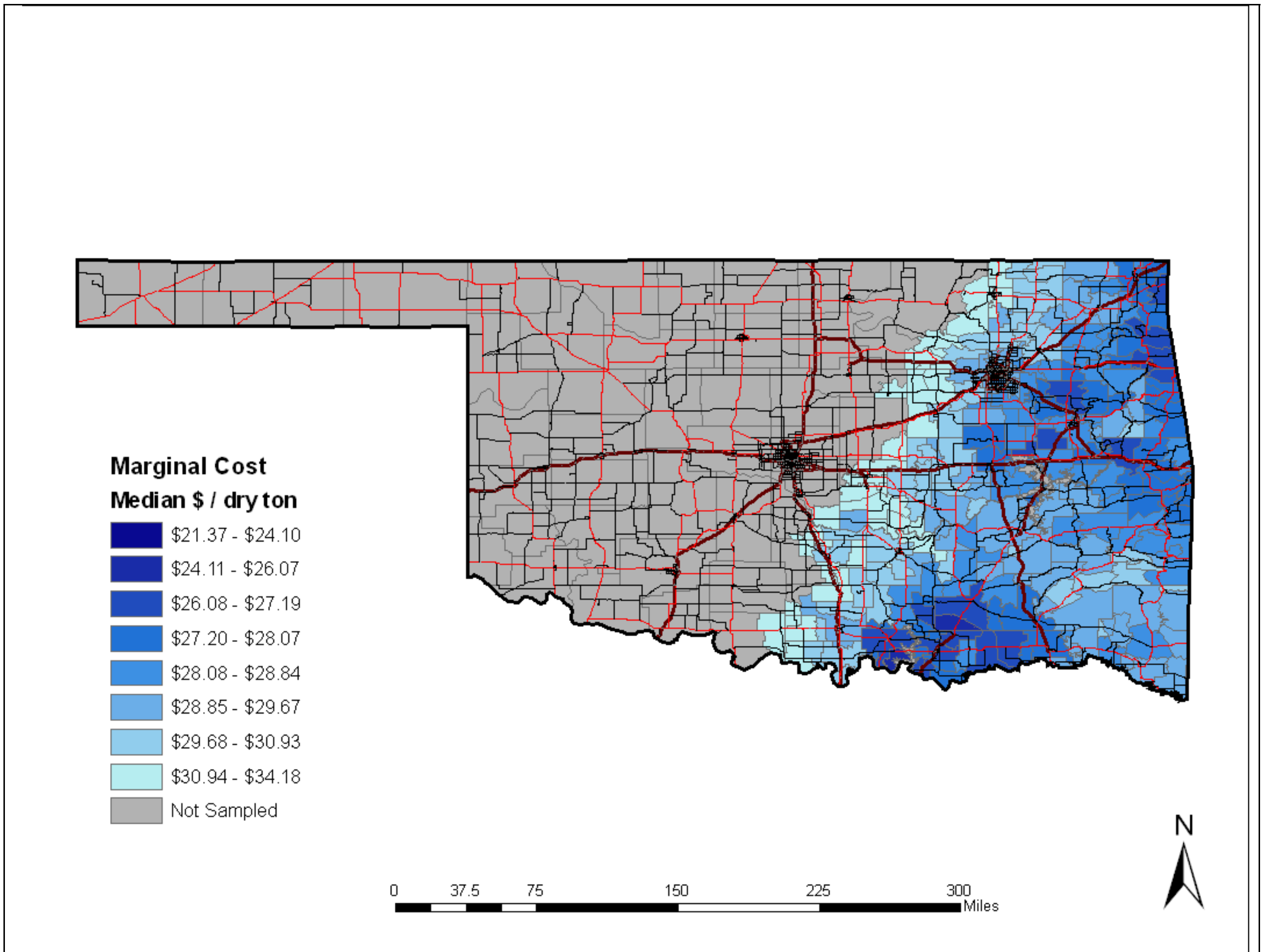

Figure D.9. Distribution of median marginal costs for "at landing" logging residues for Oklahoma.

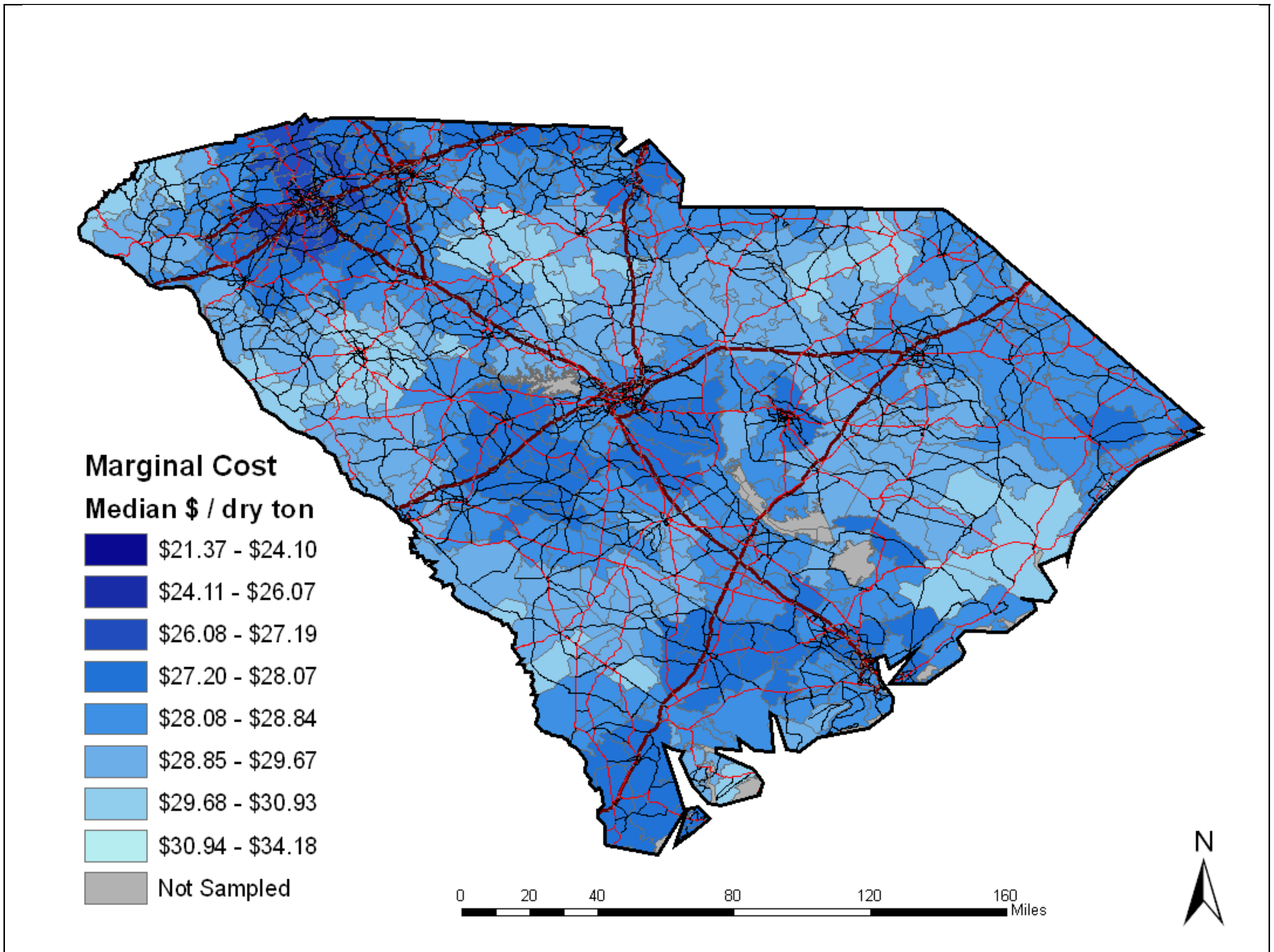

Figure D.10. Distribution of median marginal costs for "at landing" logging residues for South Carolina.

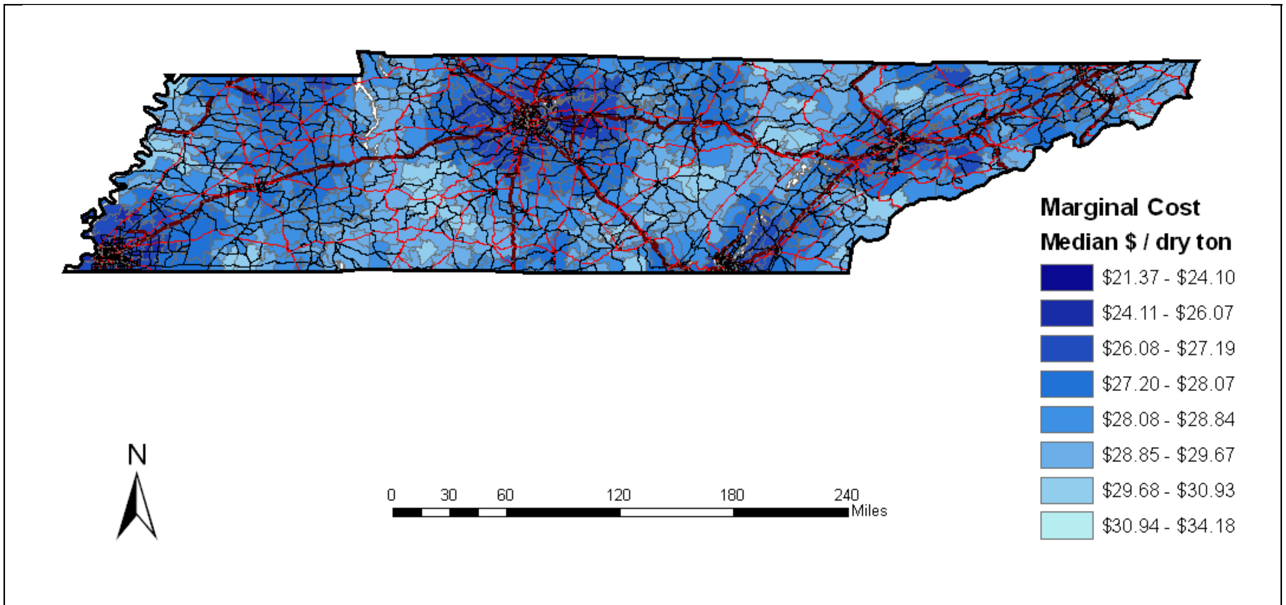

Figure D.11. Distribution of median marginal costs for "at landing" logging residues for Tennessee.

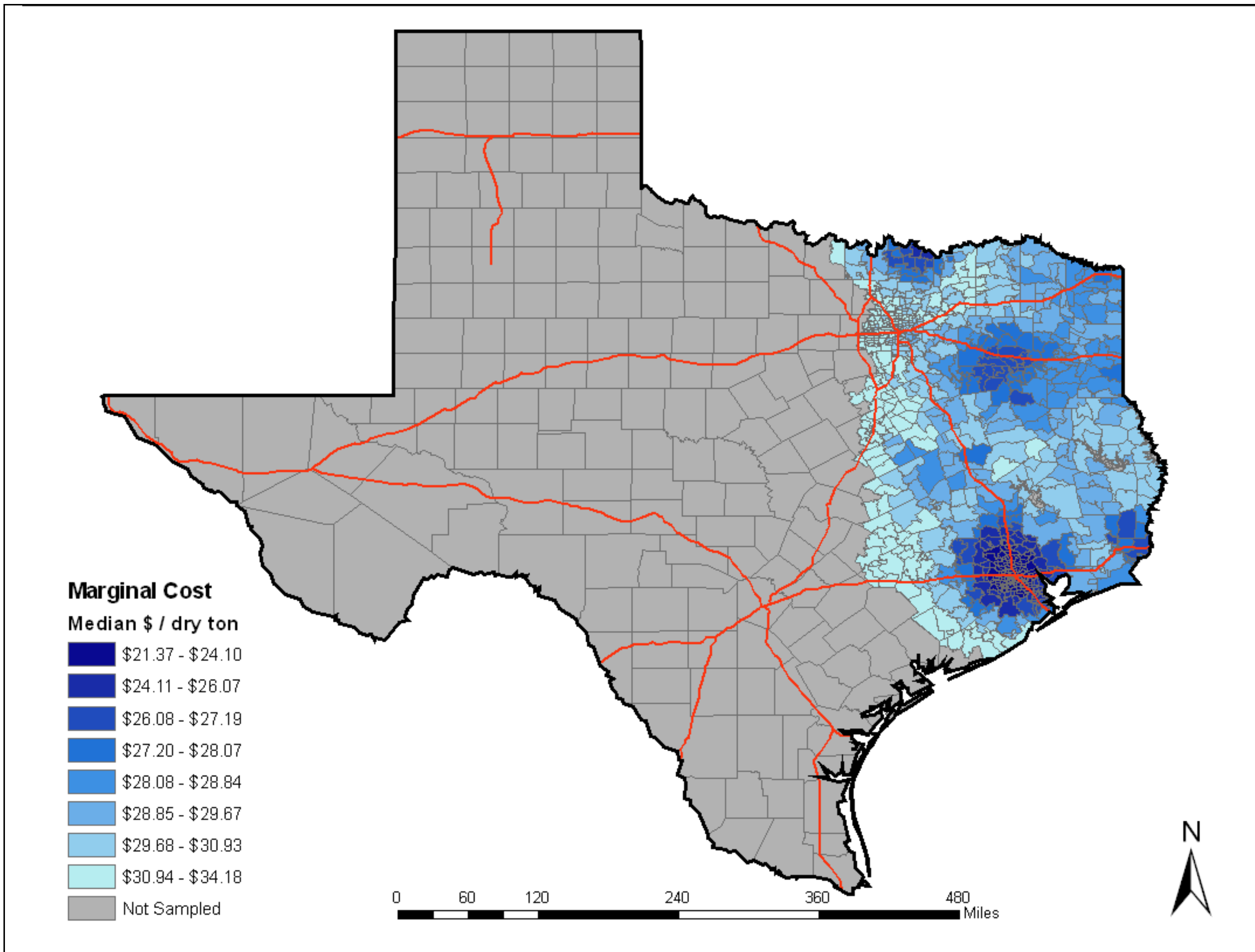

Figure D.12. Distribution of median marginal costs for "at landing" logging residues for Texas.

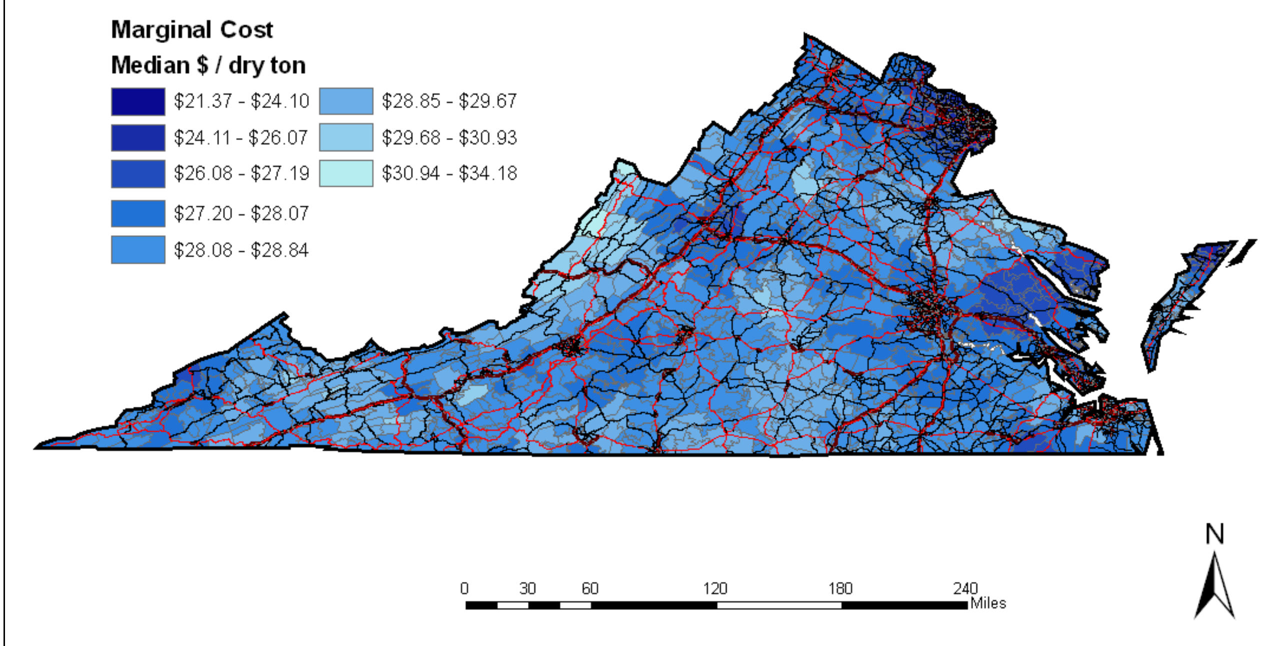

Figure D.13. Distribution of median marginal costs for "at landing" logging residues for Virginia.

Appendix E

"Kriged" ZCTA maps for total (hardwood and softwood) "at landing" logging residues categorized by median marginal cost

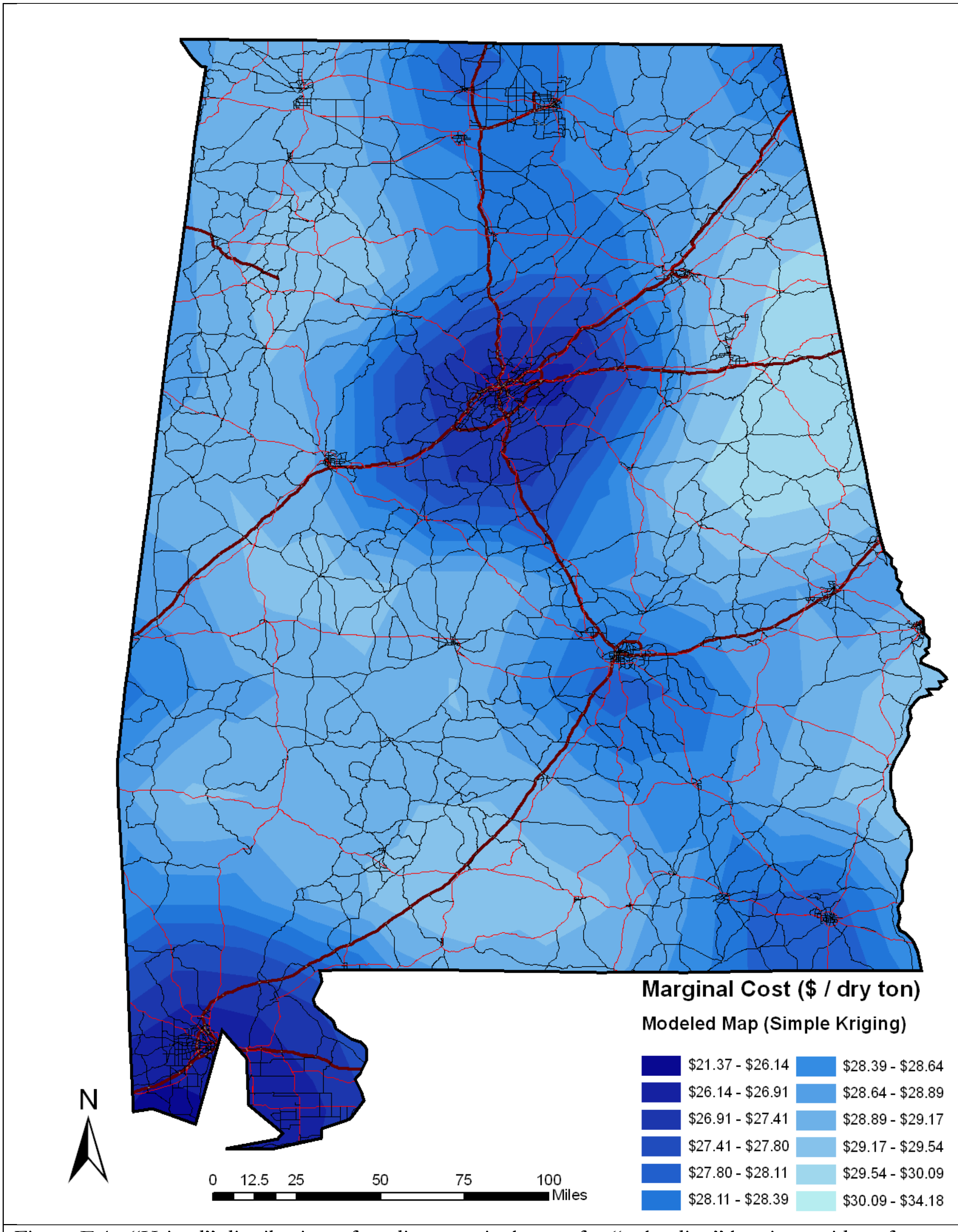

Figure E.1. "Kriged" distribution of median marginal costs for "at landing" logging residues for Alabama.

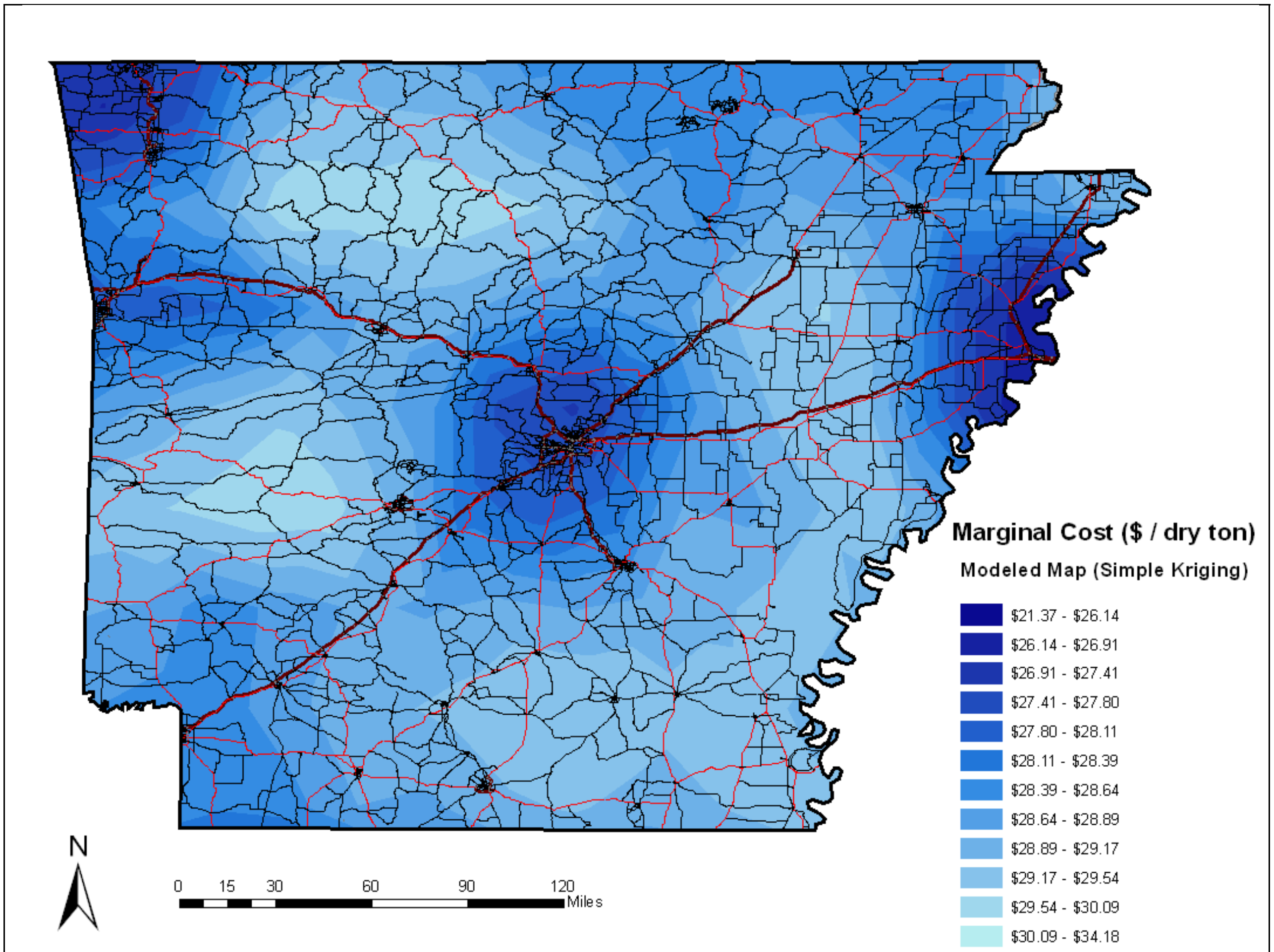

Figure E.2. "Kriged" distribution of median marginal costs for "at landing" logging residues for Arkansas.

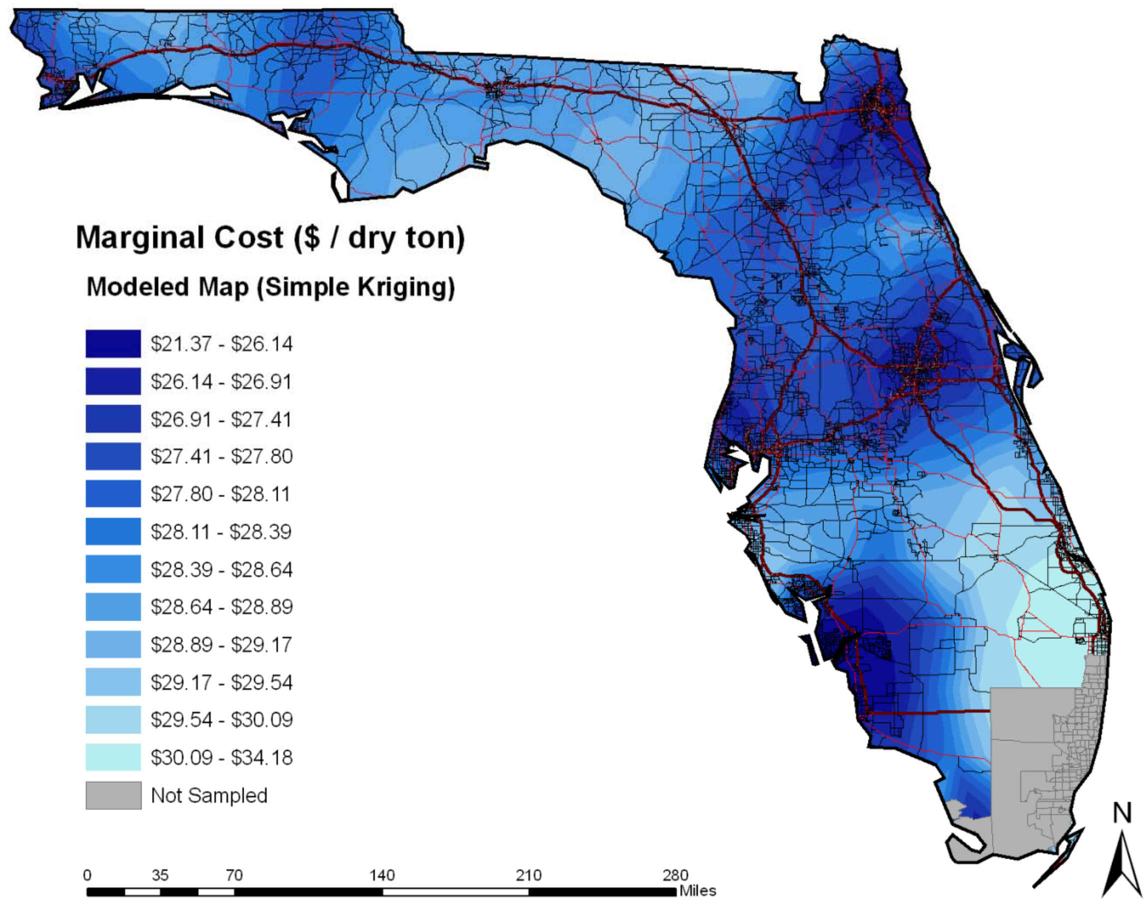

Figure E.3. "Kriged" distribution of median marginal costs for "at landing" logging residues for Florida.

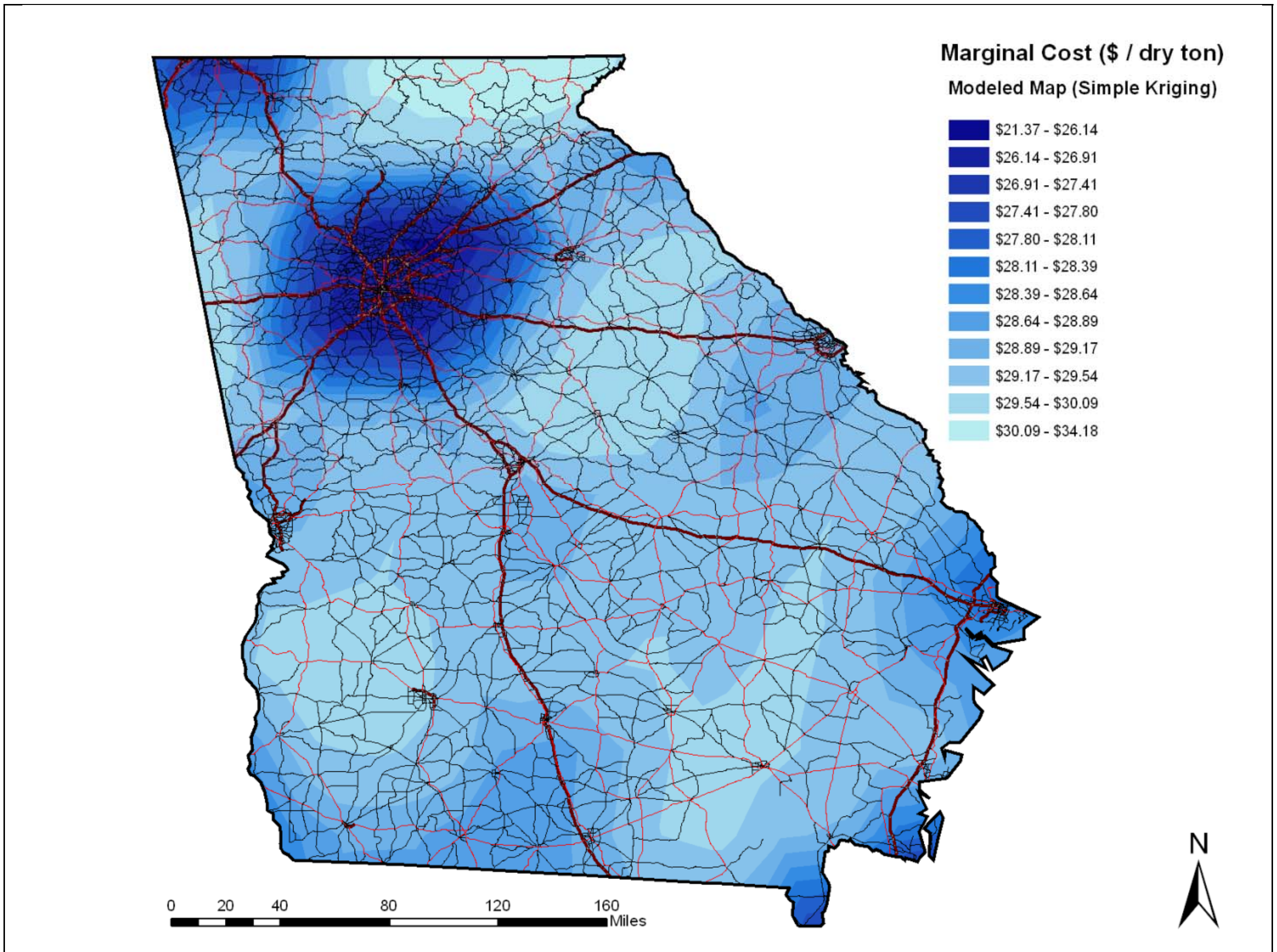

Figure E.4. "Kriged" distribution of median marginal costs for "at landing" logging residues for Georgia.

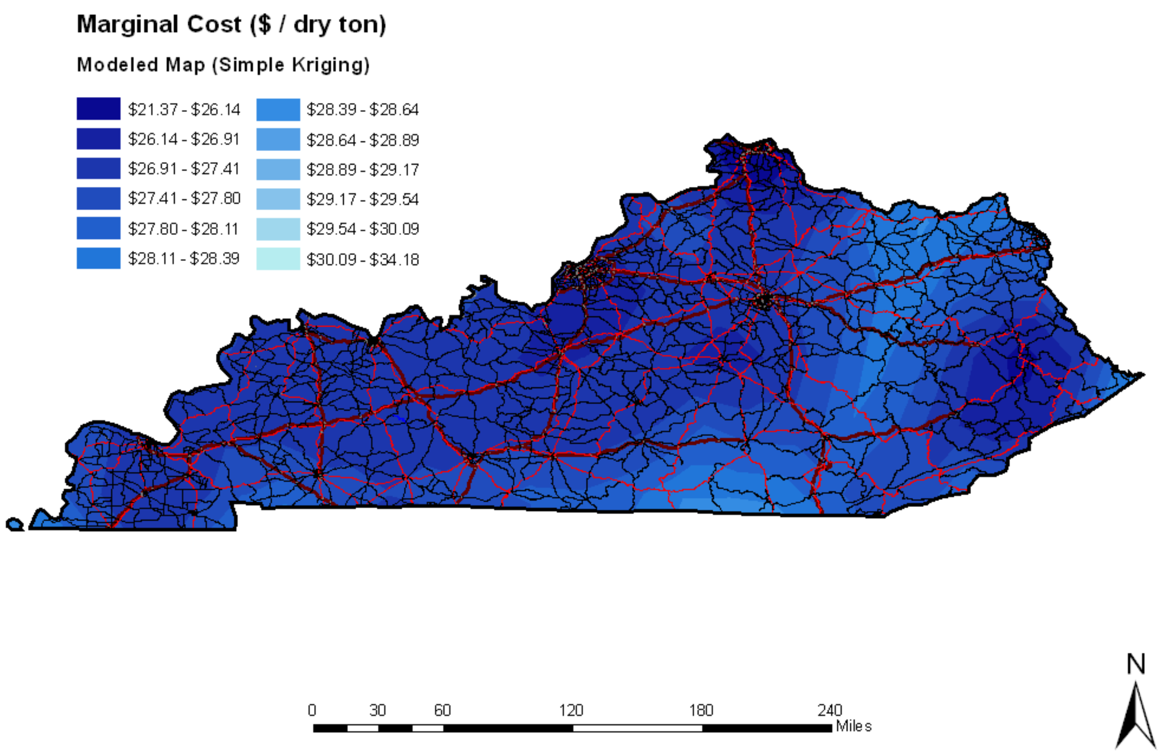

Figure E.5. "Kriged" distribution of median marginal costs for "at landing" logging residues for Kentucky.

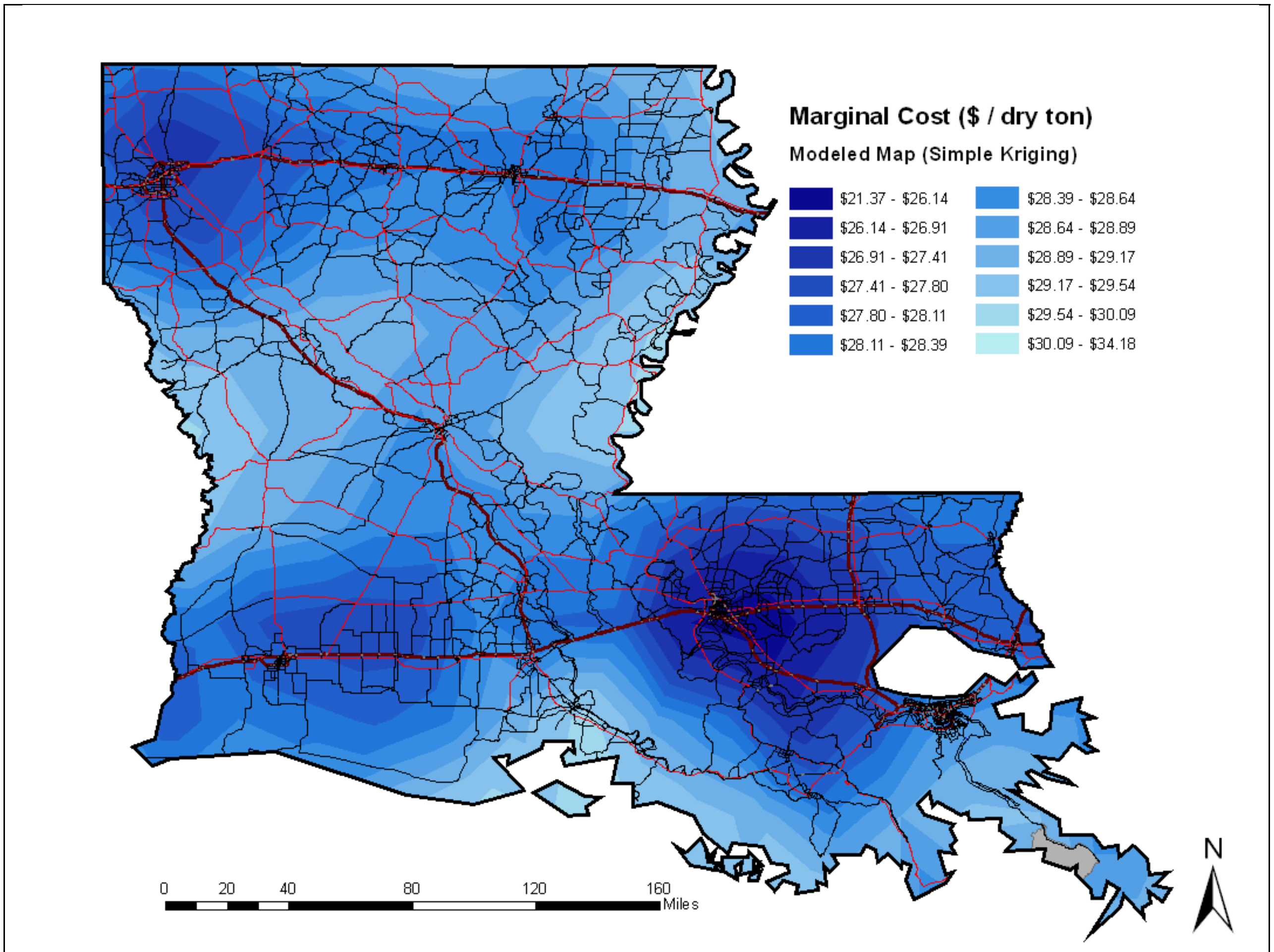

Figure E.6. "Kriged" distribution of median marginal costs for "at landing" logging residues for Louisiana.

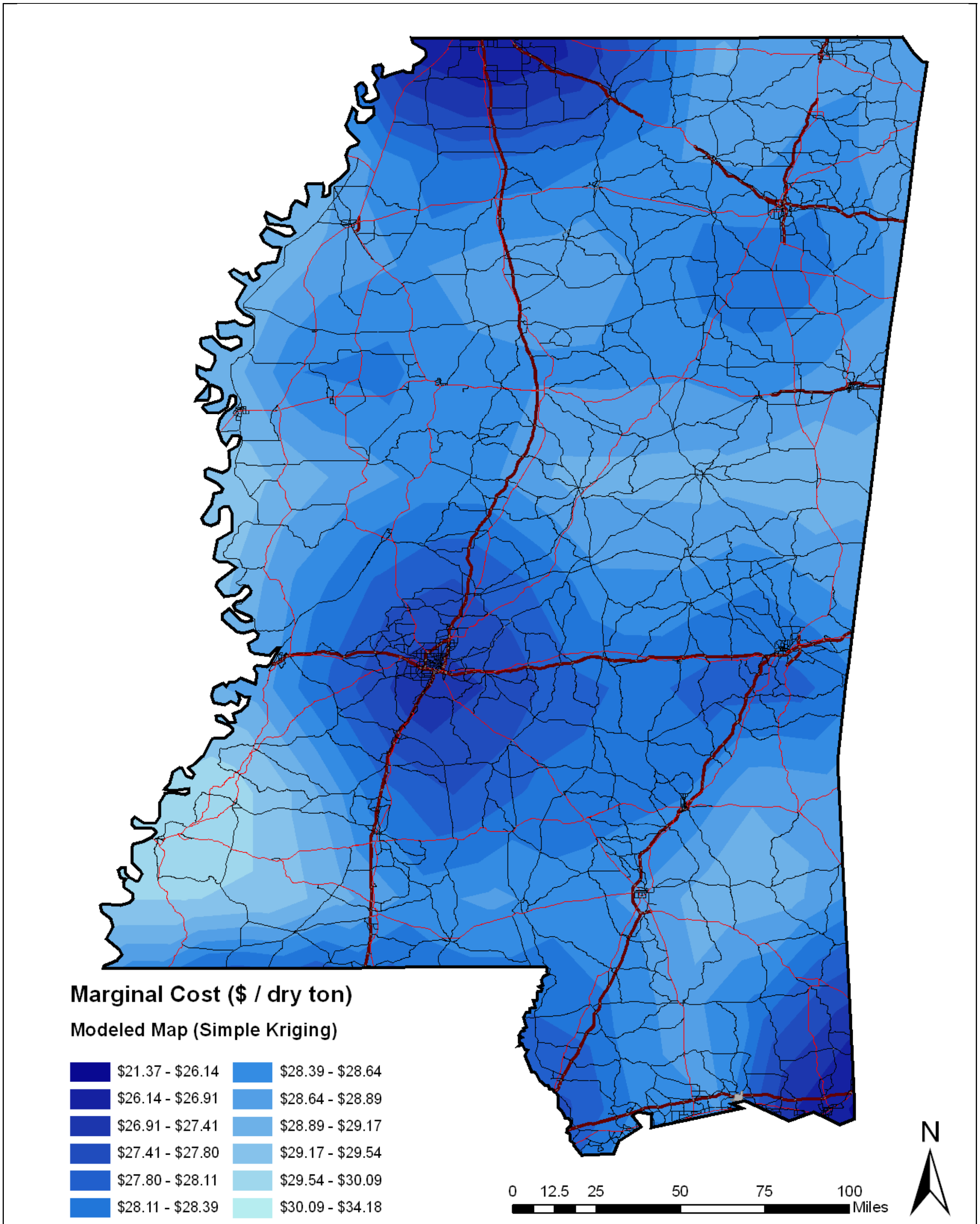

Figure E.7. "Kriged" distribution of median marginal costs for "at landing" logging residues for Mississippi.

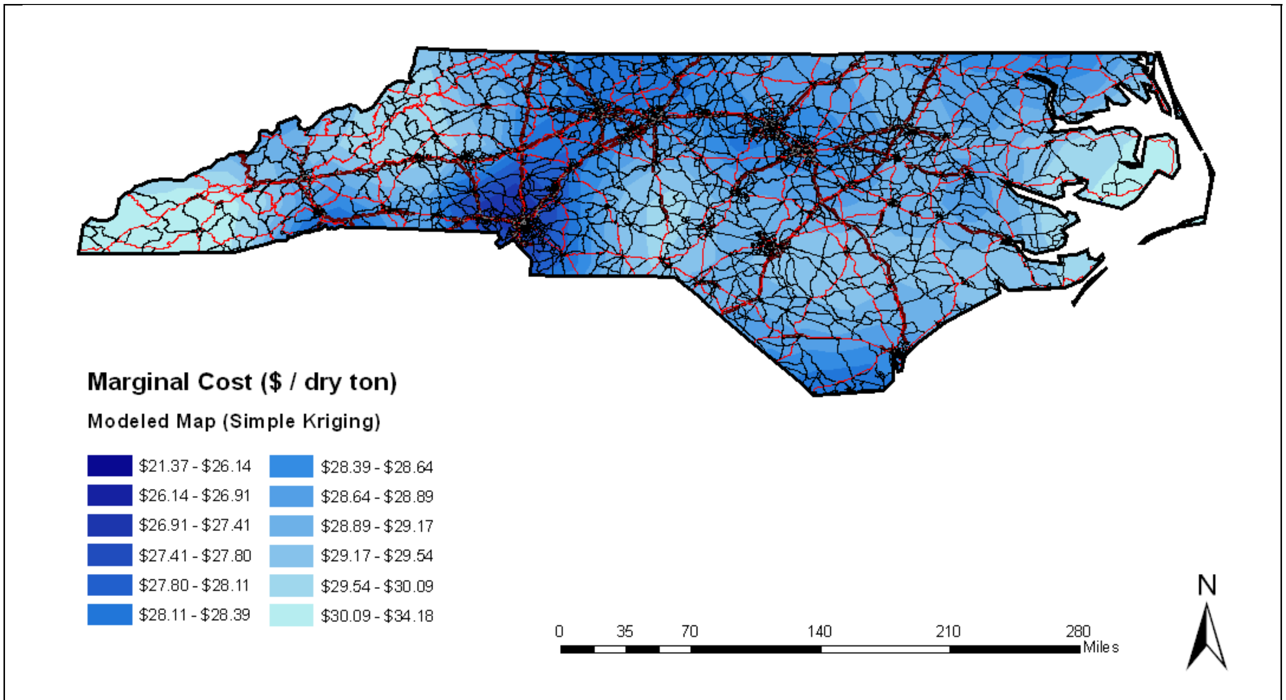

Figure E.8. "Kriged" distribution of median marginal costs for "at landing" logging residues for North Carolina.

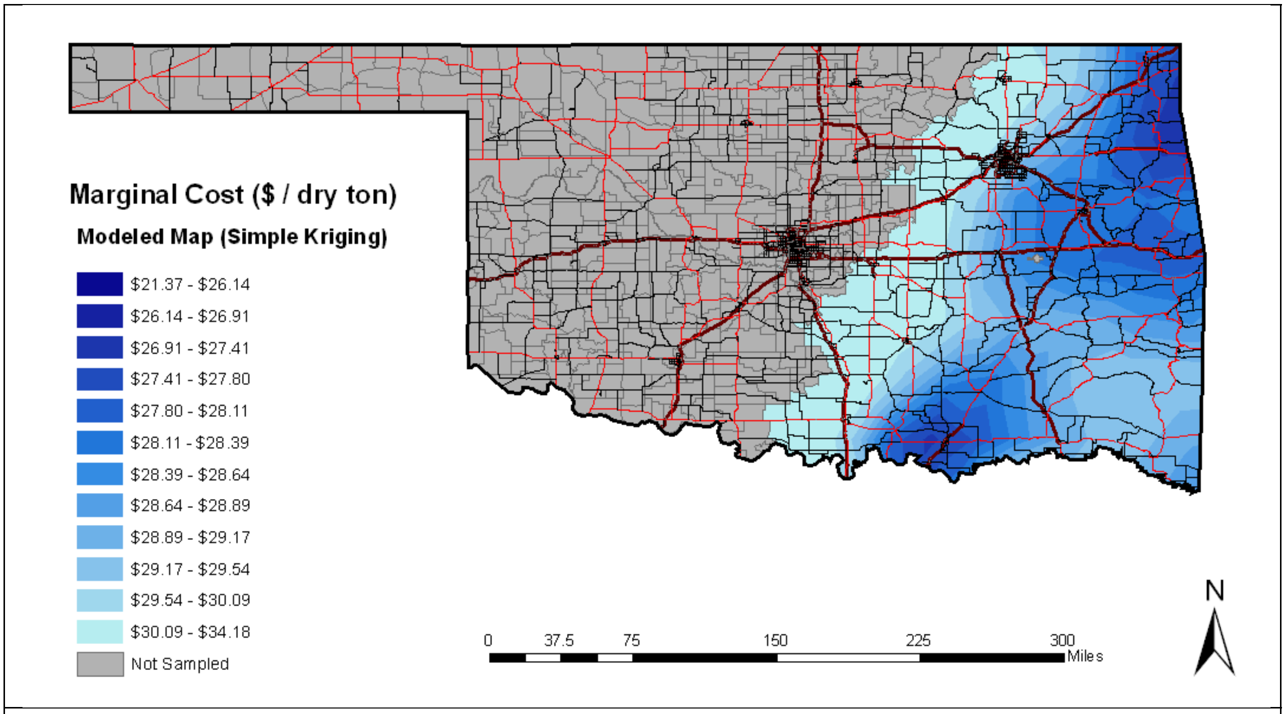

Figure E.9. "Kriged" distribution of median marginal costs for "at landing" logging residues for Oklahoma.

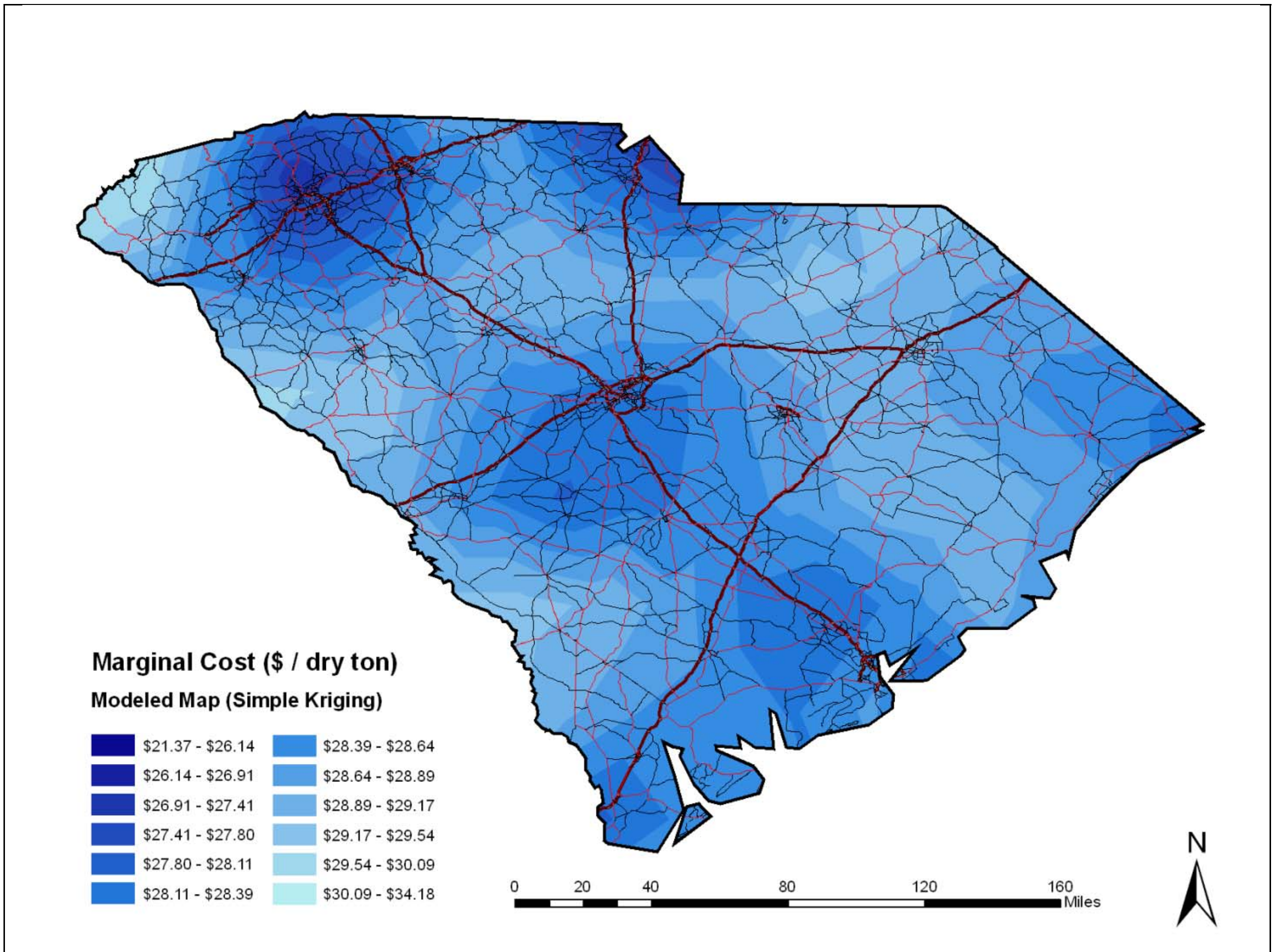

Figure E.10. "Kriged" distribution of median marginal costs for "at landing" logging residues for South Carolina.

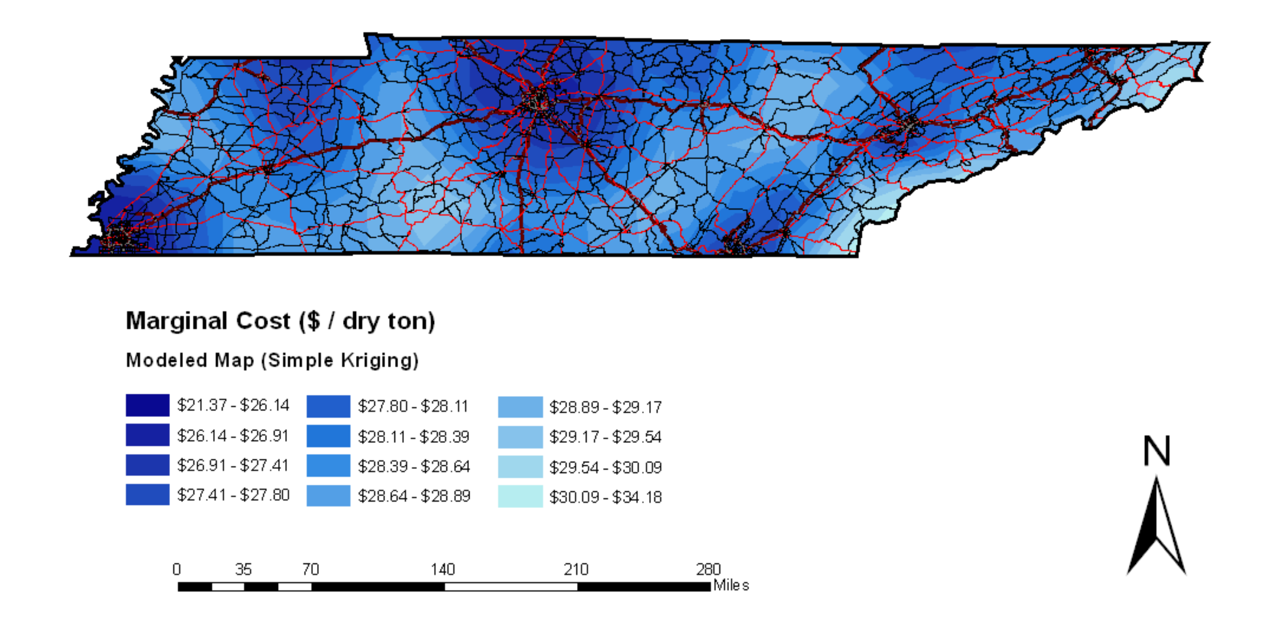

Figure E.11. "Kriged" distribution of median marginal costs for "at landing" logging residues for Tennessee.

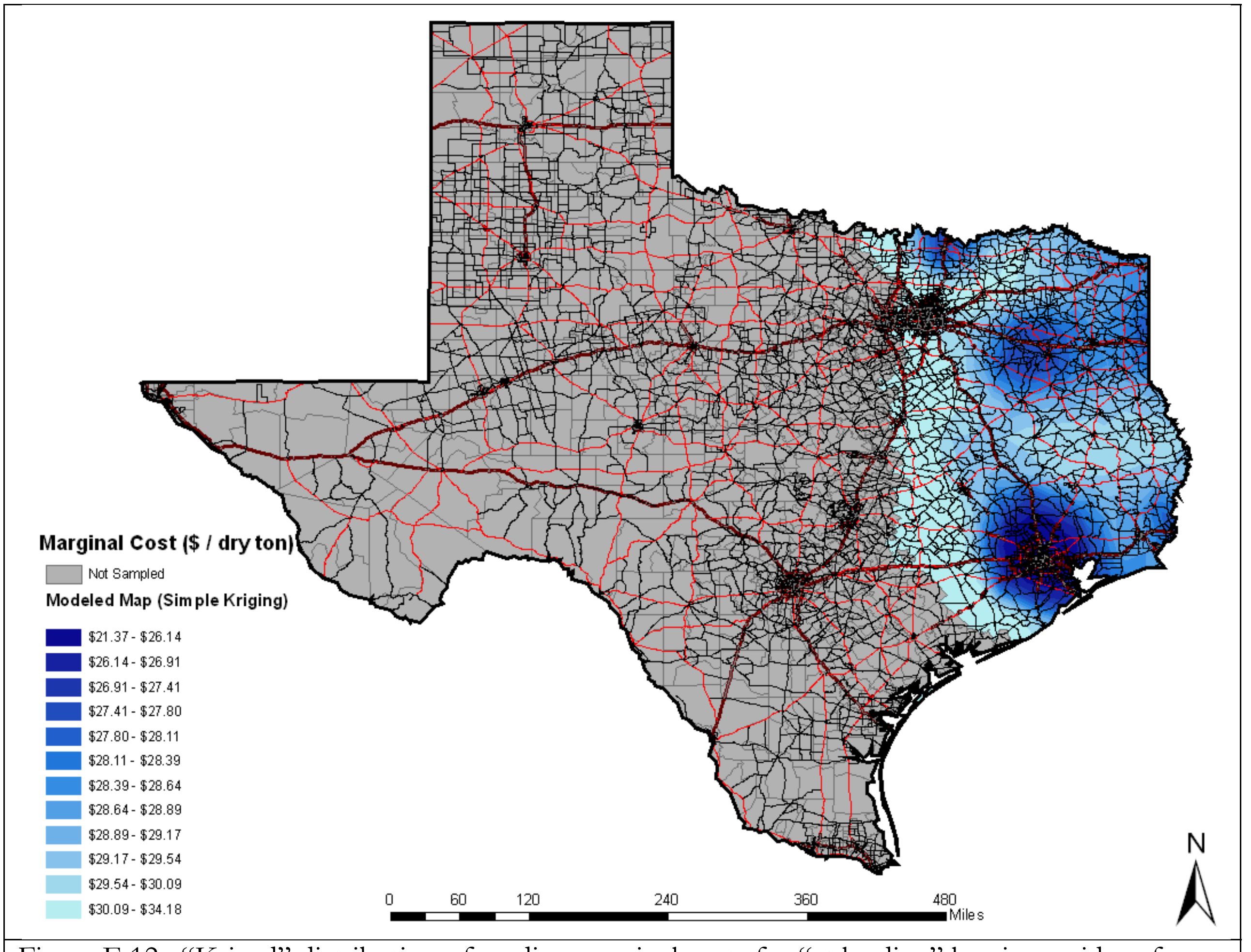

Figure E.12. "Kriged" distribution of median marginal costs for "at landing" logging residues for Texas.

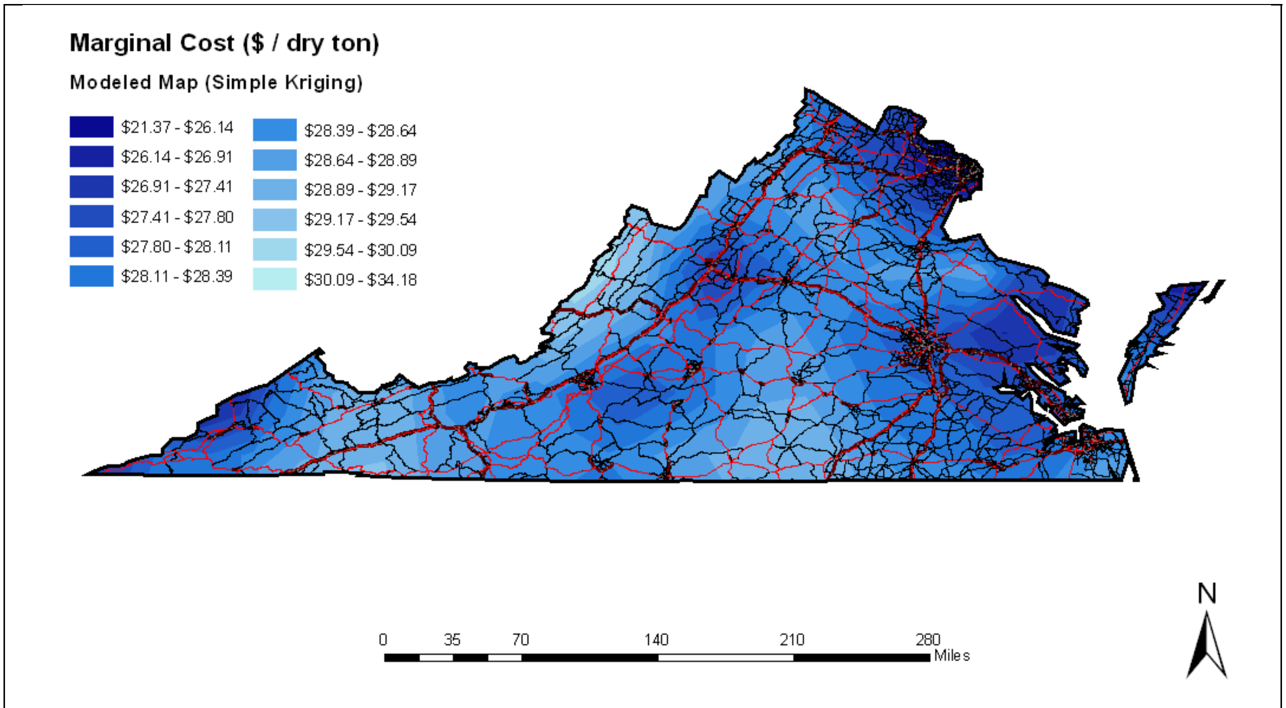

Figure E.13. "Kriged" distribution of median marginal costs for "at landing" logging residues for Virginia.

Appendix F

ZCTA maps for total (hardwood and softwood) “in woods” logging residues categorized by median marginal cost

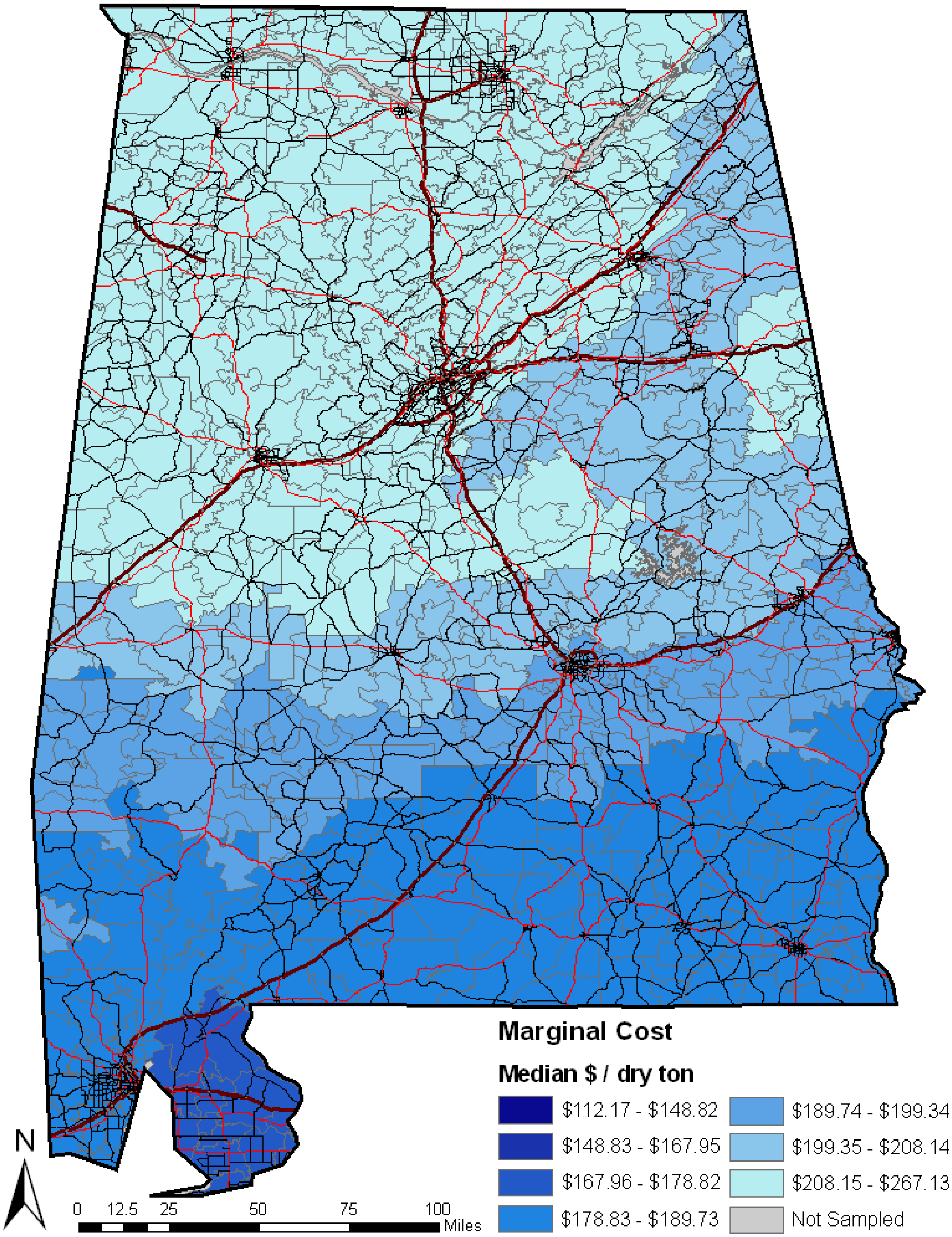

Figure F.1. Distribution of median marginal costs for total "in woods" logging residues for Alabama.

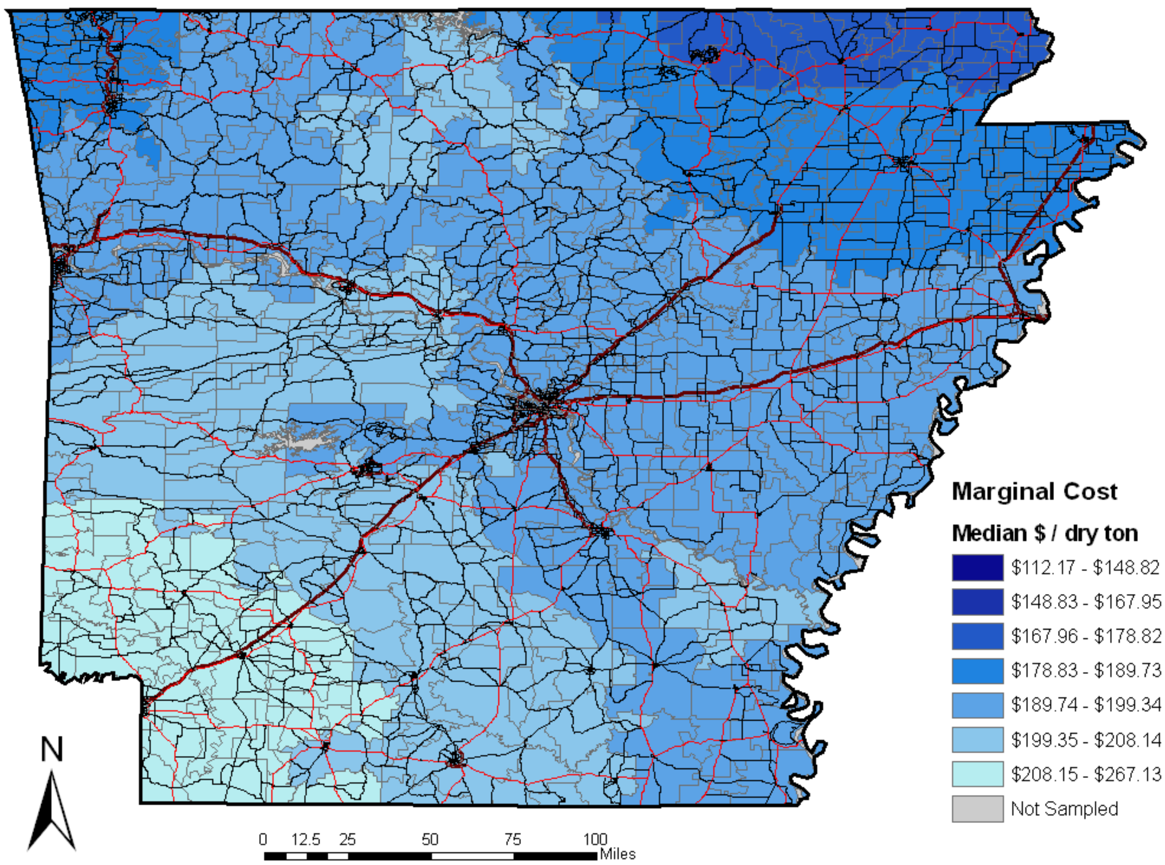

Figure F.2. Distribution of median marginal costs for total "in woods" logging residues for Arkansas.

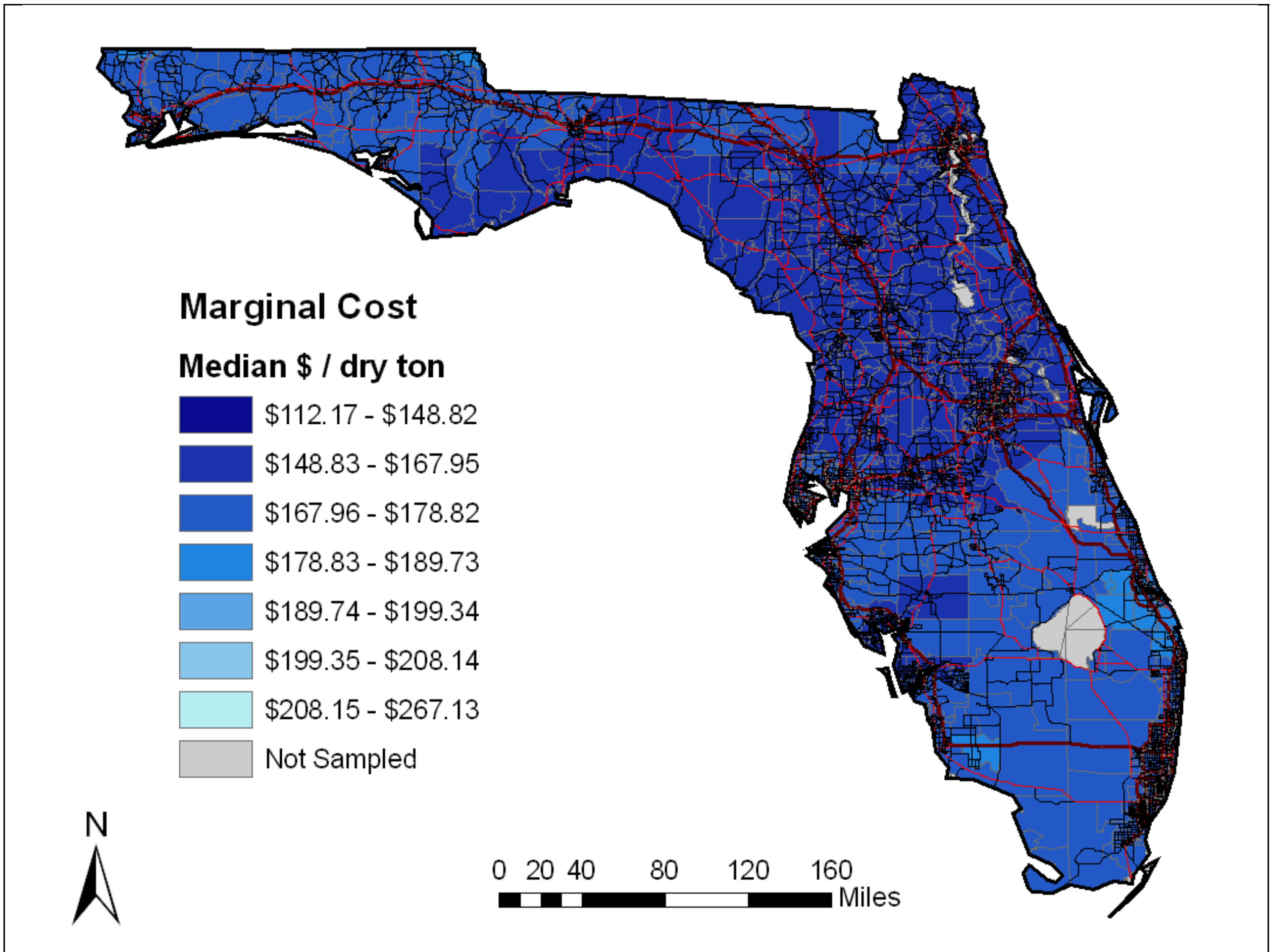

Figure F.3. Distribution of median marginal costs for total "in woods" logging residues for Florida.

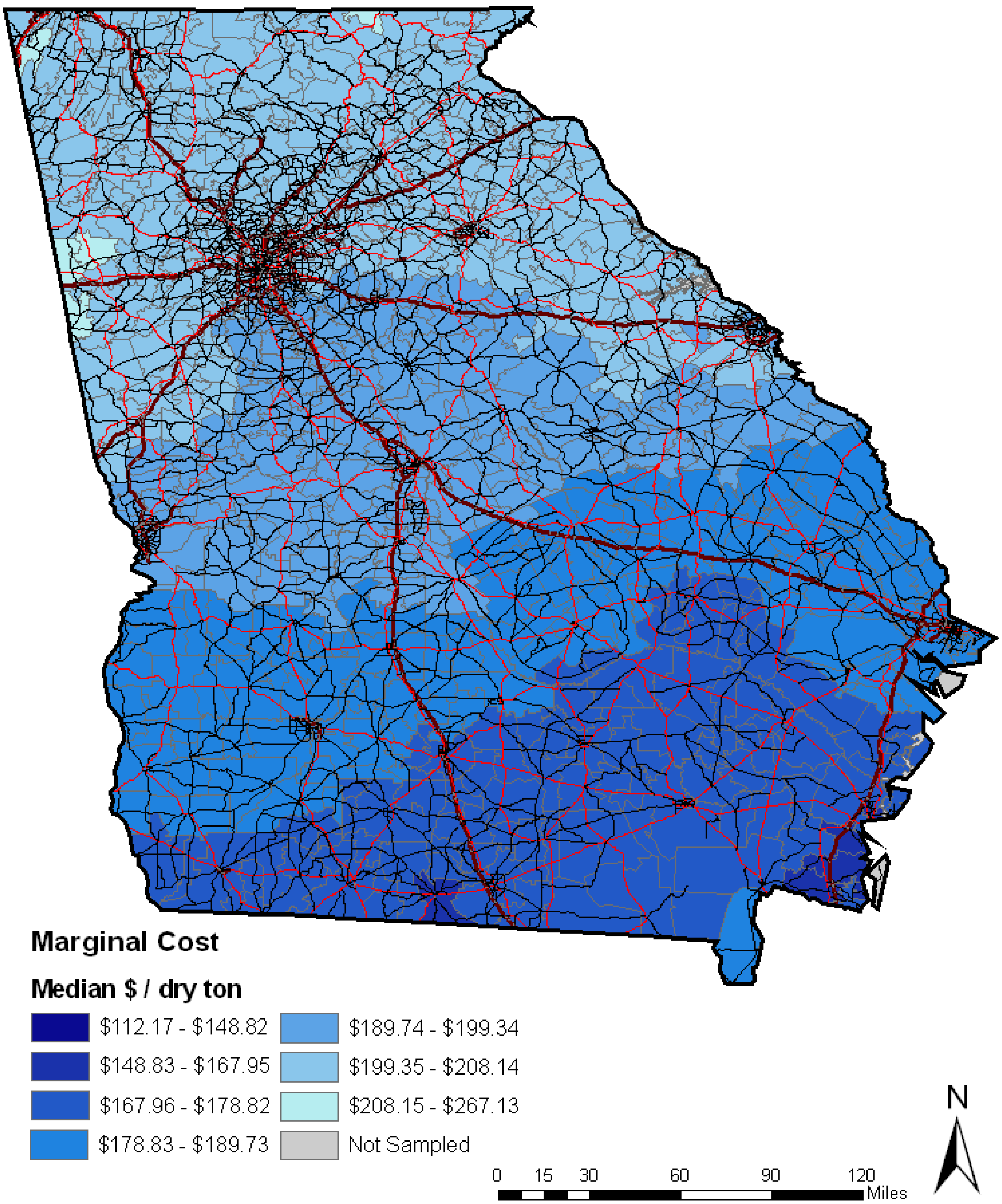

Figure F.4. Distribution of median marginal costs for total "in woods" logging residues for Georgia.

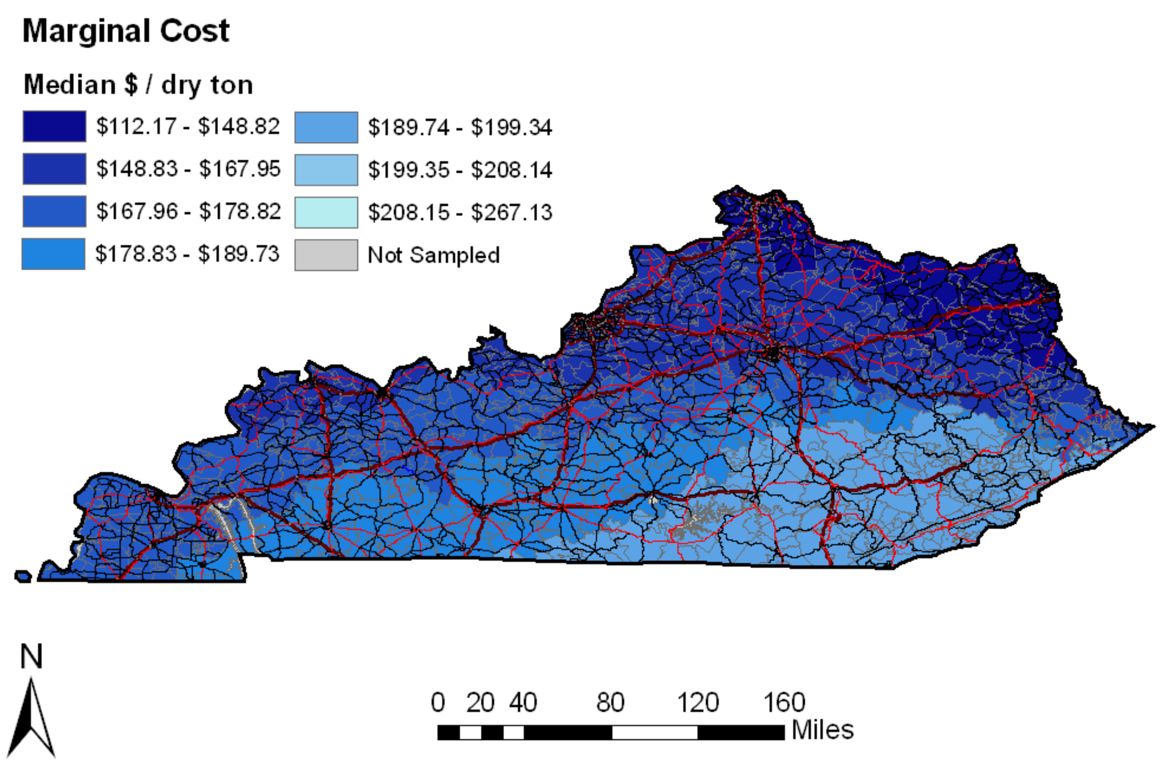

Figure F.5. Distribution of median marginal costs for total "in woods" logging residues for Kentucky.

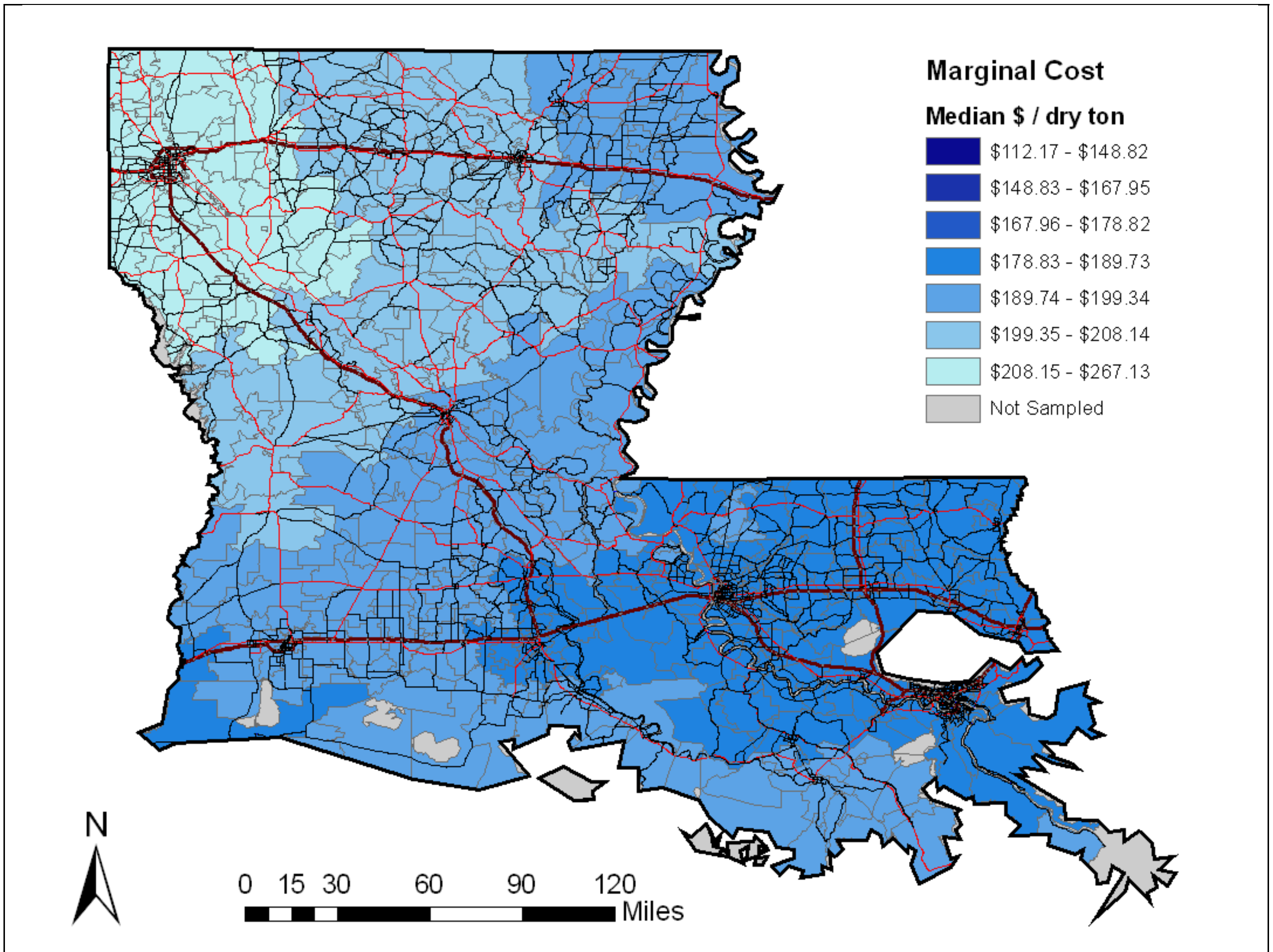

Figure F.6. Distribution of median marginal costs for total "in woods" logging residues for Louisiana.

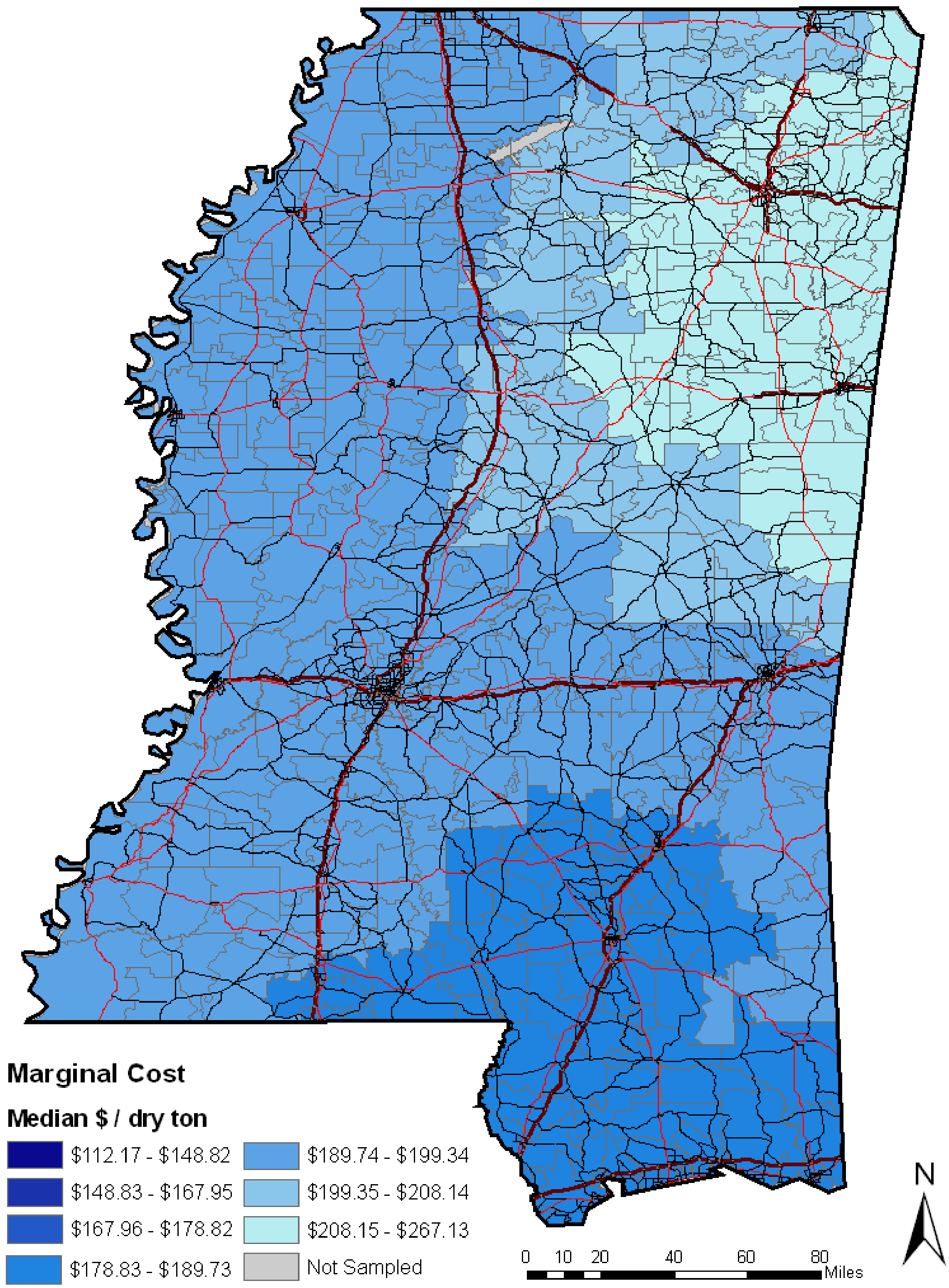

Figure F.7. Distribution of median marginal costs for total "in woods" logging residues for Mississippi.

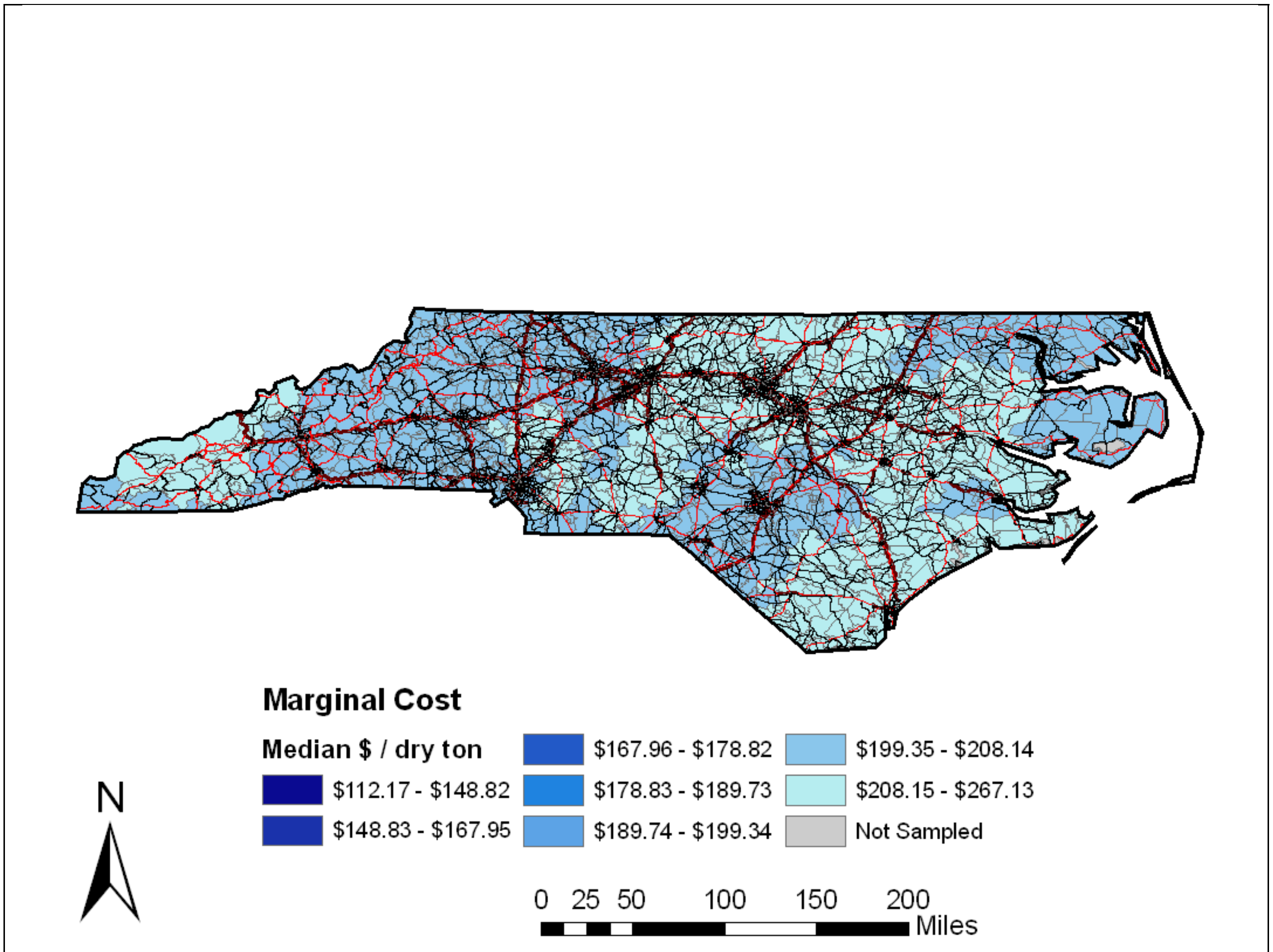

Figure F.8. Distribution of median marginal costs for total "in woods" logging residues for North Carolina.

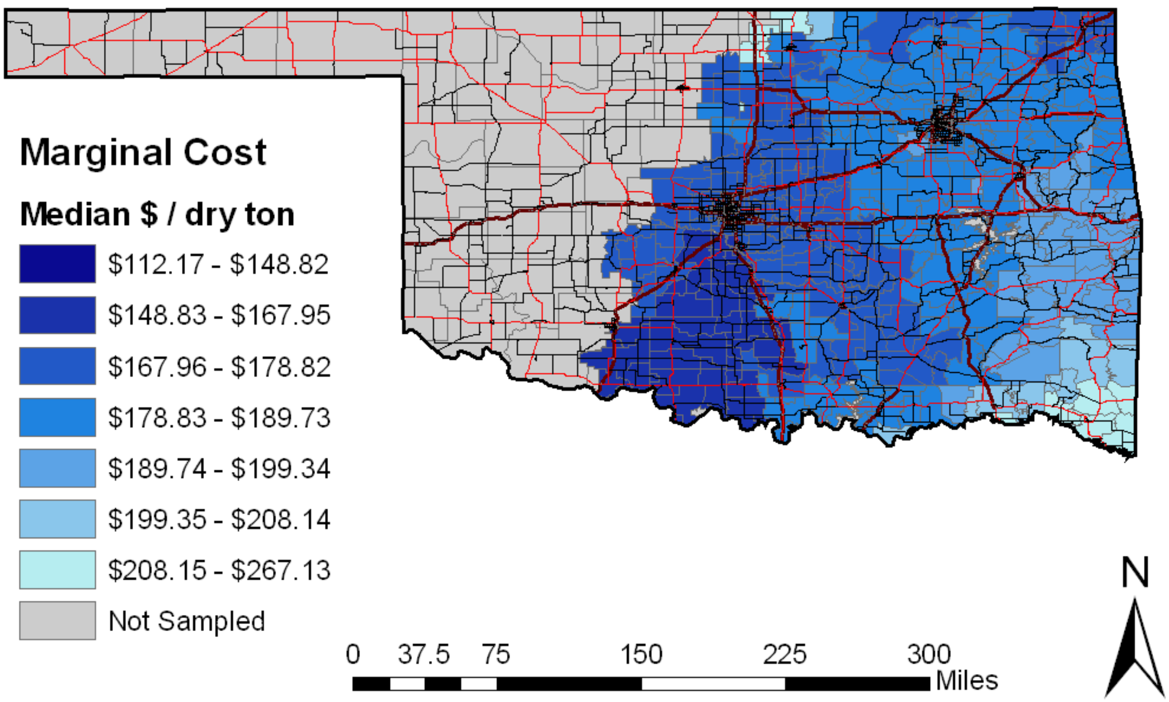

Figure F.9. Distribution of median marginal costs for total "in woods" logging residues for Oklahoma.

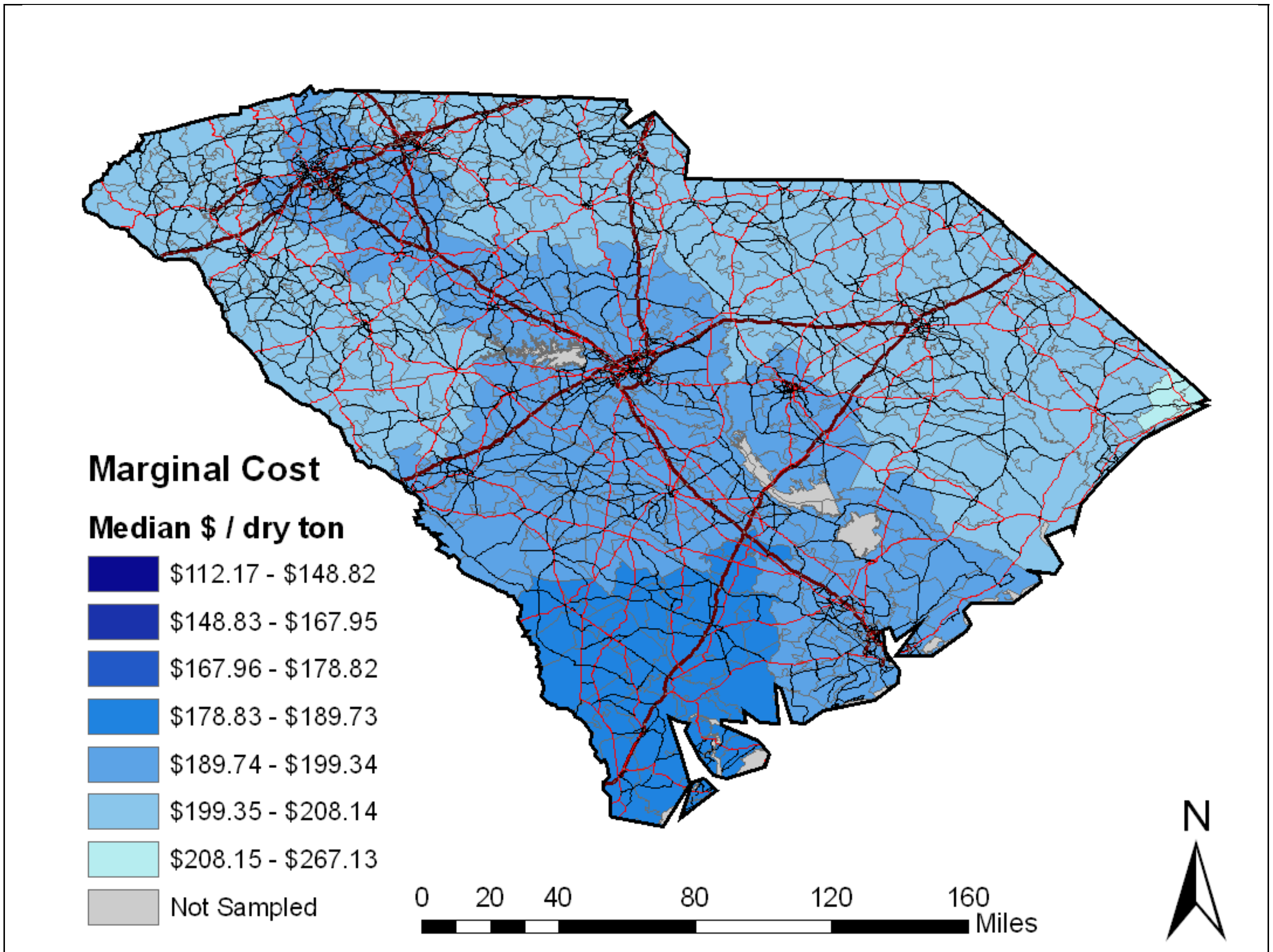

Figure F.10. Distribution of median marginal costs for total "in woods" logging residues for South Carolina.

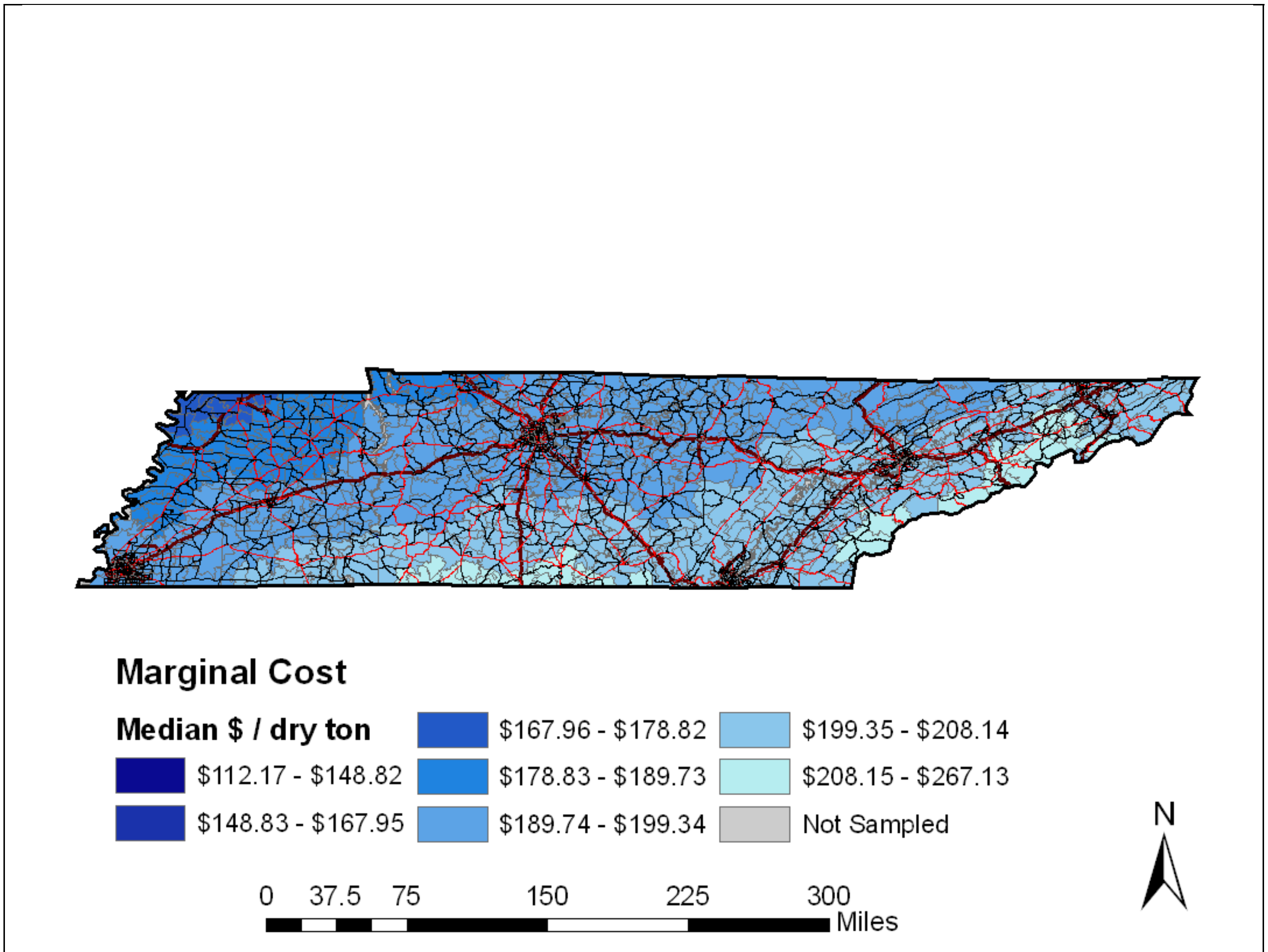

Figure F.11. Distribution of median marginal costs for total "in woods" logging residues for Tennessee.

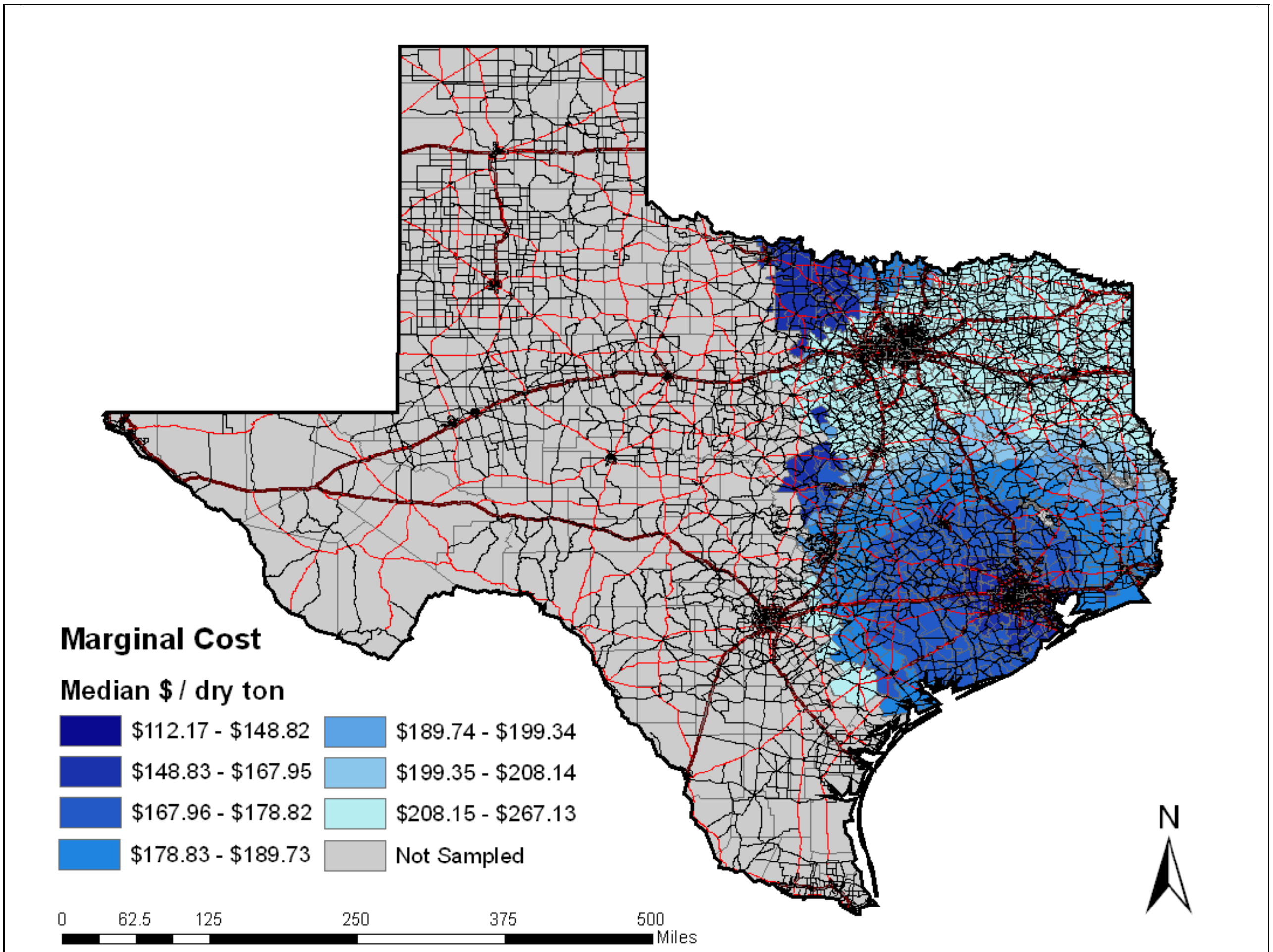

Figure F.12. Distribution of median marginal costs for total "in woods" logging residues for Texas.

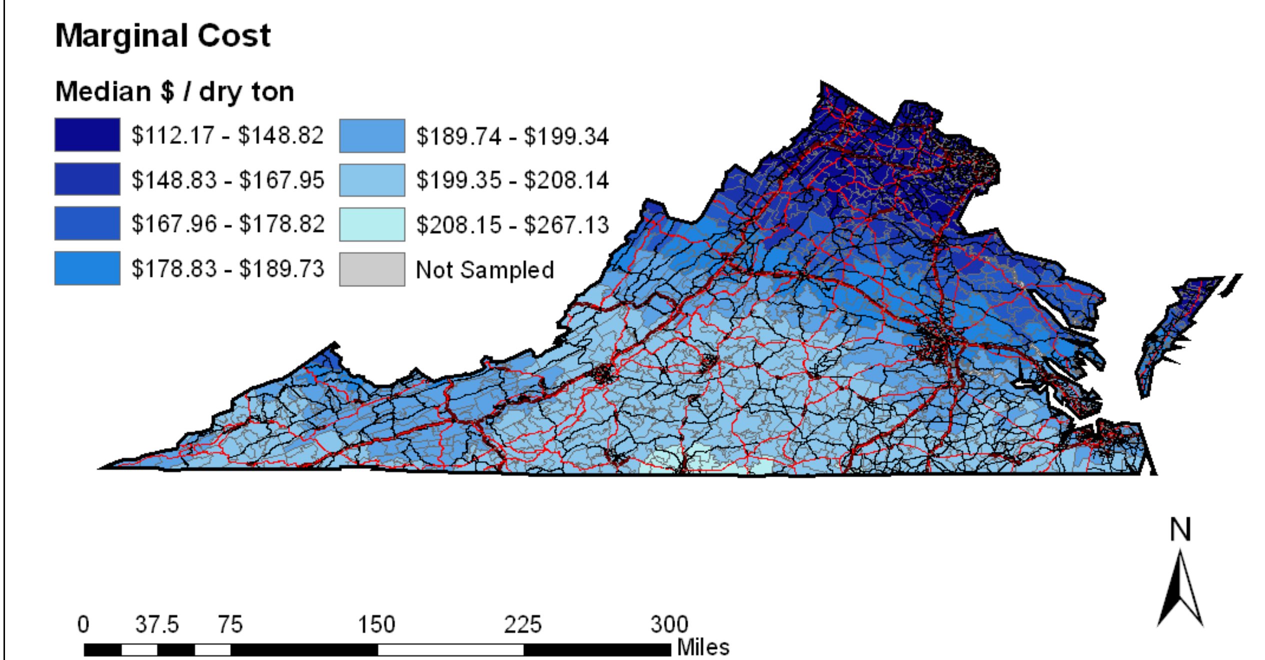

Figure F.13. Distribution of median marginal costs for total "in woods" logging residues for Virginia.

Appendix G

"Kriged" ZCTA maps for total (hardwood and softwood) "in woods" logging residues categorized by median marginal cost

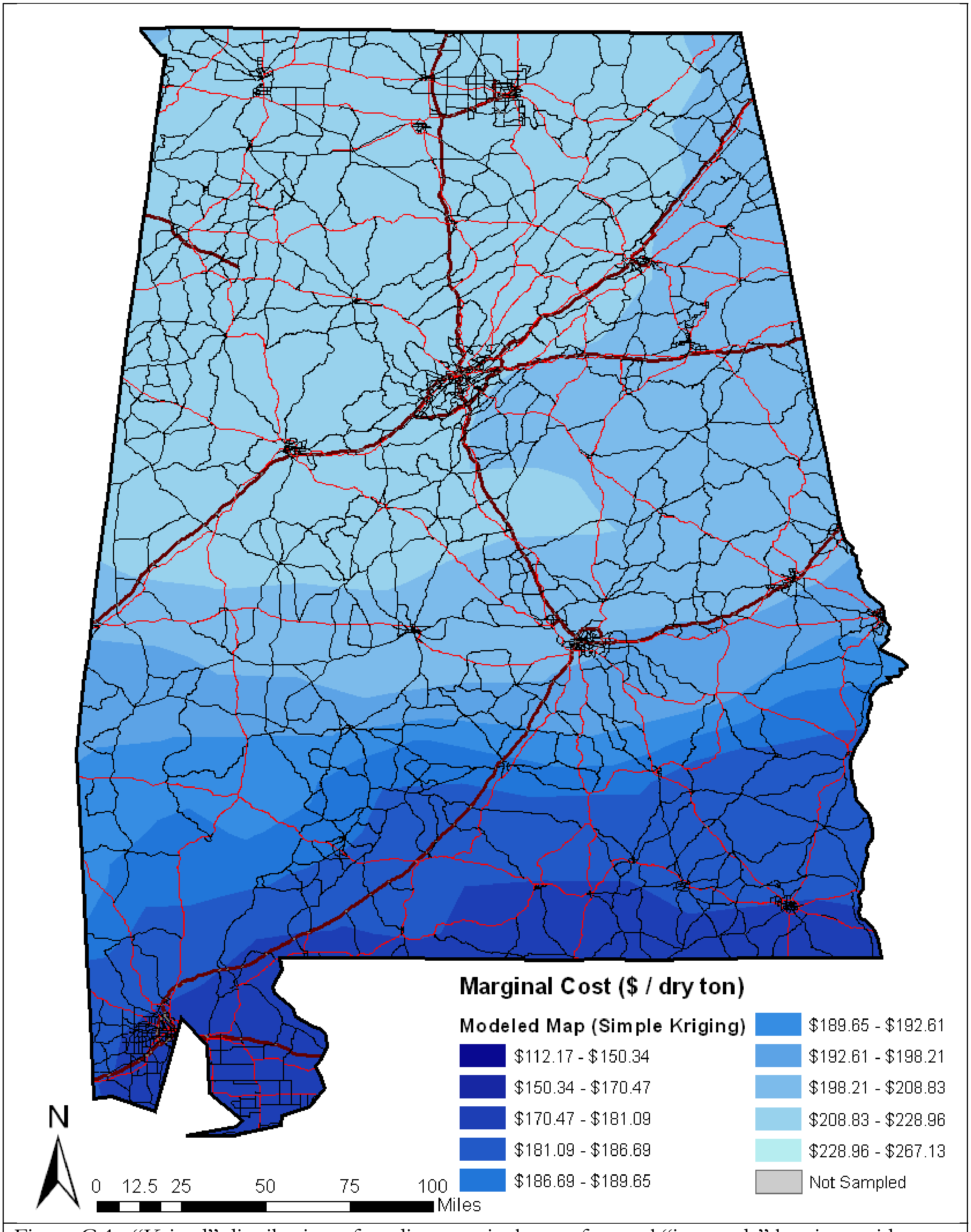

Figure G.1. "Kriged" distribution of median marginal costs for total "in woods" logging residues for Alabama.

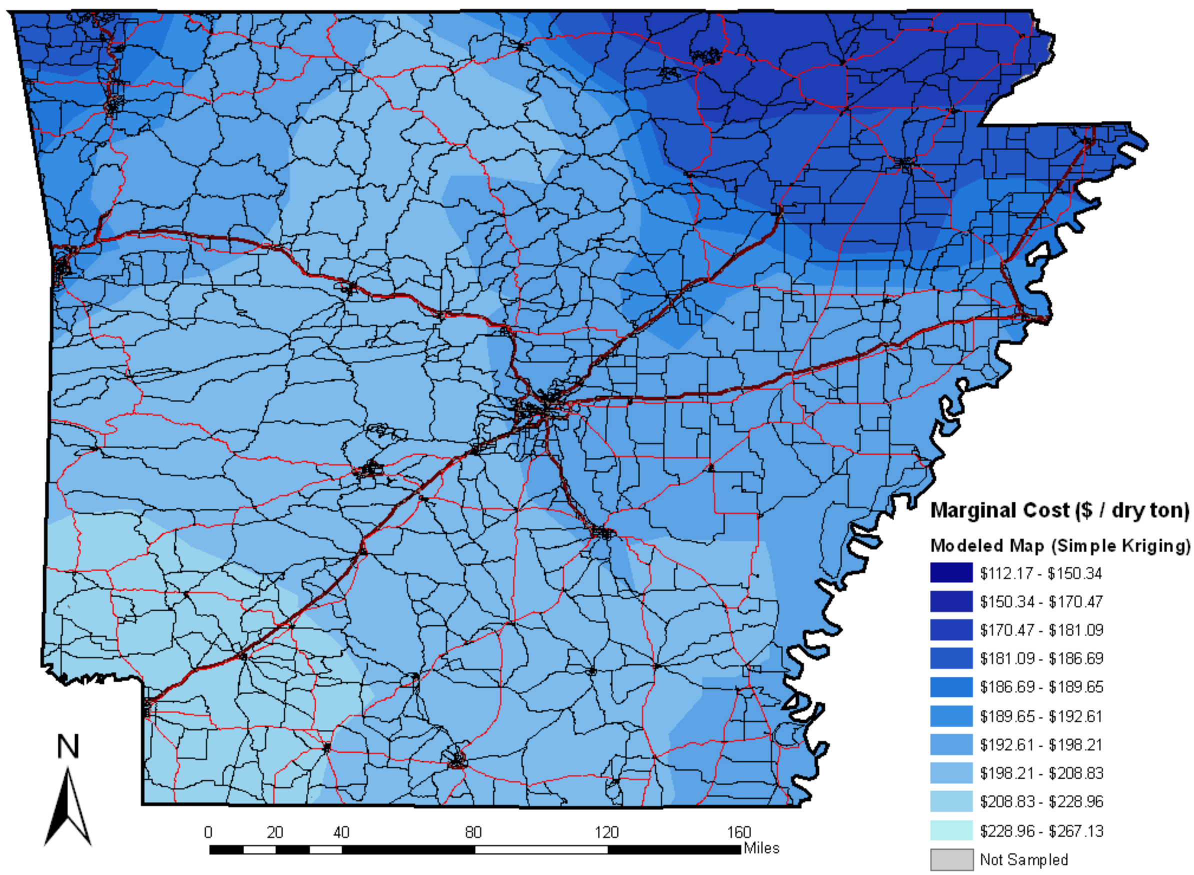

Figure G.2. "Kriged" distribution of median marginal costs for total "in woods" logging residues for Arkansas.

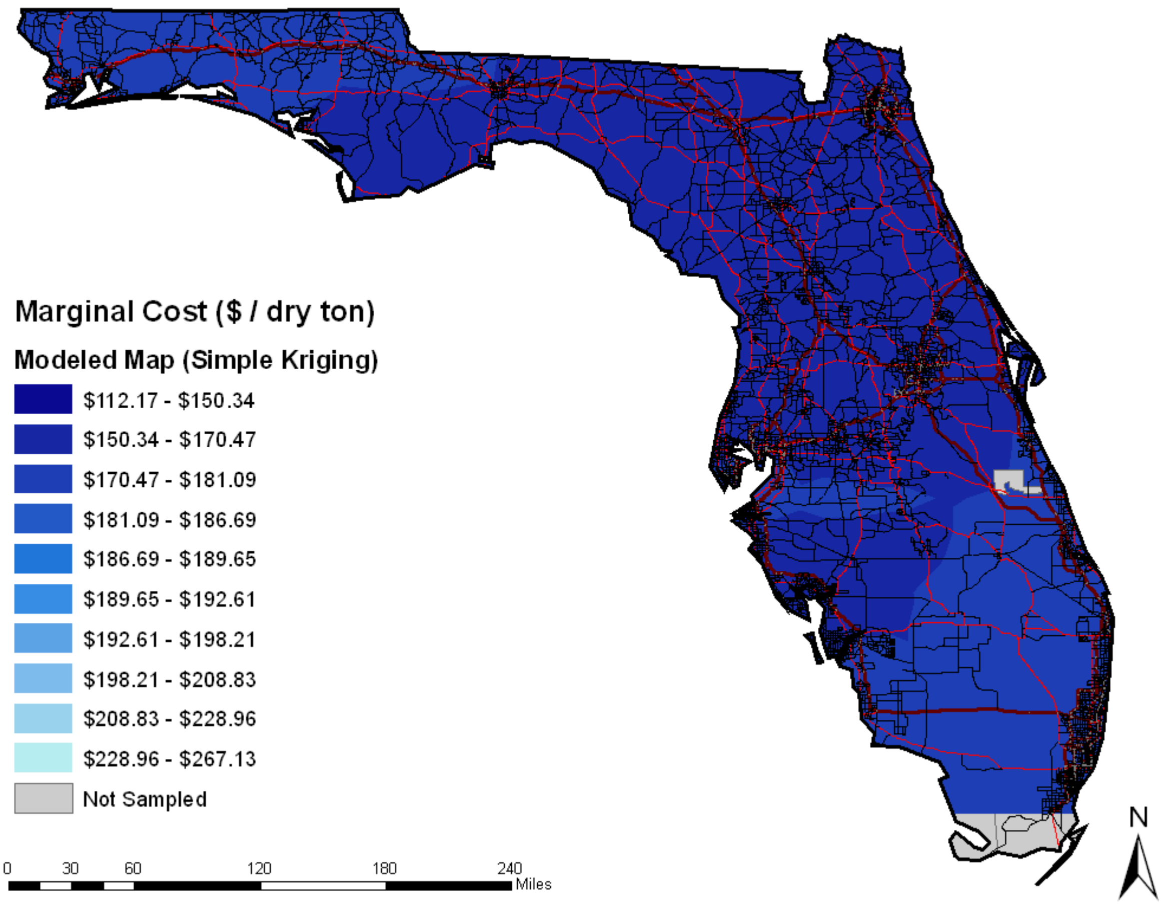

Figure G.3. "Kriged" distribution of median marginal costs for total "in woods" logging residues for Florida.

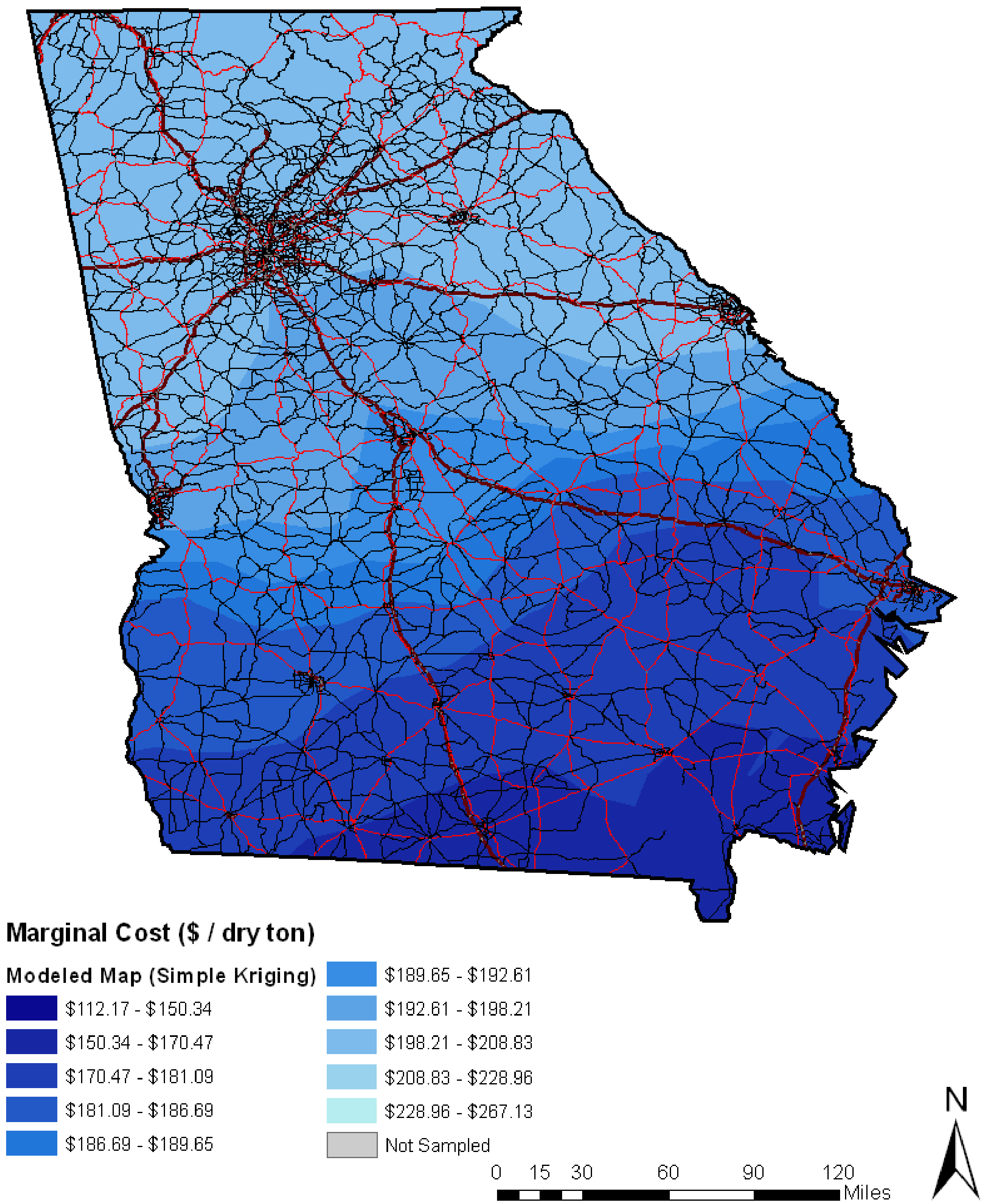

Figure G.4. "Kriged" distribution of median marginal costs for total "in woods" logging residues for Georgia.

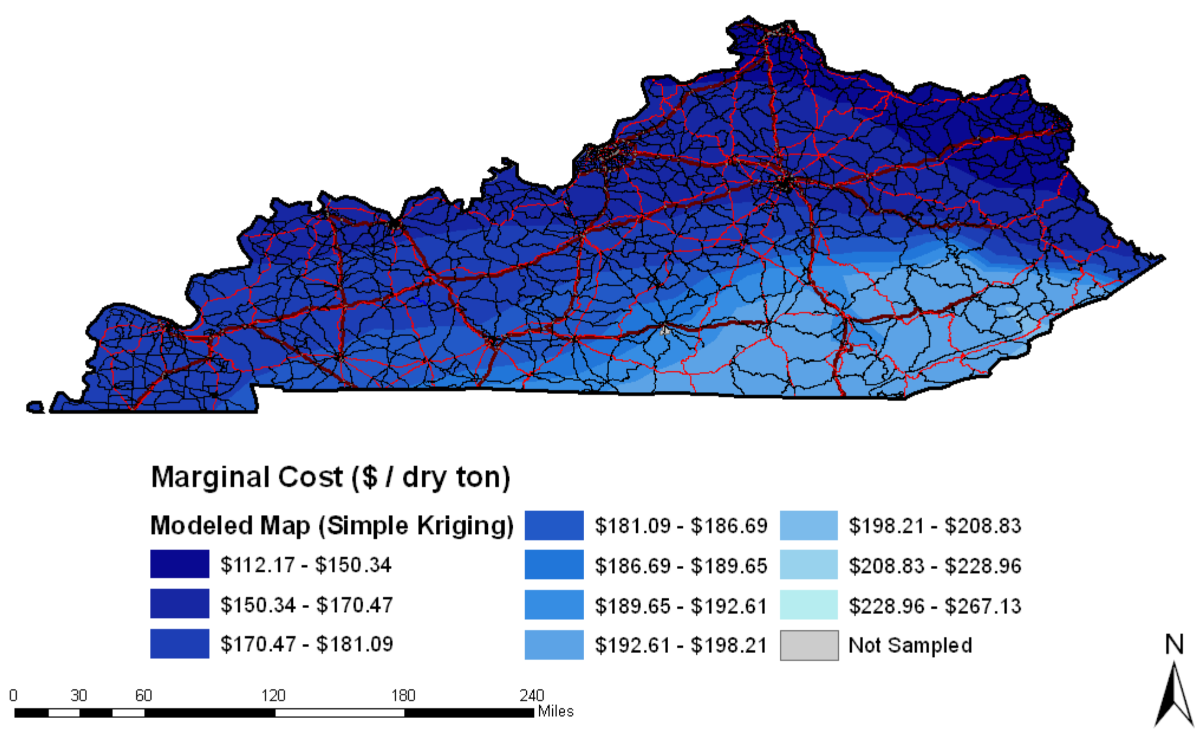

Figure G.5. "Kriged" distribution of median marginal costs for total "in woods" logging residues for Kentucky.

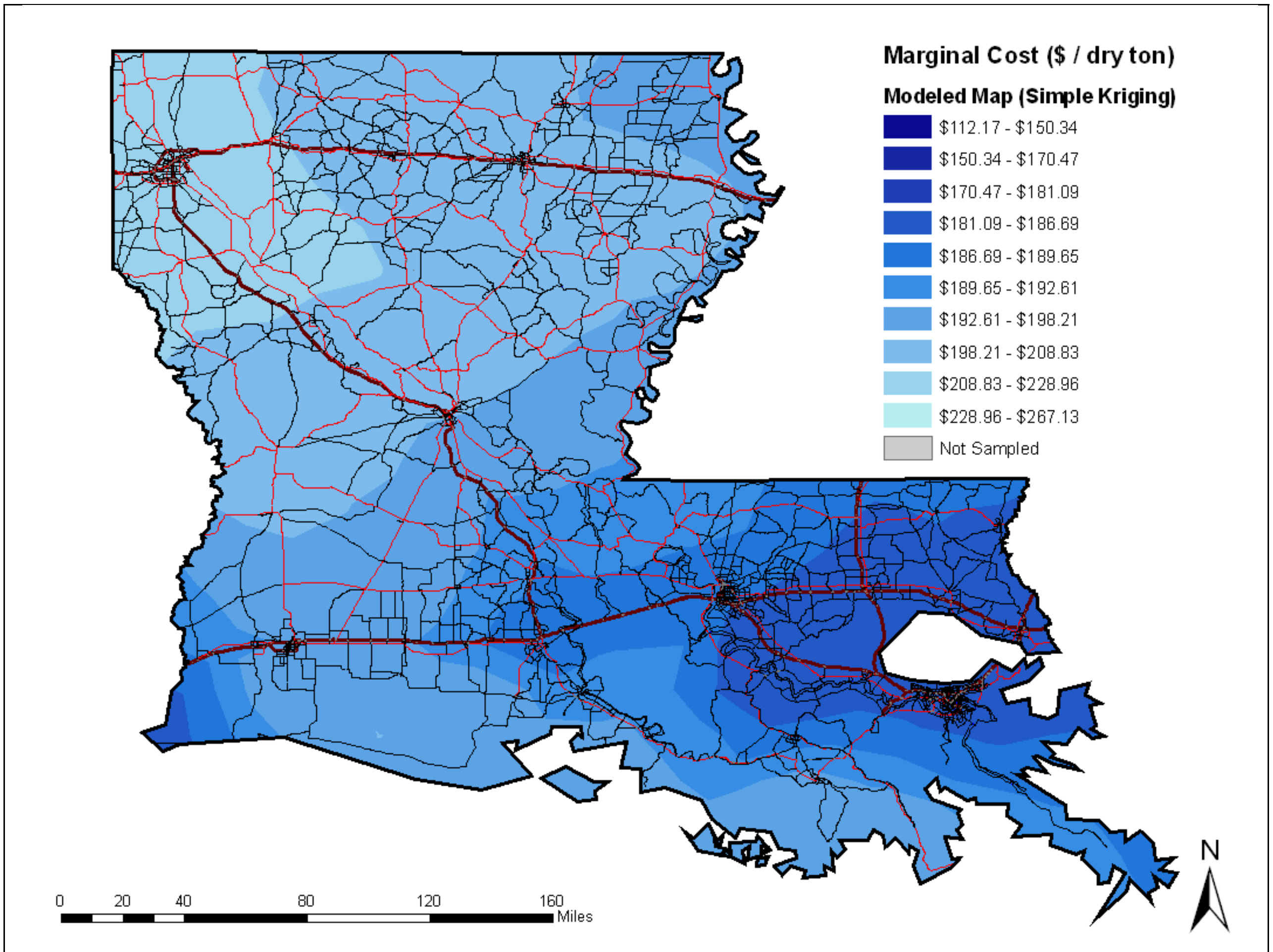

Figure G.6. "Kriged" distribution of median marginal costs for total "in woods" logging residues for Louisiana.

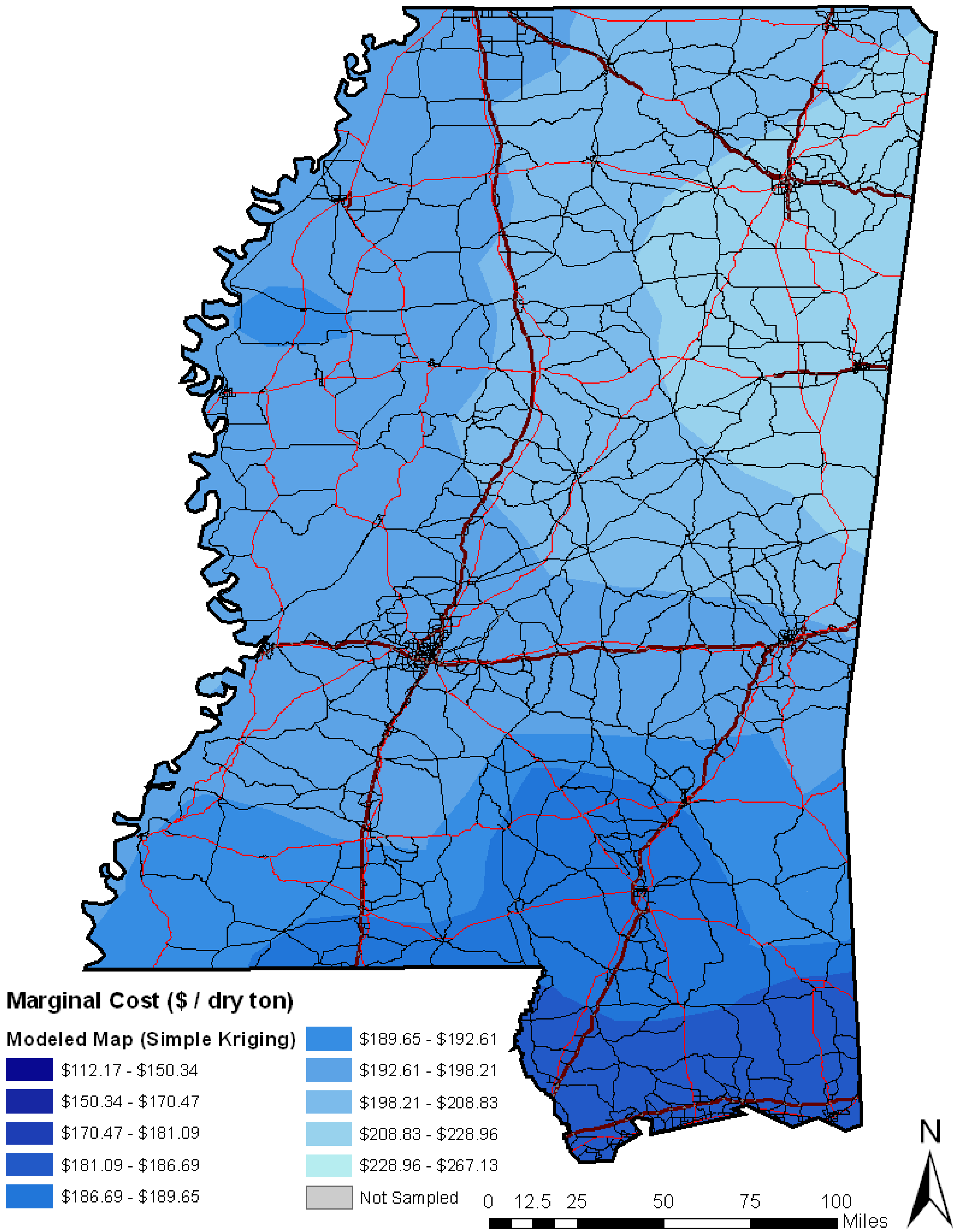

Figure G.7. "Kriged" distribution of median marginal costs for total "in woods" logging residues for Mississippi.

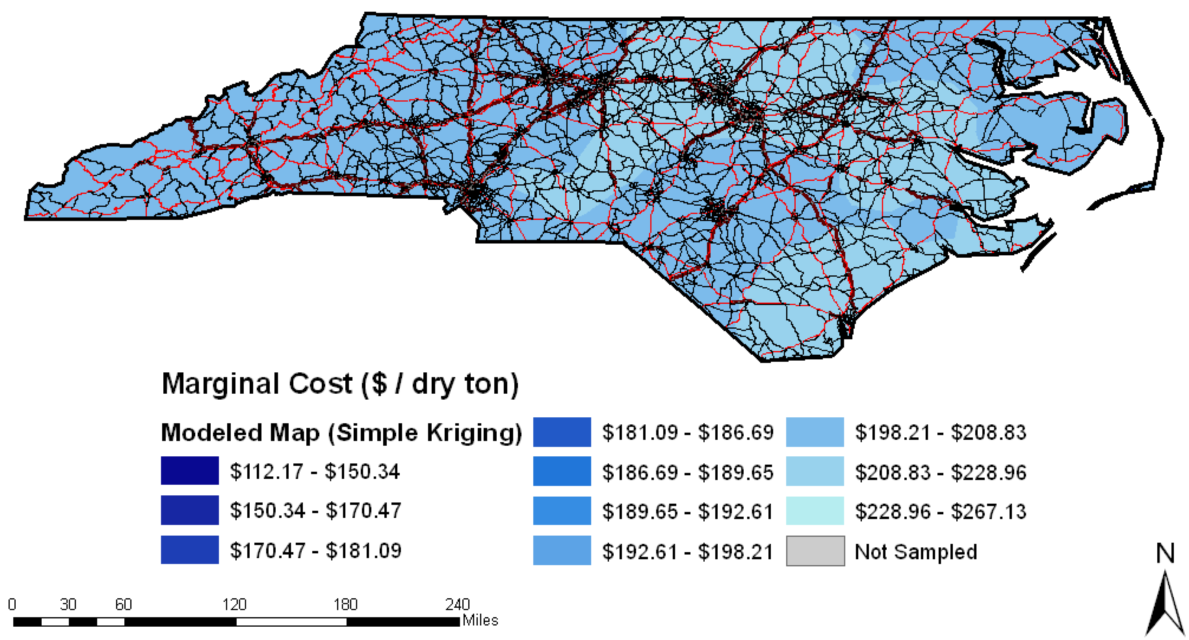

Figure G.8. "Kriged" distribution of median marginal costs for total "in woods" logging residues for North Carolina.

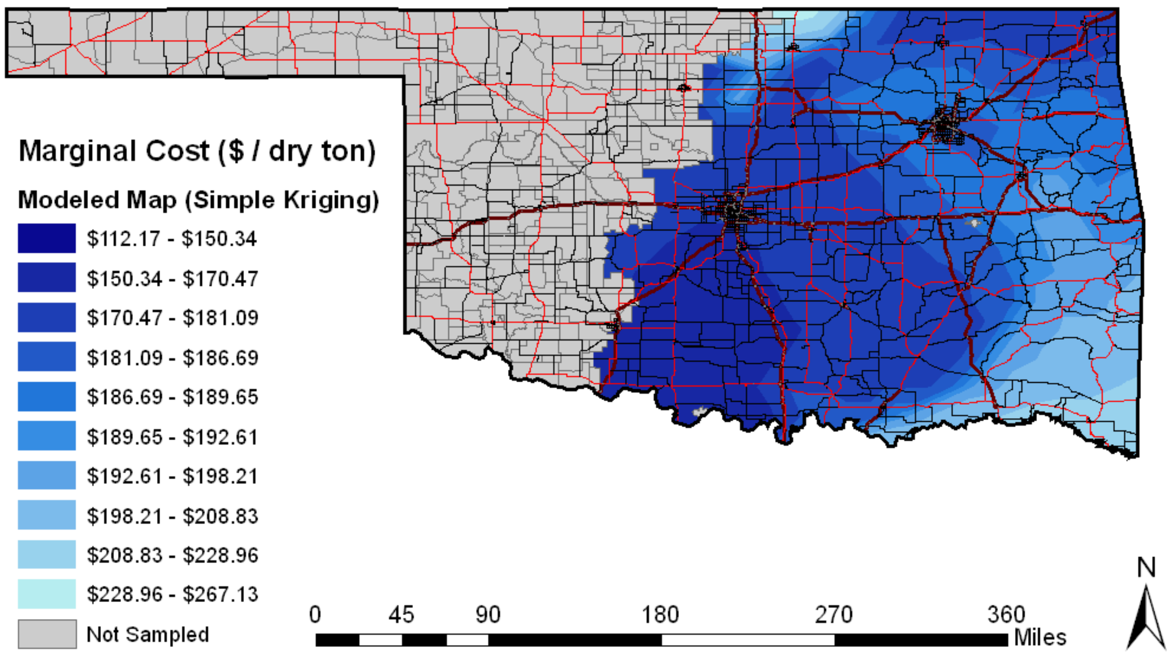

Figure G.9. "Kriged" distribution of median marginal costs for total "in woods" logging residues for Oklahoma.

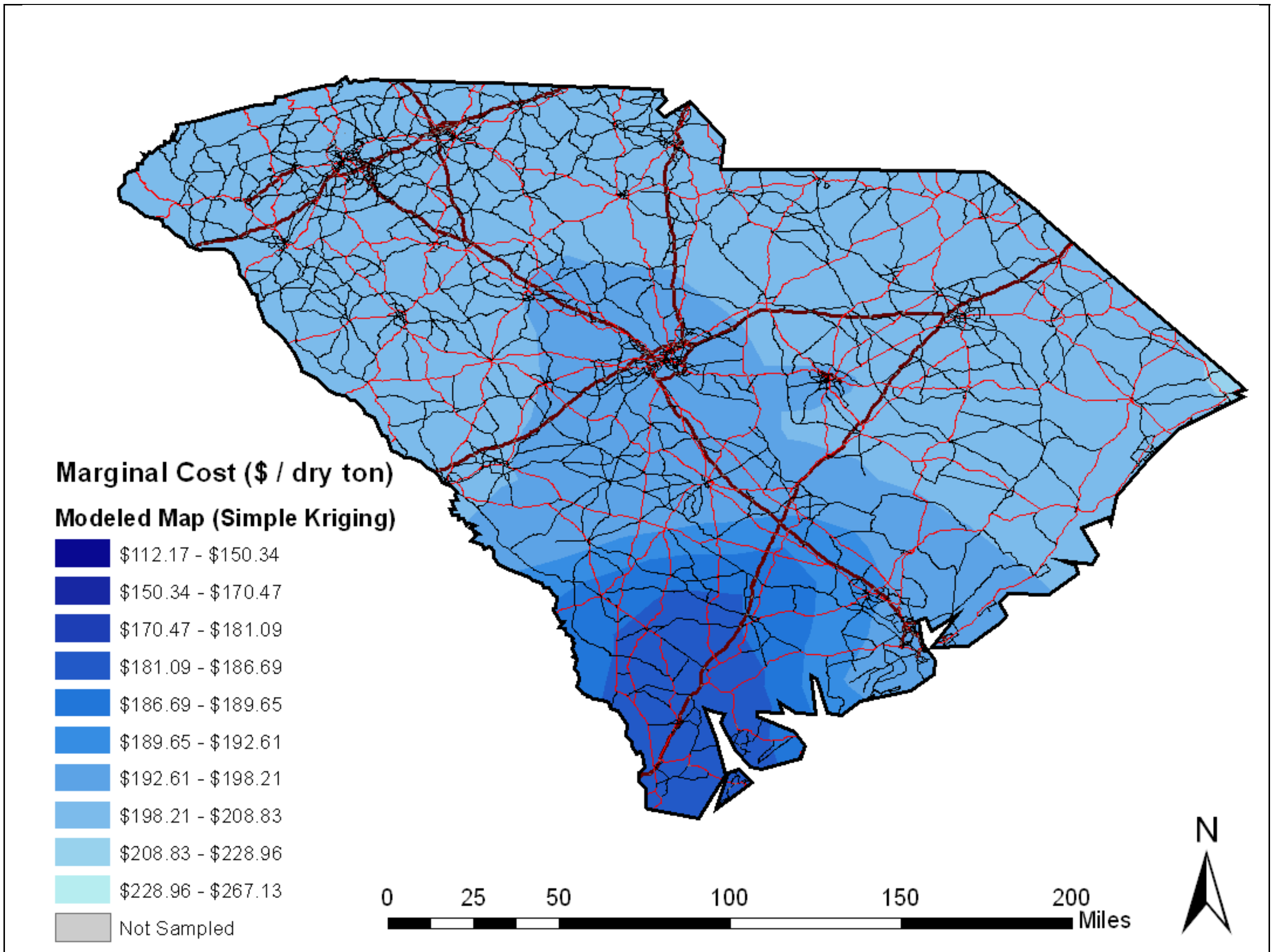

Figure G.10. "Kriged" distribution of median marginal costs for total "in woods" logging residues for South Carolina.

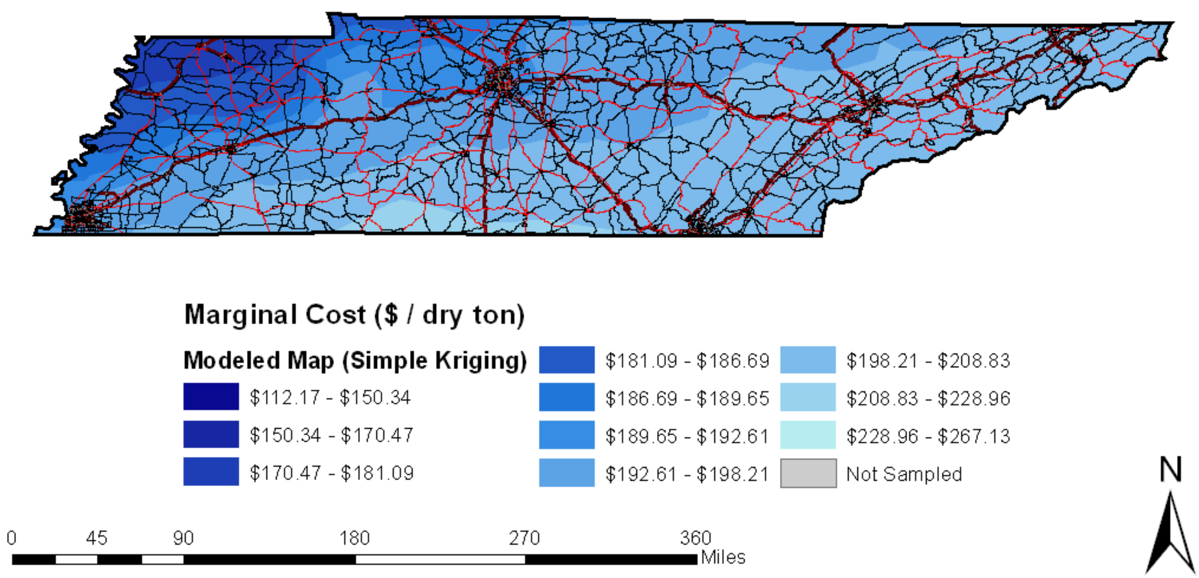

Figure G.11. "Kriged" distribution of median marginal costs for total "in woods" logging residues for Tennessee.

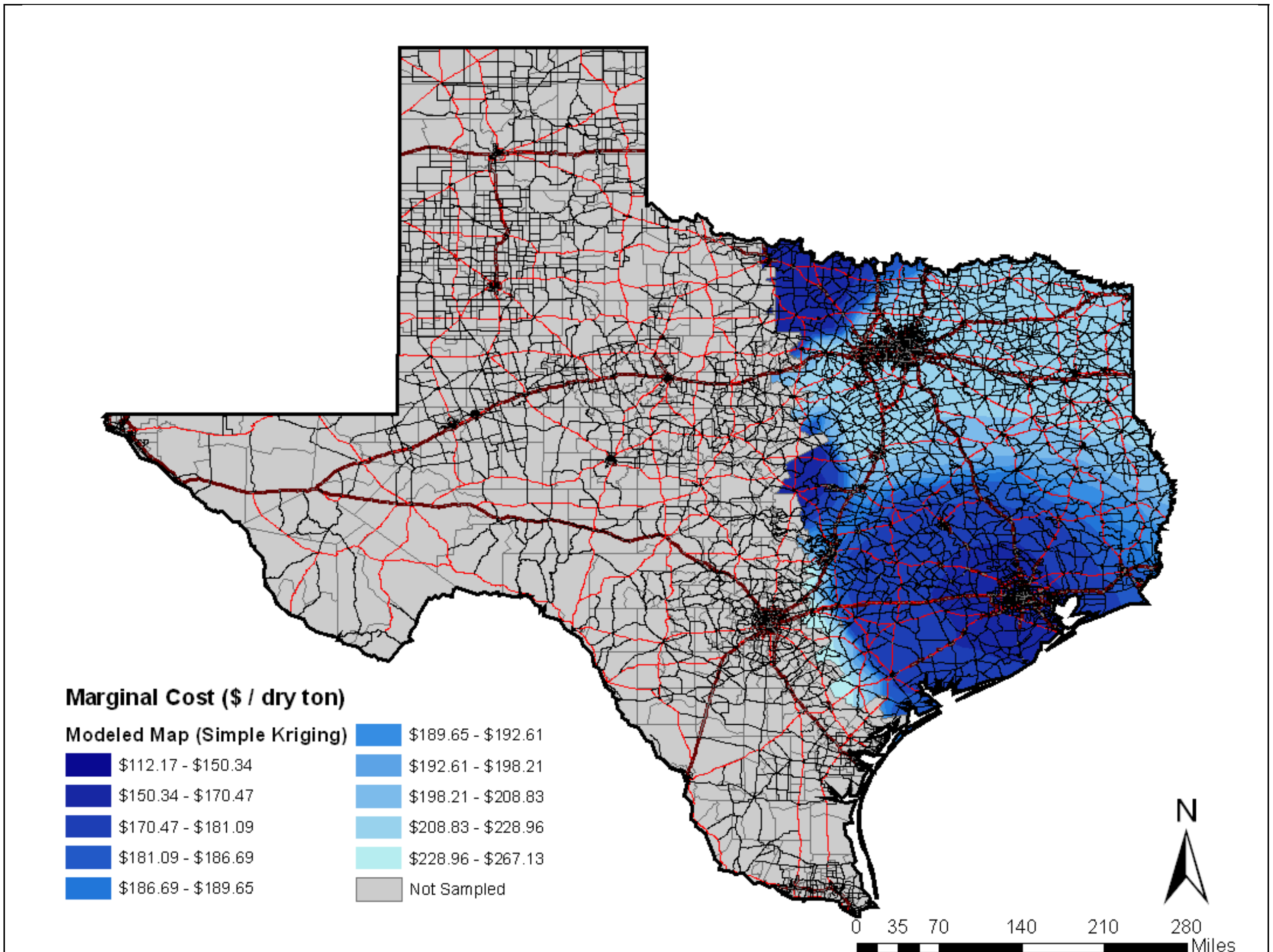

Figure G.12. "Kriged" distribution of median marginal costs for total "in woods" logging residues for Texas.

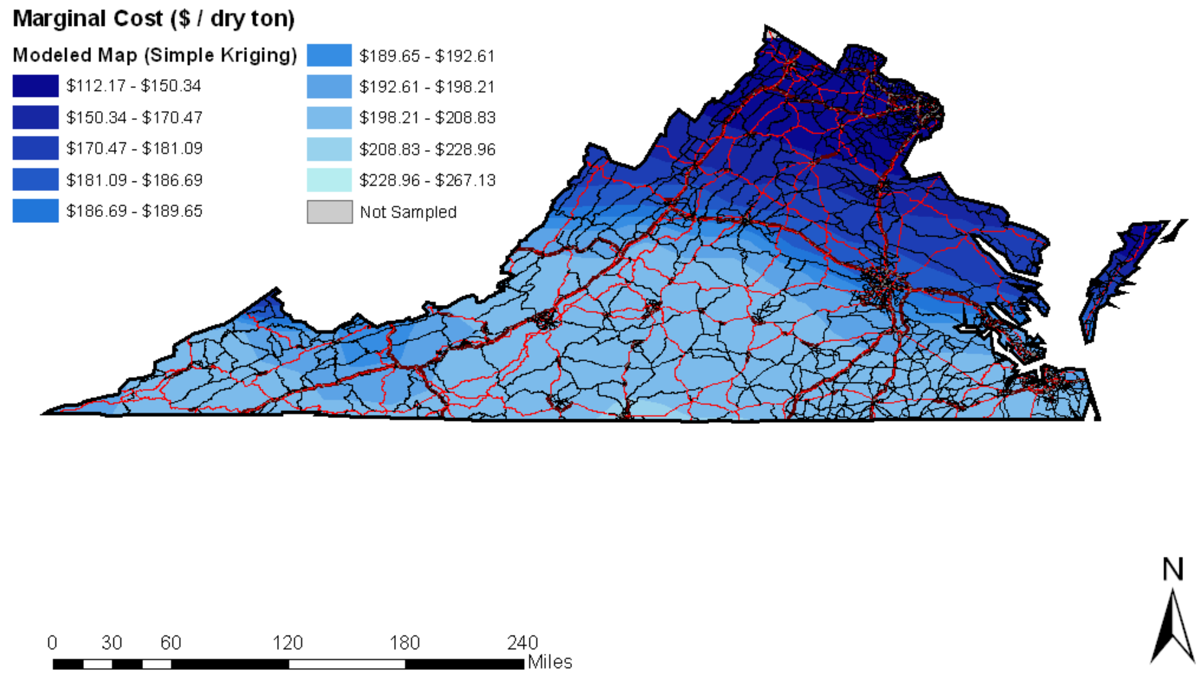

Figure G.13. "Kriged" distribution of median marginal costs for total "in woods" logging residues for Virginia.

Appendix H

SRTS Model Projections of Pulpwood and Sawtimber Removals
and Inventory by State

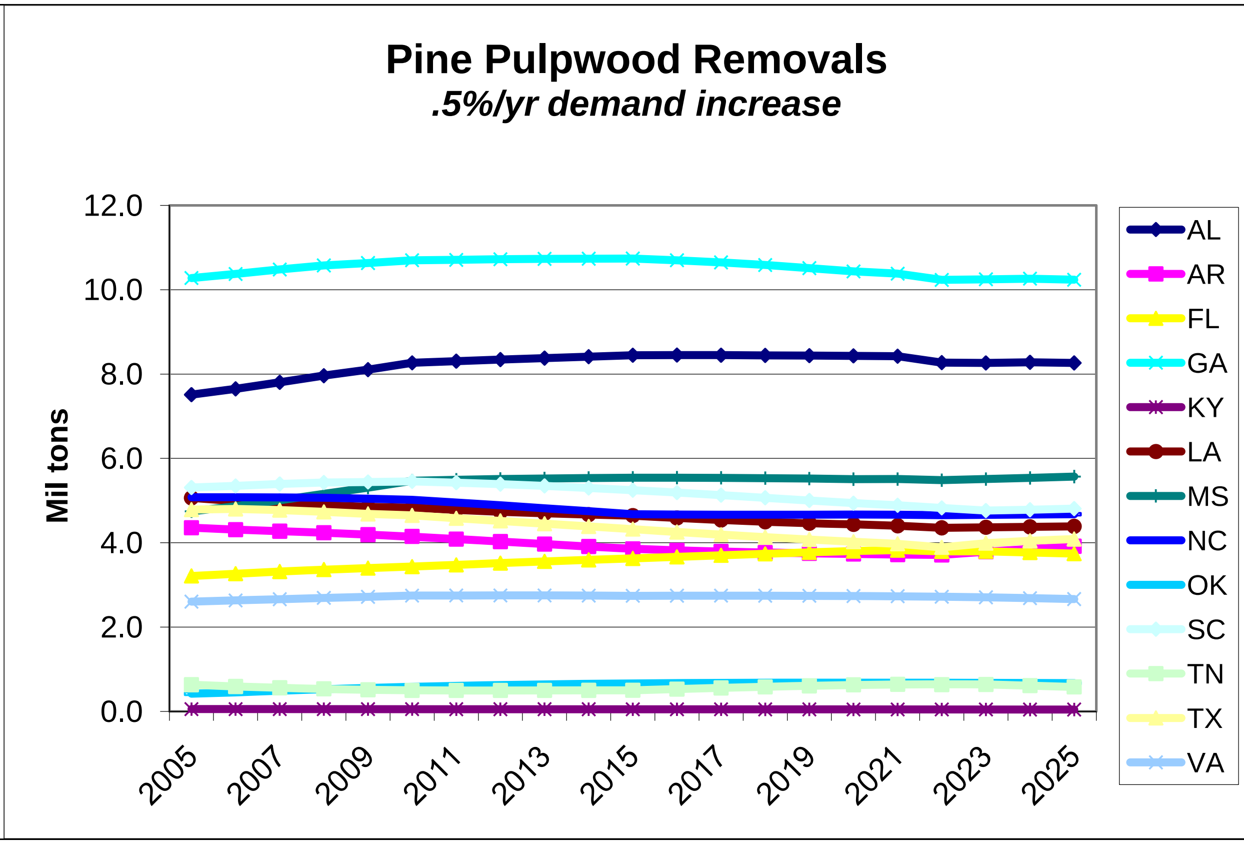

Figure H.1. SRTS model projections of pine pulpwood removals by state from 2005 to 2050 with a 0.5% per year demand increase.

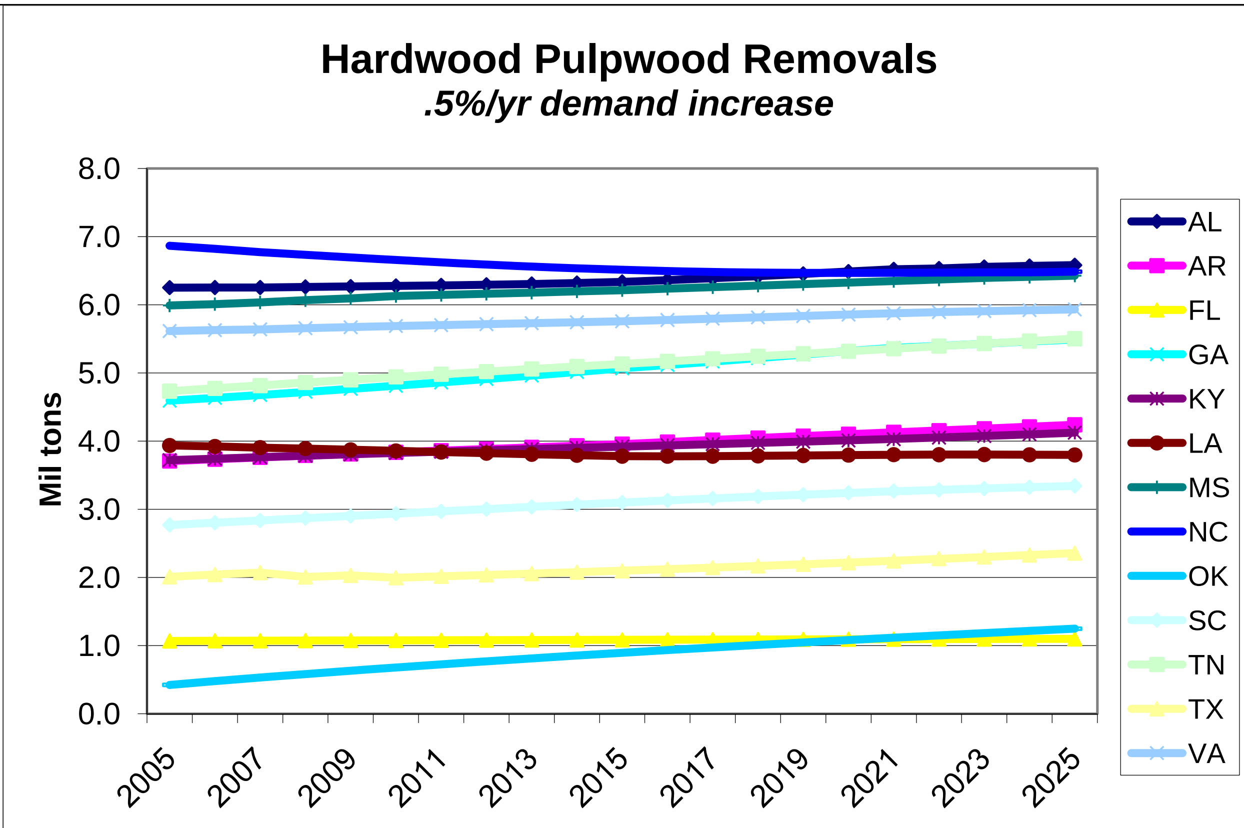

Figure H.2. SRTS model projections of hardwood pulpwood removals by state from 2005 to 2050 with a 0.5% per year demand increase.

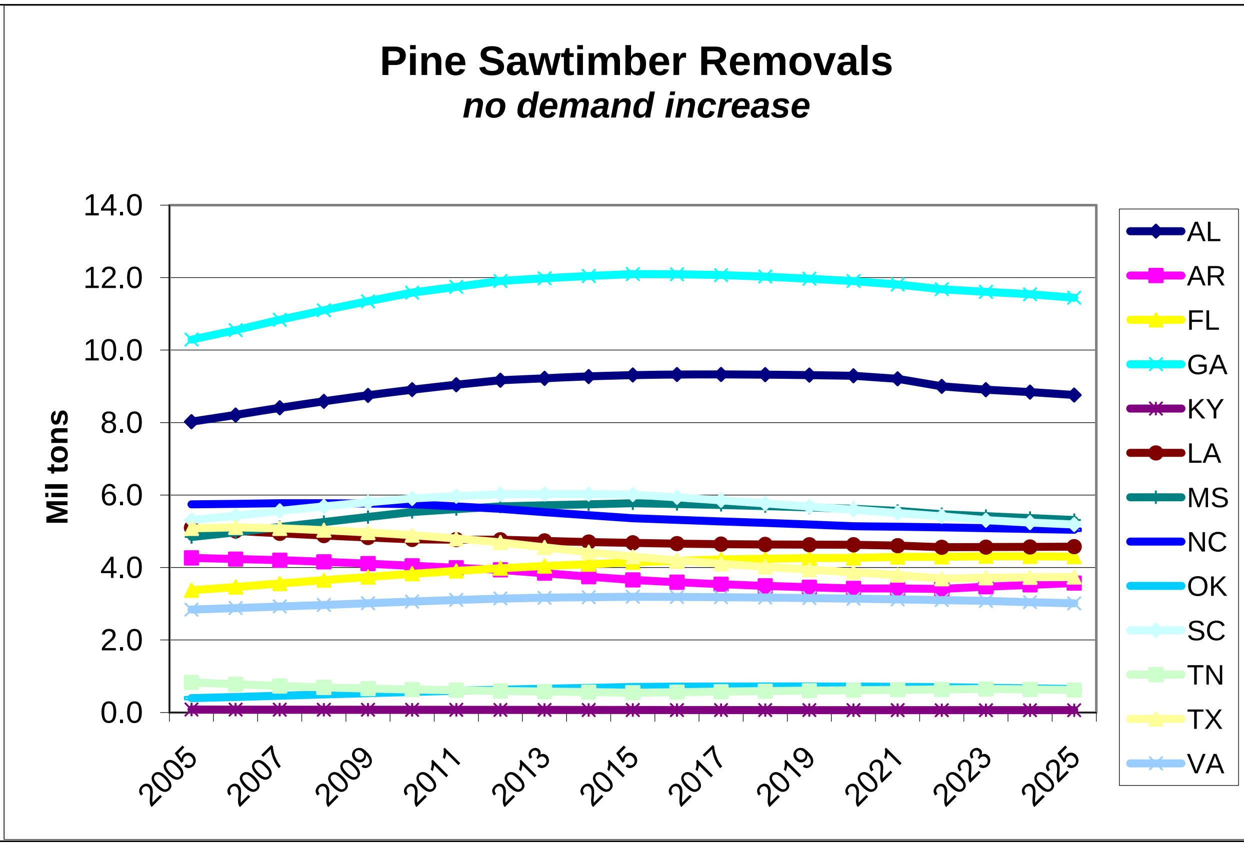

Figure H.3. SRTS model projections of pine sawtimber removals by state from 2005 to 2050 with no demand increase.

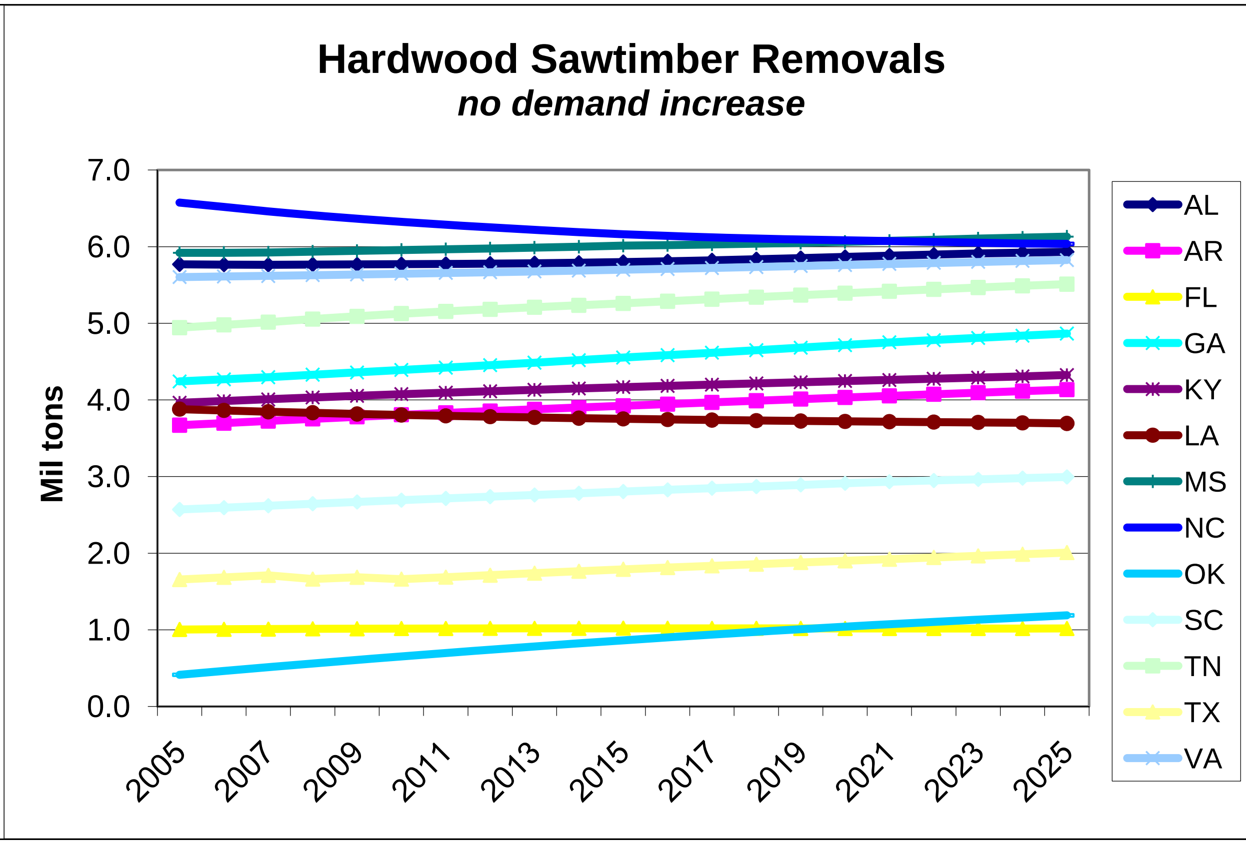

Figure H.4. SRTS model projections of hardwood sawtimber removals by state from 2005 to 2050 with no demand increase.

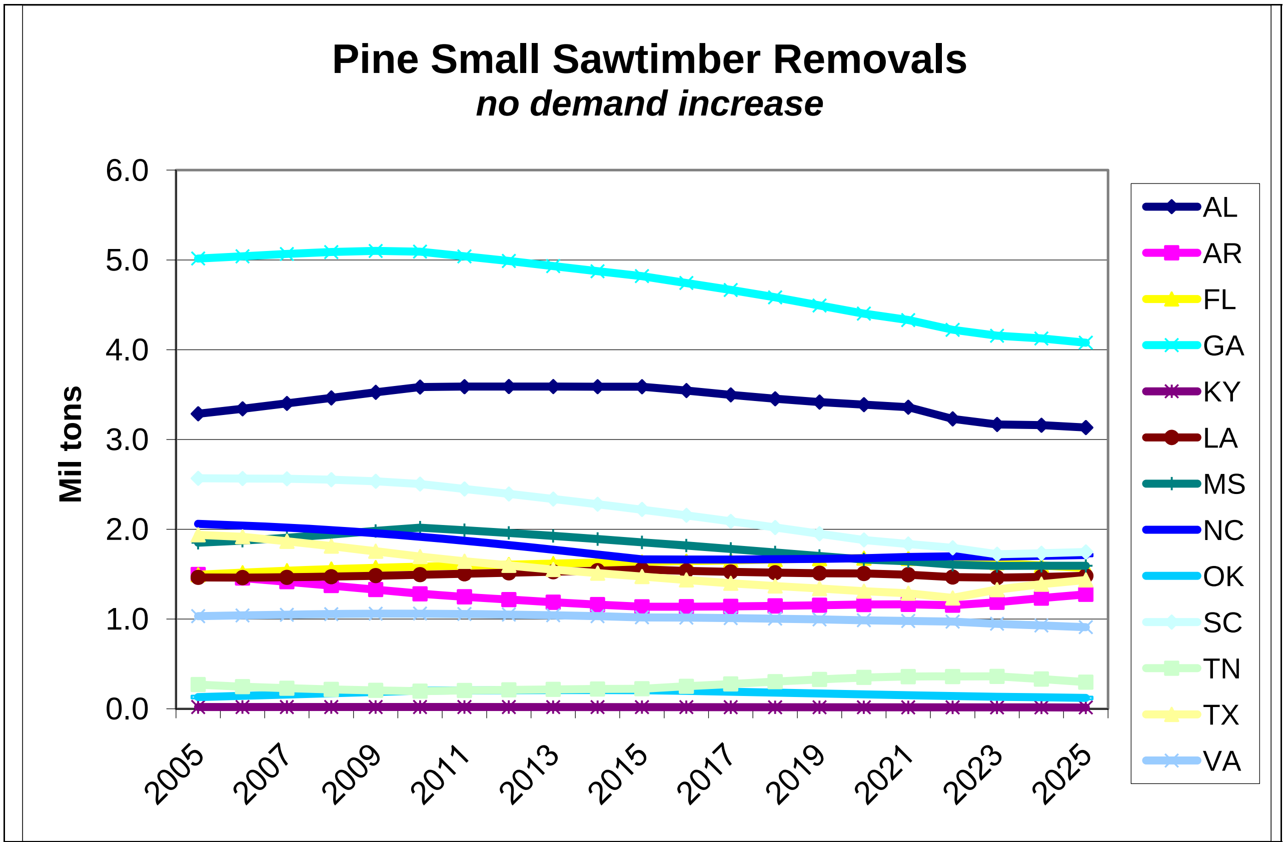

Figure H.5. SRTS model projections of pine small sawtimber removals by state from 2005 to 2050 with no demand increase.

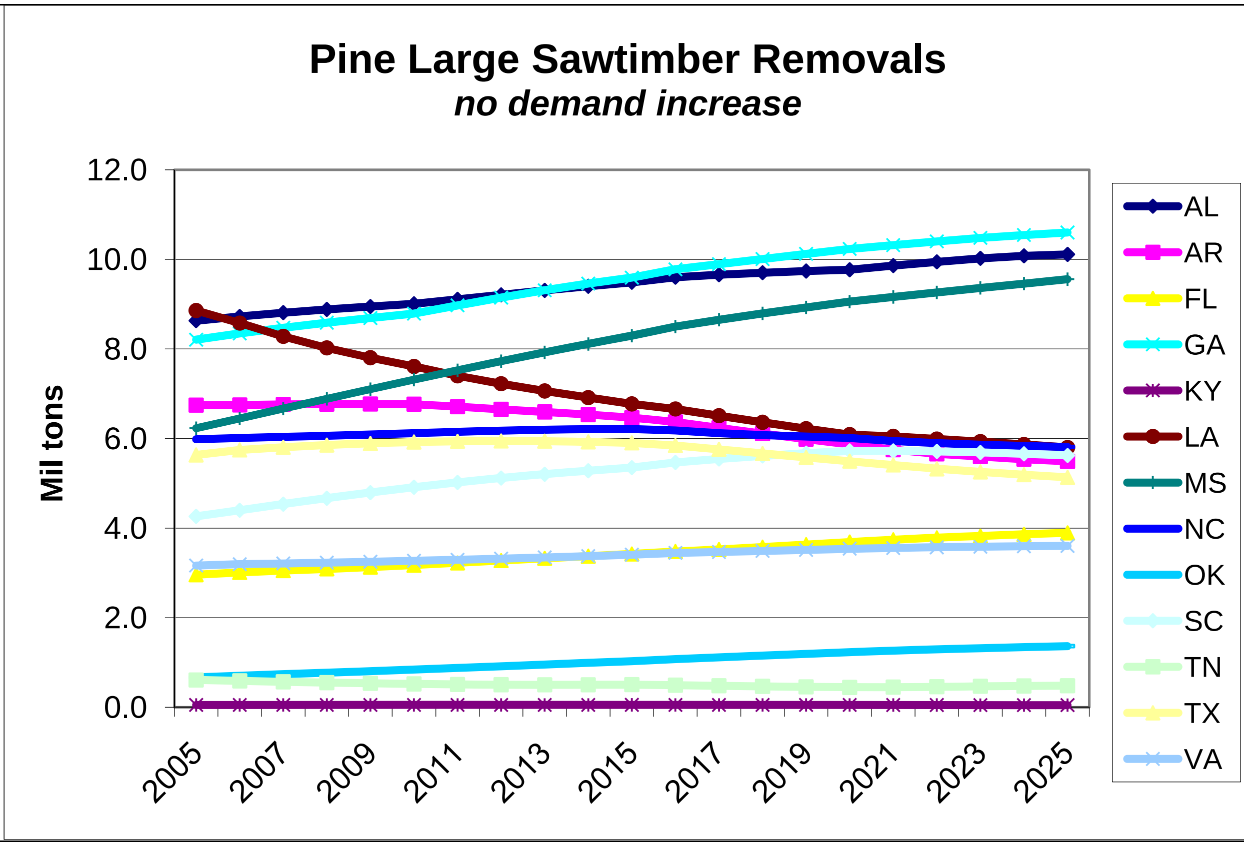

Figure H.6. SRTS model projections of pine large sawtimber removals by state from 2005 to 2050 with no demand increase.

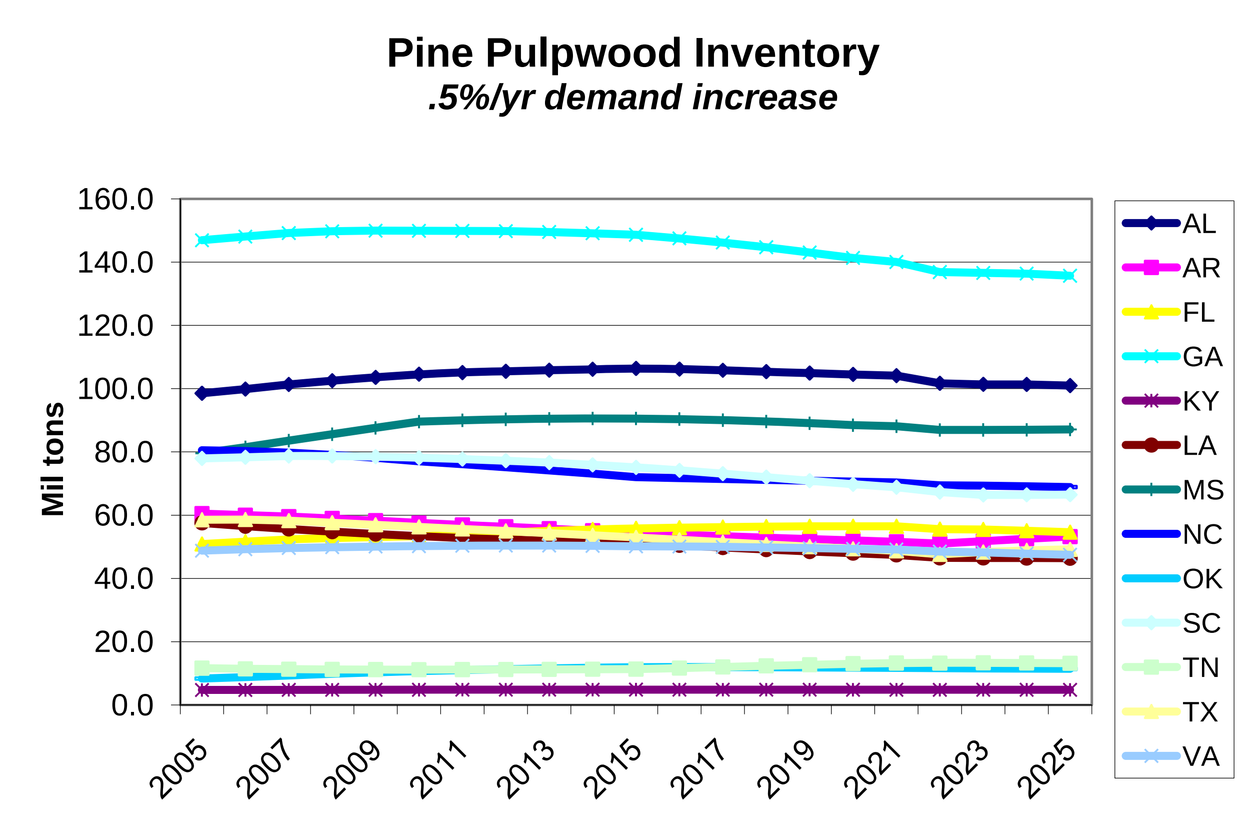

Figure H.7. SRTS model projections of pine pulpwood inventory by state from 2005 to 2050 with a 0.5% per year demand increase.

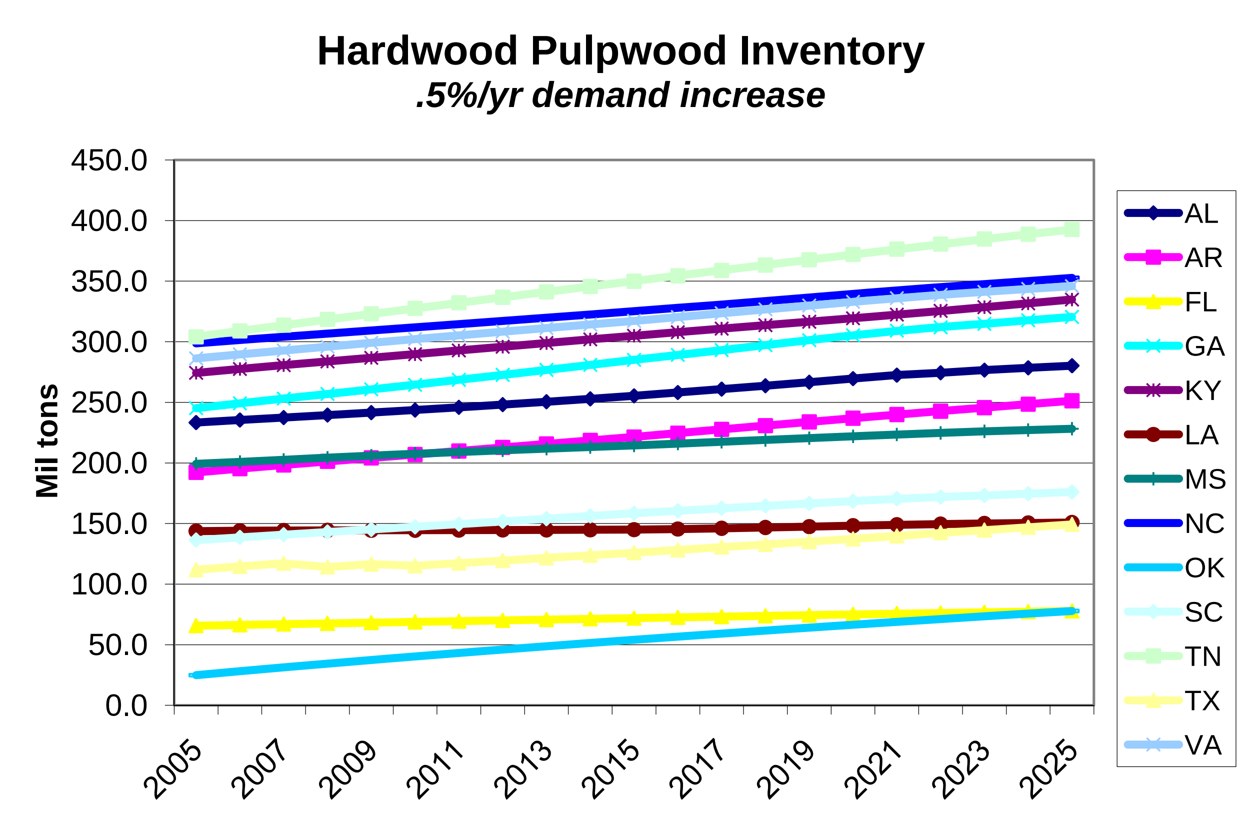

Figure H.8. SRTS model projections of hardwood pulpwood inventory by state from 2005 to 2050 with a 0.5% per year demand increase.

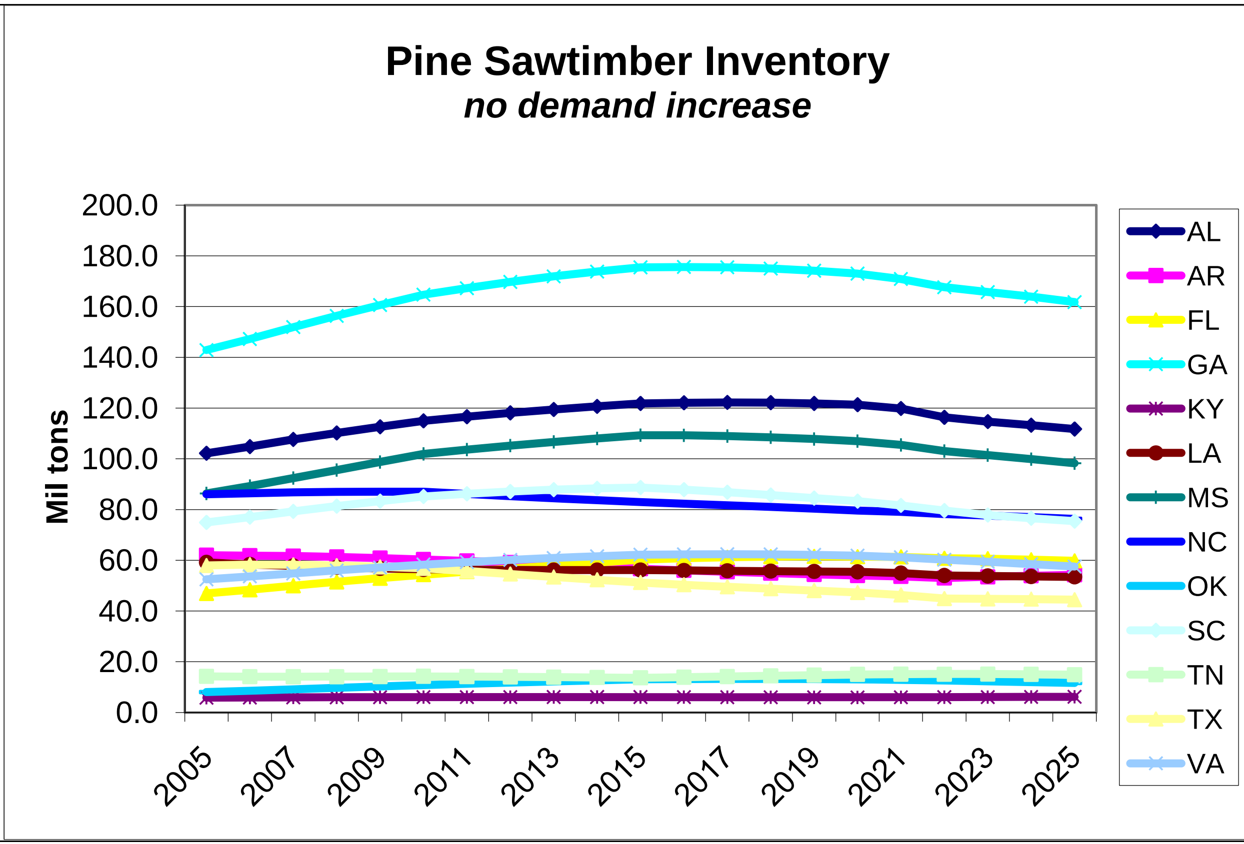

Figure H.9. SRTS model projections of pine sawtimber inventory by state from 2005 to 2050 with no demand increase.

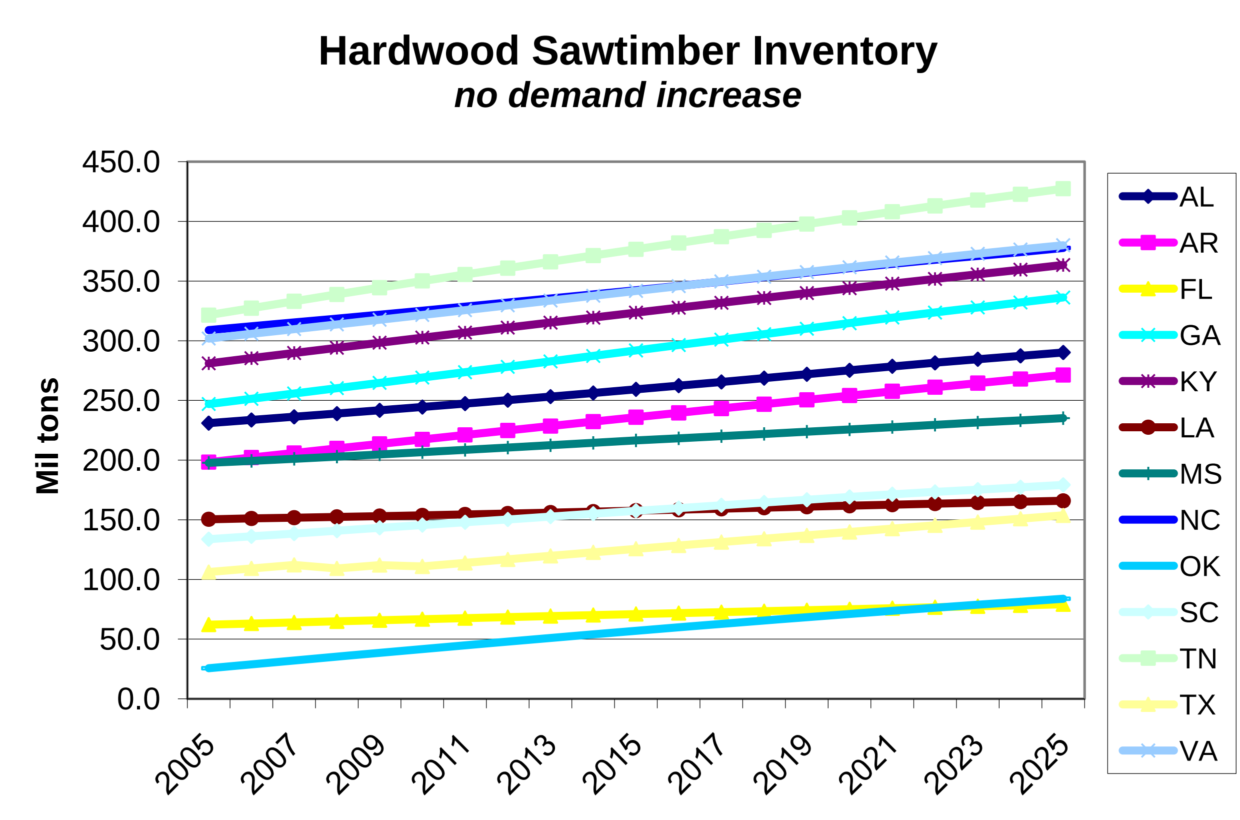

Figure H.10. SRTS model projections of hardwood sawtimber inventory by state from 2005 to 2050 with no demand increase.

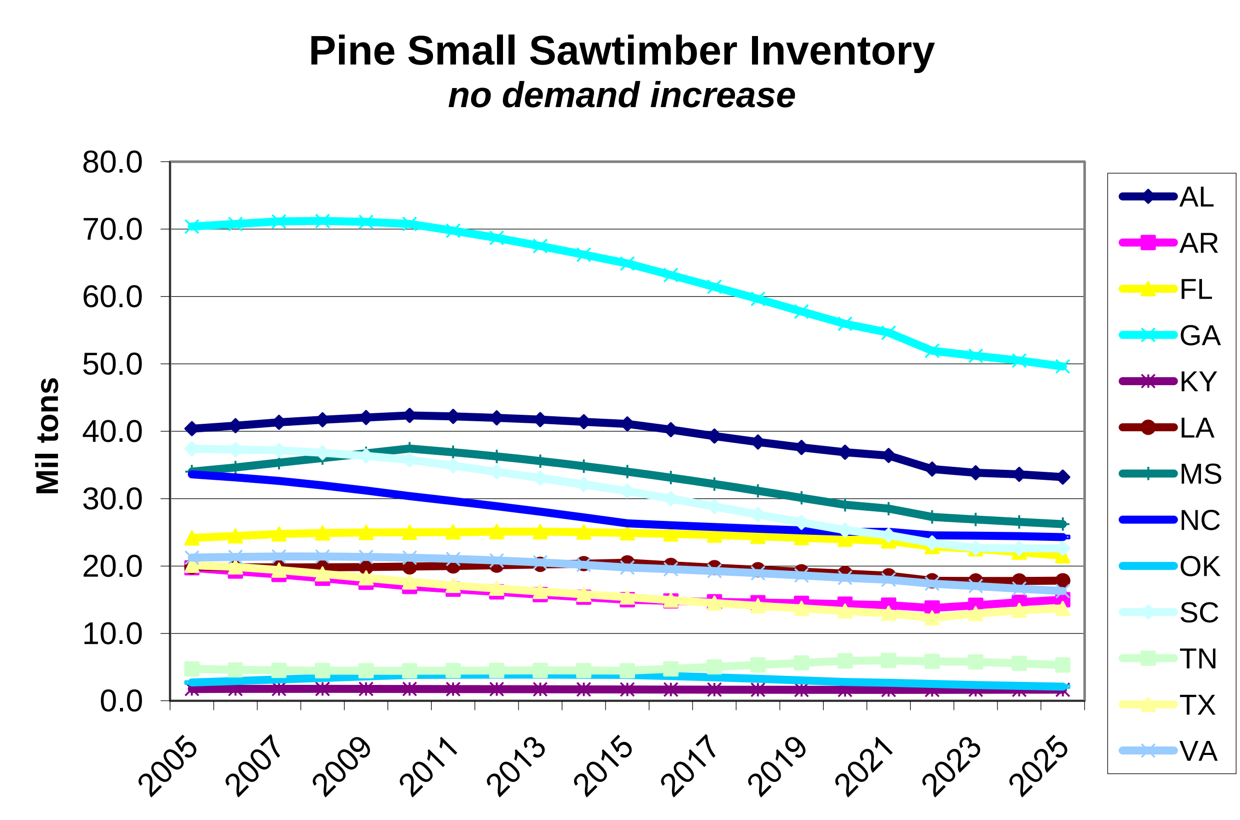

Figure H.11. SRTS model projections of pine small sawtimber inventory by state from 2005 to 2050 with no demand increase.

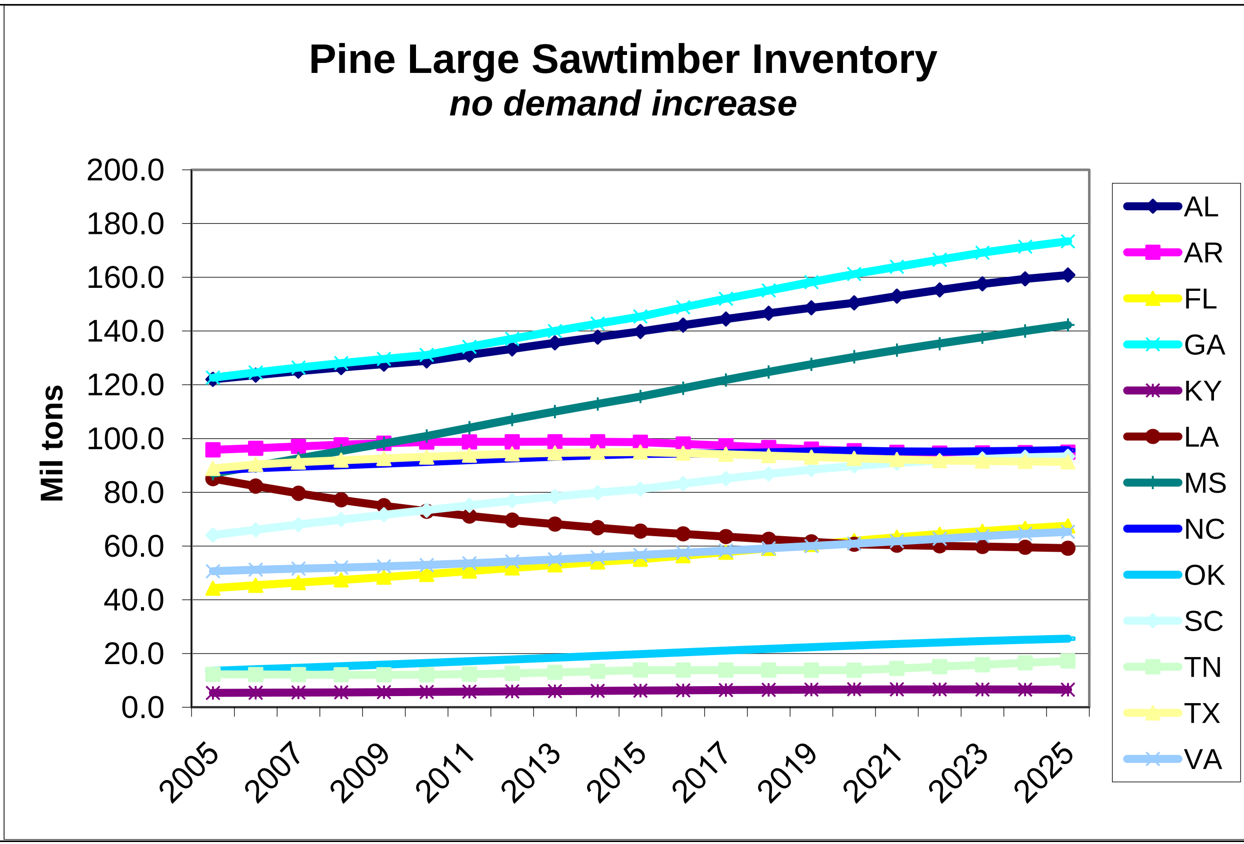

Figure H.12. SRTS model projections of pine large sawtimber inventory by state from 2005 to 2050 with no demand increase.