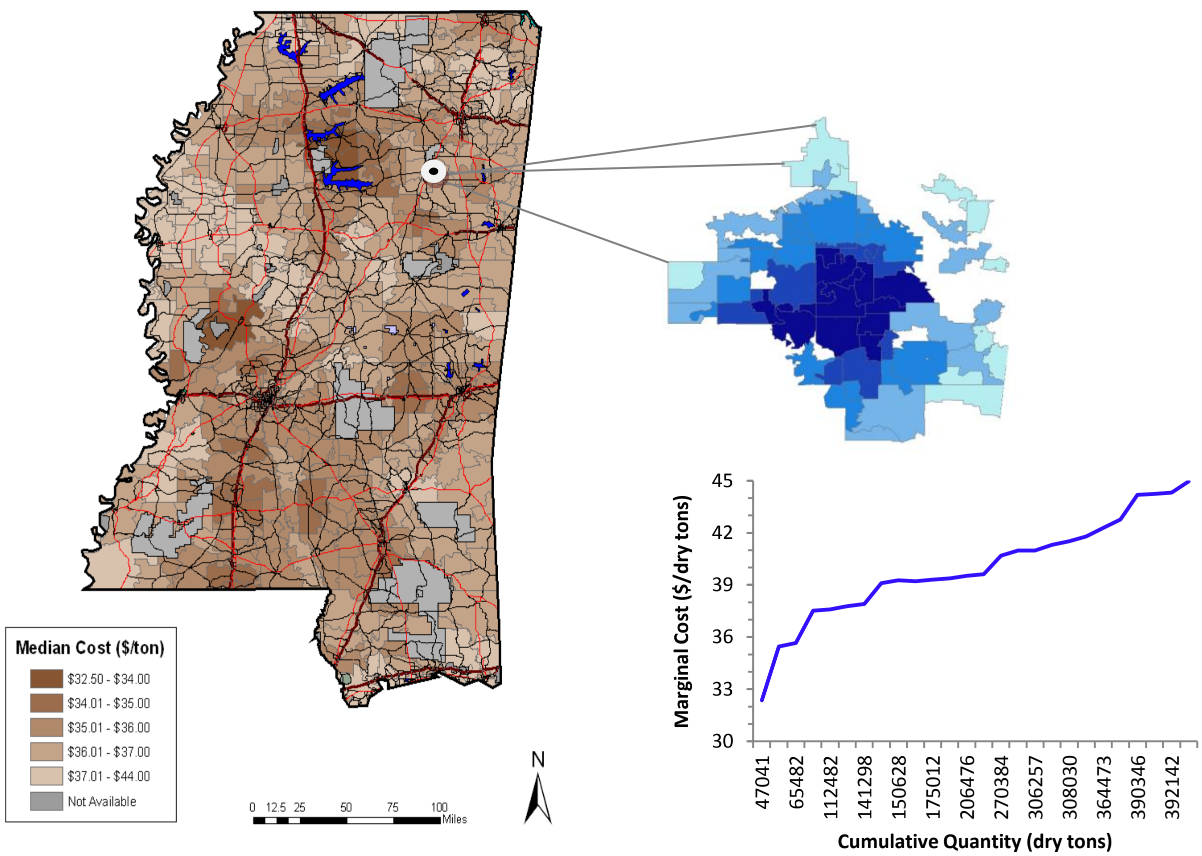
The Biomass Site Assessment Tool (BioSAT)



Final Report

U.S. Forest Service

Southern Research Station

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The Biomass Site Assessment Tool (BioSAT)

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Executive Summary

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 Administration 2009). Key sources of oil for U.S. markets are located in complex geopolitical environments that increase risk to the U.S. economy.[1] Since the 1970s, macroeconomists have viewed changes in the price of oil as an important source of economic fluctuations, as well as a paradigm for 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 had a declining trend from July, 2008 through 2010, oil prices trended upward in 2011 to a high of $119.42 per barrel on April 15, 2011. This instability of oil prices and the associated negative economic consequences has created a renewed interest in bioenergy and biofuels. However, there are a plethora of research questions concerning the use of cellulosic feedstocks for energy and fuels. 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 all potential constraints that need to be better understood.

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.* 1991a 1991b, Lunnan 1997, Walsh 1998, 2000, DiPardo 2000, Ugarte *et al.* 2000, 2006, 2007, Biomass Research and Development Board 2008, Western Governors Association 2008, Perez *et al.* 2009, Galik *et al.* 2009, U.S. Dept. of Energy 2011). 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, U.S. Dept. of Energy 2011).

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

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, loss of timberland to urbanization, and land fragmentation 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 and sustained sluggish economy of 2010/2011, which has seen record low housing starts, wood consumption, and historic levels of decommissioning of manufacturing capacity by the forest products industry.

Aggregate south wide trends may mask significant regional differences in resource availability and current demand which is clarified by this study. The focus of this study was to identify and project spatial comparative advantages for cellulosic feedstocks for 33 eastern U.S. states.[2] While prior studies have examined the availability of wood for biomass or the transportation costs associated with cellulosic biomass (Langholtz *et al.* 2006, Perlack *et al.* 2005, Jensen *et al.* 2002, Noon and Day 1996), this study is unique in that "at-plant-gate" delivered costs associated with providing cellulosic feedstocks to biorefineries were assessed at the 5-digit zip code tabulation area (ZCTA) and made available on a public domain web site www.biosat.net where input costs are periodically updated. The study developed geo-referenced estimates of resources costs, logging costs, and transportation costs, and incorporated these costs to develop aggregate supply curves or the producers' marginal cost curves for cellulosic woody and agricultural residues feedstocks delivered to biomass using facilities.

[2] Alabama, Arkansas, Connecticut, Delaware, Florida, Georgia, Illinois, Indiana, Iowa, Kentucky, Louisiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, New Hampshire, New Jersey, New York, North Carolina, Ohio, Oklahoma, Pennsylvania, Rhode Island, South Carolina, Tennessee, Texas, Vermont, Virginia, West Virginia, Wisconsin.

In this study, bio-basins were often non-concentric aggregations which were a function of the road network and available biomass supply. Resource cost data (*e.g., mill residue prices, pulpwood prices, etc.*) were obtained from Timber Mart South (TMS), Timber Mart North, and state-level reporting services. The transportation cost model of the overall BioSAT model estimated trucking costs based on the shortest travel time (*influence variable costs*) between the potential demand ZCTA and its associated supply ZCTAs.[3] Microsoft© MapPoint® 2006[4] 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 logging residue supply and recovery rates (Abt *et al.* 2000, Abt 2008). The Fuel Reduction Cost Simulator (FRCS), as modified for the Billion Ton Study, was used to estimate the costs of harvesting logging residues (Dykstra 2008). The Auburn Harvest Analyzer (AHA) was used to estimate harvesting costs for roundwood (Greene and Lanford 1987, Tufts *et al.* 1985, Tufts *et al.* 1988, Lanford and Stokes 1996, Holtzscher and Lanford 1997). The AHA model was adapted for the 33-state study region for six ecoregions, five forest stand types, and six harvesting systems.[5] Agricultural residues costs were estimated from the literature (Gallagher *et al.* 2003, U.S. Bureau of Labor Statistics, 2009).[6] Forest volume estimates were obtained from the Forest Inventory and Analysis Database (FIADB) version 3.0 (U.S. Department of Agriculture, Forest Service 2008a). Mill residue estimates were obtained from the U.S. Forest Service Forest Inventory and Analysis Database Timber Product Output Reports (U.S. Department of Agriculture, Forest Service 2008a). Agricultural residue estimates were obtained using USDA National Agricultural Statistics Service survey data and residue derivatives were estimated using the equations and conversion factors of the literature (Proctor 1994, Nelson *et al.* 2004, USDA National Agricultural Statistics Service 2008).

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[3] Travel distance which influences fixed costs was allocated over the tractor-trailer's estimated annual miles which was 100,000 miles for the tractor and dry van and flatbed trailers; 80,000 miles for the long-log and short-log trailers.

[4] http://www.microsoft.com/mappoint/en-us/home.aspx

[5] Ecoregions were: Gulf Coastal Plain, Appalachian Mountains, Eastern Broadleaf, Lake States, and Northeast (Bailey 1995). Tree stand types were: Upland Hardwoods, Lowland Hardwoods, Natural Softwood, Mixed Natural Pine and Hardwood, and Pine Plantation (Personal e-mail communication W.H. McNab 4/6/2011). Harvesting systems were: feller-buncher/grapple skidder, chainsaw/cable skidder, harvester/forwarder, chipper systems, swing feller-buncher/cable, and shovel/grapple. Note, not all eco-regions, tree stand types, and harvesting system combinations are used in the AHA adapted model.

[6] http://cnre.vt.edu/harvestingsystems/Costing.htm#costingmodels

Softwood and hardwood logging residue marginal cost curves were estimated for "*chipping tops and limbs at the 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"*). Marginal cost curves 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"*). Marginal cost curves for roundwood were estimated for *"lowland hardwood," "mixed natural softwood and hardwood," "natural softwood," "pine plantation,"* and *"upland hardwood"* for both pulpwood and sawtimber. Agricultural residue marginal cost curves were estimated for *"barley straw," "corn stover," "oat straw," "sorghum straw,"* and *"wheat straw."*

Given that there were cost estimates for 84 possible combinations of feedstocks types available from the BioSAT model, cost data for only a select set of feedstocks are reported in this executive summary. More detail is given in the results section of the report and cost data for all feedstock types are available at www.biosat.net.

Least cost bio-basins for the southern region of the study area for softwood mill residues were identified for southern Georgia, southern Mississippi, southern Arkansas, and central Louisiana. Average total costs (ATC) ranged from $43.19 to $48.89/dry ton with marginal costs (MC) ranging from $41.06 to $44.88/dry ton. Least cost bio-basins for the southern region for hardwood mill residues were identified in central Mississippi, southwestern Alabama, western Alabama, northwestern Louisiana, and eastern Mississippi. ATC ranged from $40.29 to $46.41/dry ton. MC ranged from $44.42 to $46.86/dry ton. Least cost bio-basins for this region for softwood and hardwood *"at-landing"* logging residues were located in southern Arkansas, northeastern North Carolina, northern Louisiana, and eastern Mississippi. ATC ranged from $37.59 to $40.58/dry ton. MC ranged from $32.93 to $35.84/dry ton. Least cost bio-basins for "*natural softwood pulpwood"* occurred in North Carolina, South Carolina, and Virginia. ATC ranged from $43.77 to $50.77/dry ton. MC ranged from $46.16 to $60.47/dry ton. Higher cost bio-basins with the largest concentrations of natural softwood pulpwood were located in Alabama, Florida, and southeast Oklahoma.

Least cost bio-basins in the northern region for hardwood mill residues were located in West Virginia. ATC ranged from $30.74 to $32.58/dry ton. MC ranged from $49.29 to $53.67/dry ton. Least cost bio-basins in the northern region for softwood mill residues were located in southern Maine and southeastern New Hampshire. ATC ranged from $78.86 to $81.21/dry ton. MC ranged from $81.96 to $82.84/dry ton. Least cost bio-basins in the northern region for "*at-landing*" logging residues (softwood or hardwood) were located in southern West Virginia. ATC ranged from $29.85 to $31.34/dry ton. MC ranged from $33.61 to $37.50/dry ton. Least cost bio-basins in the northern region for "*upland hardwood pulpwood"* occurred in Delaware, Indiana, Ohio, and Pennsylvania. ATC ranged from $23.93 to $53.95/dry ton. MC ranged from $34.33 to $56.01/dry ton. Higher costs bio-basins with the largest concentrations of upland hardwood pulpwood were located in Maryland, Missouri, and Wisconsin. However, even though Missouri had large concentrations of upland hardwood pulpwood it had the highest ATC consistently exceeding $53.95/dry ton with MC consistently exceeding $56.01/dry ton.

Least cost bio-basins for corn stover were located in northwest Texas, southern Minnesota, western Indiana, northern Illinois, and northeastern Iowa. ATC for corn stover ranged $14.03 to $15.14/dry ton in the northern states and in Texas ranged from $23.05 to $26.13/dry ton. MC ranged from $18.33 to $20.10/dry ton in the northern states and in Texas ranged from $24.01 to $27.68/dry ton. Least cost bio-basins for wheat straw were located in northwestern Mississippi, eastern Arkansas, southwestern Kentucky, southern Missouri, northwestern Indiana, southern Ohio, and lower Michigan. ATC for wheat straw ranged from $27.27 to $30.80/dry ton in the southern states and from $30.91 to $42.61/dry ton in the northern states. MC for wheat straw ranged from $29.74 to $31.87/dry ton in the southern states, and ranged from $35.57 to $46.71/dry ton in the northern states. Least cost bio-basins for sorghum straw were located in southeast Texas. ATC for sorghum straw ranged from $30.25 to $31.04/dry ton. MC for sorghum straw ranged from $34.27 to $36.27/dry ton.

1. 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 cellulosic feedstocks. Elbehri (2007) also noted that lack of cellulosic feedstock production capacity, high relative costs of production, logistics, and transportation of cellulosic feedstocks are all potential constraints that need to be better understood. The goal of this U.S. Forest Service, Southern Research Station sponsored research project was to assess the economic availability of cellulosic feedstocks for the Eastern United States and improve the understanding of the supply chain for cellulosic feedstocks. The rationale for the research was to provide decision-makers in the cellulosic feedstock-using industries with a better tool that would allow them to assess the economic comparative advantages of cellulosic supply at the regional, inter-state, and intra-state levels. This study and its supporting statistics were not developed primarily to support policy development at a national level. However, the study supports the research goals and priorities of the U.S. Department of Agriculture, U.S. Forest Service, *i.e., the Forest Service R&D Strategic Plan for 2006-2010 noted the decreasing economic availability of conventional energy supplies will necessitate the need for improved energy efficiency and conservation* (U.S. Department of Agriculture Forest Service 2008a and 2008b). However, energy efficiency and conservation are only part of the solution to meet the demand for more energy. Bioenergy is an important long-term solution to providing a sustainable domestic energy supply that is secure. The U.S. Forest Service R&D Strategic Plan for 2006-2010 notes the key role that availability of loans and grants will play in the development of the bioenergy industry. Loan guarantees will depend on the stability of the supply infrastructure that supports bioenergy plants. Study results may be useful in providing important research data to support loan guarantees which are critical for infrastructure development.

Cellulosic feedstocks are renewable resources procured from multiple sources which include land clearings, landscaping, industrial by-products, agricultural residues, and abundant forest resources (Caputo 2009). Developing any new industry, however, involves establishing many relationships (Altman and 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 research 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, U.S. Dept. of Energy 2011, and others). A recent report by the U.S. Dept. of Agriculture and Dept. of Energy concluded that 1.3 billion tons of biomass are available annually for energy production (U.S. Dept. of Energy 2011). Perlack *et al*. (2005) and U.S. Dept. of Energy (2011) 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.

The problem addressed by this study was to *"develop a web-based, economic decision tool with periodic data updates to assist business planners in the development of facilities that require cellulosic feedstocks, e.g., biorefineries, biopower, traditional biomass, etc."* Given this problem definition, there were three research objectives: 1) develop spatially explicit economic data for potential users of woody and agricultural cellulosic feedstocks; 2) develop a supply chain cost model for resources, harvesting, and transportation of feedstocks to the mill-gate (*feedstocks include mill residues, logging residues, merchantable roundwood, and agricultural residues*); and 3) develop a public domain website of the outcomes of the first and second objectives. Spatially explicit GIS data was overlayed to provide geo-referenced marginal cost curves (producer supply curves) of cellulosic feedstocks (Figure 1). While prior studies have examined the availability of wood for biomass or the transportation costs associated with cellulosic biomass (Langholtz *et al.* 2006, Perlack *et al.* 2005, Jensen *et al.* 2002, Noon and Day 1997), this study was unique in that cost data for supplying cellulosic feedstocks to biorefineries are updated periodically and available in the public domain, www.biosat.net for 33 Eastern states at the 5-digit zip code tabulation area (ZCTA) resolution, see U.S. Census Bureau (2000b).[7]

[7] ZIP Code Tabulation Areas (ZCTAs™) are a relatively new statistical entity developed by the U.S. Census Bureau (2000b) 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).

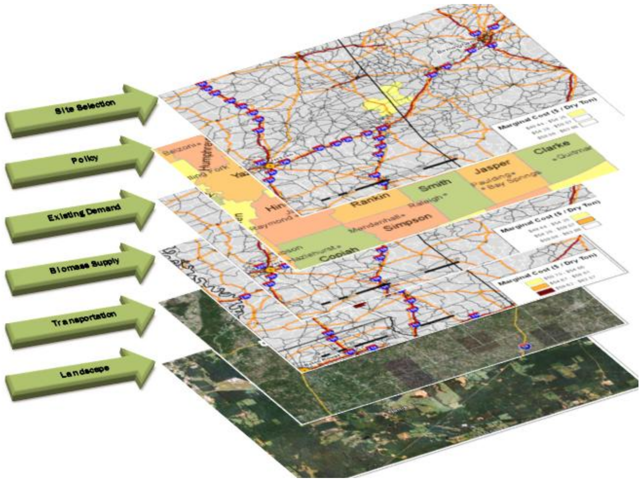

Figure 1. Illustration of GIS data overlays to support geo-referenced supply curves.

All research objectives in the study were satisfied and a key outcome of the research was the development of the BioSAT model (Biomass Site Assessment Tool) which is accessible on the public domain, www.biosat.net (Figure 2). The BioSAT model can be used as a tool to help ensure low cost production of cellulosic feedstocks for biorefineries which is essential for the nation's long-term use of alternative bio-based feedstocks for energy and other bio-based

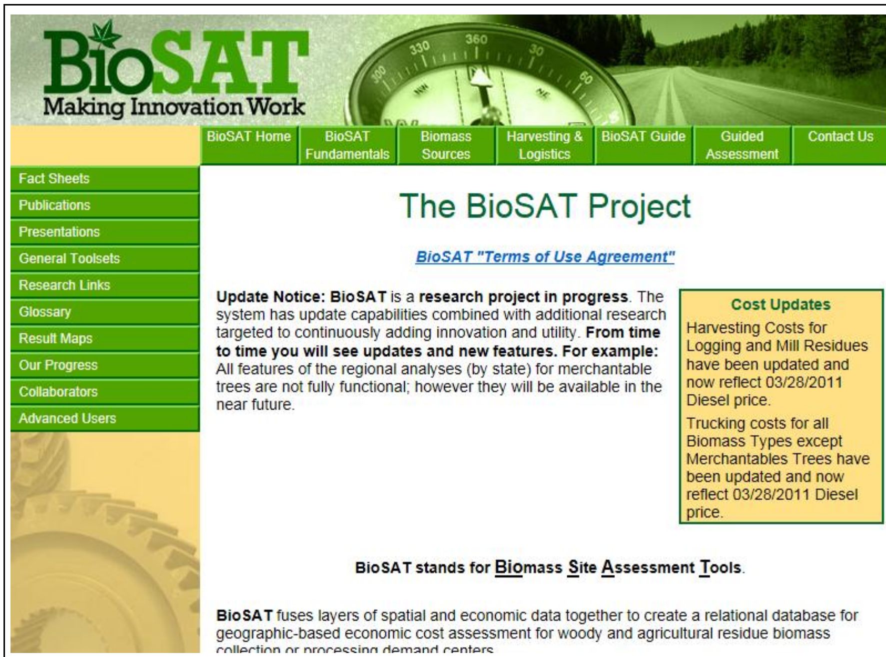

Figure 2. Homepage of BioSAT website, www.biosat.net

products. This final report summarizes the findings and methods of the study and presents examples of geo-referenced supply curves for cellulosic feedstocks across the 33-state study region (see example Figures 3 to 7).[8] Also see related thesis studies by Liu (2009) and Huang (2010) which provide potential biorefinery site locations in the southeastern U.S. using statistical logistic and Bayesian logistical regression models.

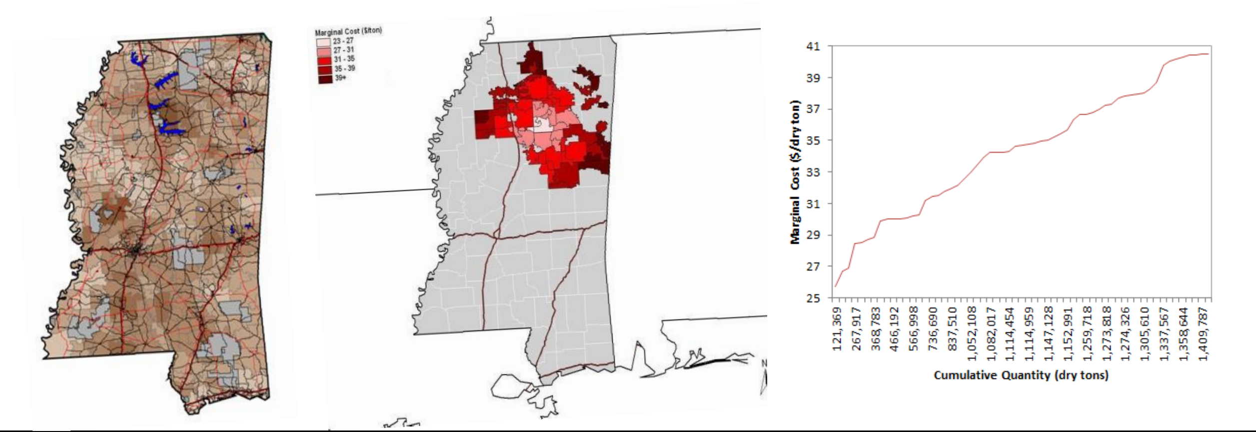

Figure 3. Bio-basin in Mississippi with geo-referenced supply curve for mill residues.

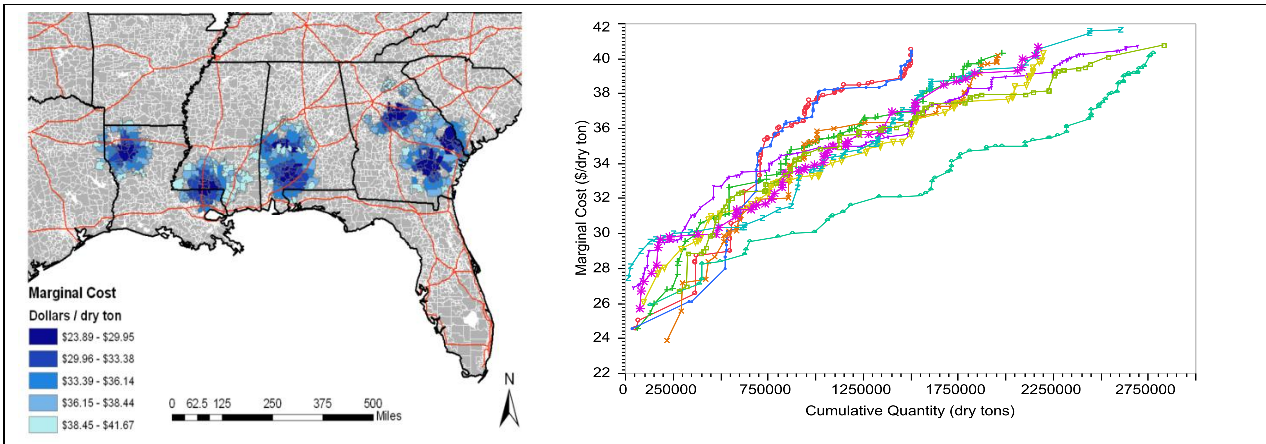

Figure 4. Low cost bio-basins and corresponding marginal cost curves for mill residues in the southeastern U.S.

[8]Alabama, Arkansas, Connecticut, Delaware, Florida, Georgia, Illinois, Indiana, Iowa, Kentucky, Louisiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, New Hampshire, New Jersey, New York, North Carolina, Ohio, Oklahoma, Pennsylvania, Rhode Island, South Carolina, Tennessee, Texas, Vermont, Virginia, West Virginia, Wisconsin.

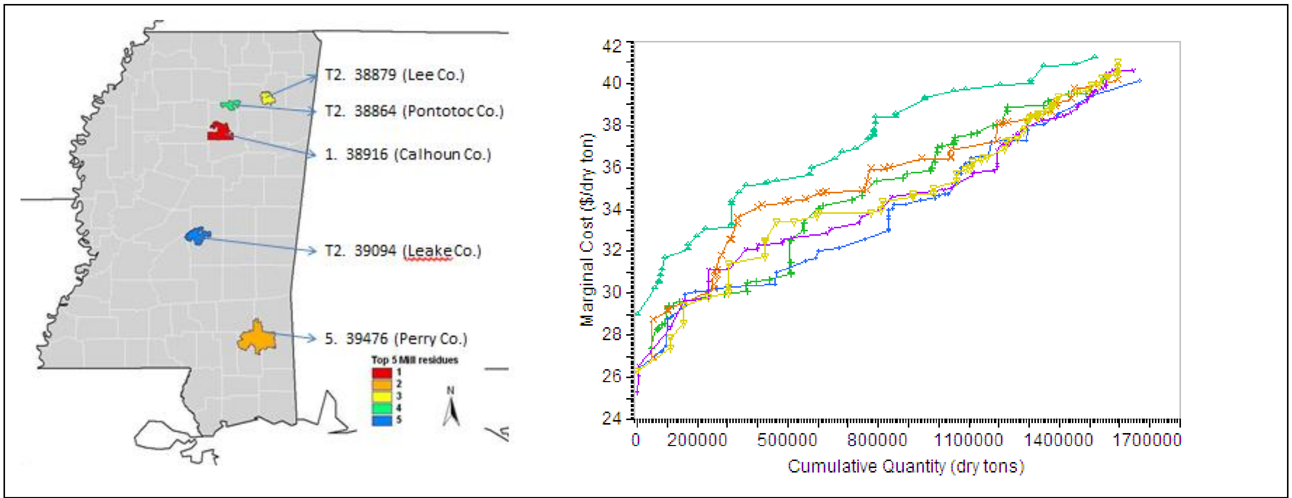

Figure 5. Low cost bio-basins in Mississippi with corresponding marginal cost curves for mill residues.

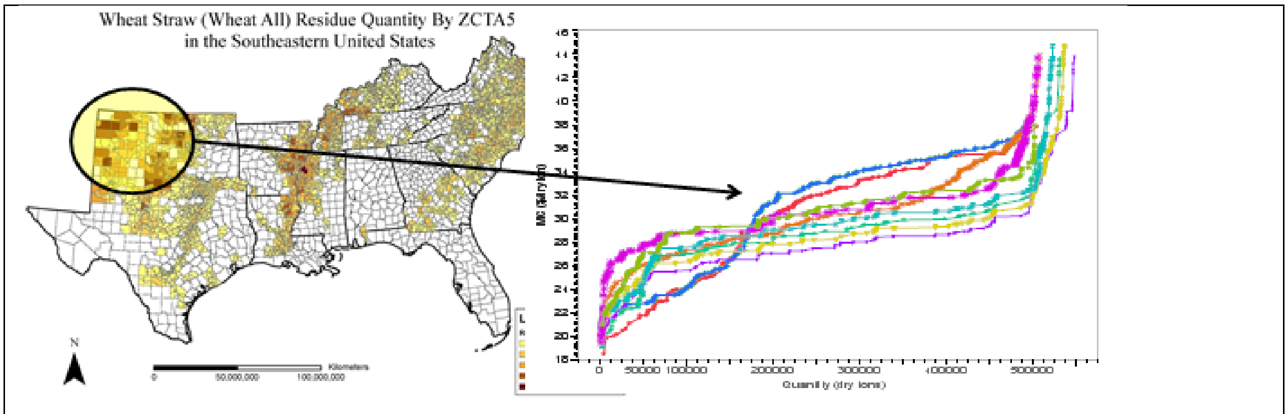

Figure 6. Low cost bio-basins with corresponding marginal cost curves for wheat straw.

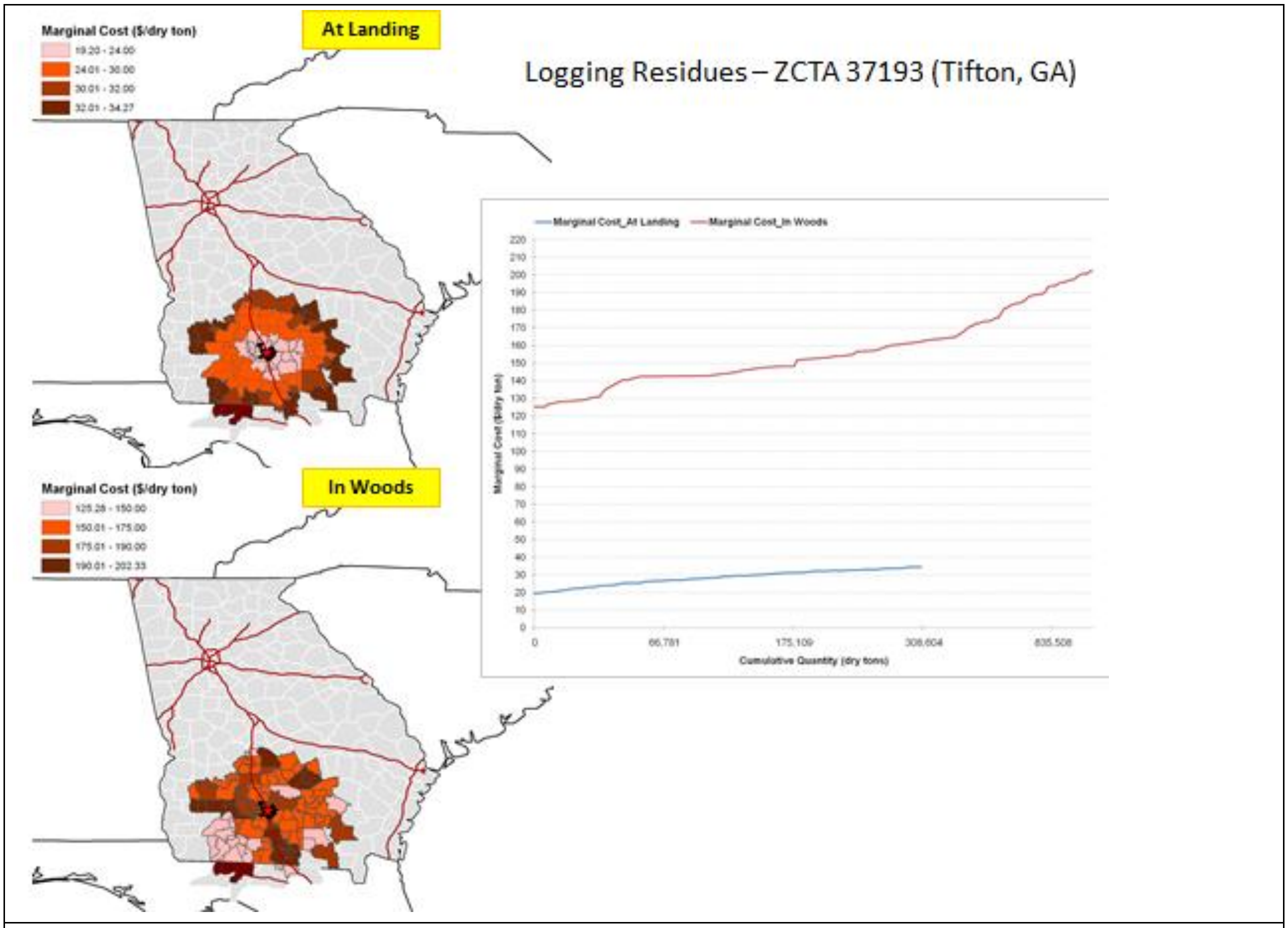

Figure 7. Logging residues (at-landing and in-woods) for biorefinery at Tifton, GA.

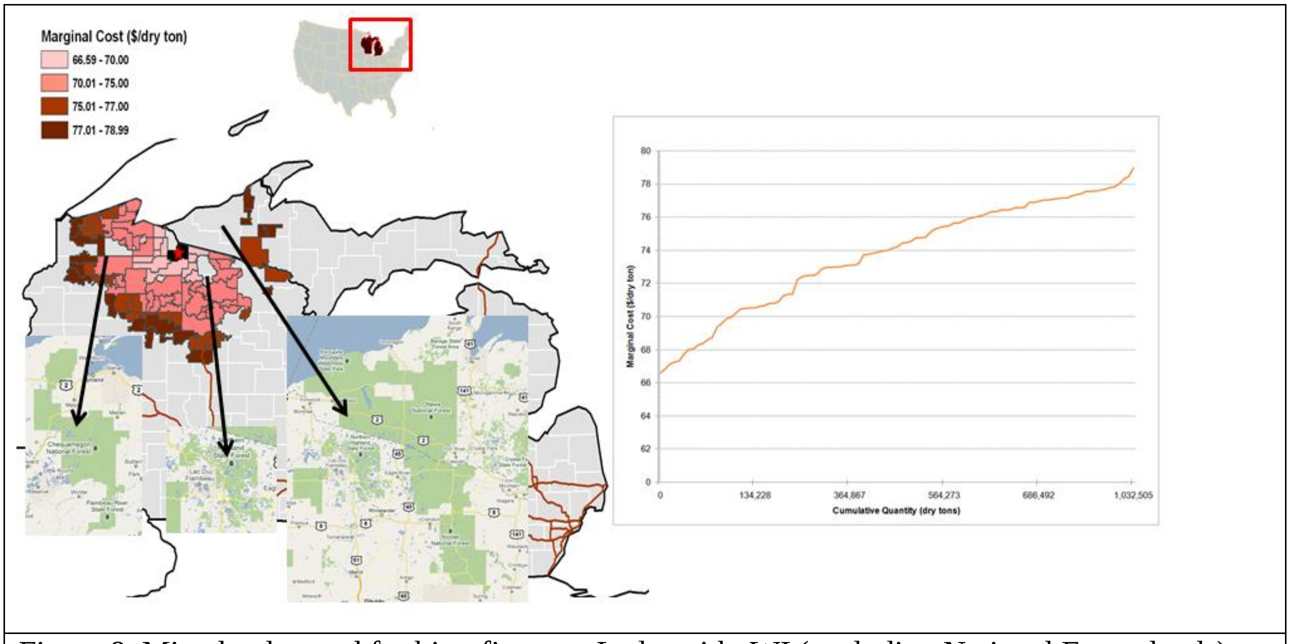

Figure 8. Mixed pulpwood for biorefinery at Ladysmith, WI (excluding National Forest lands).

2. Methods

The supply chain supporting the BioSAT model has three main cost components: resource, harvesting, and transportation. Detailed flow charts of the supply chain cellulosic feedstock model used in the BioSAT model are given on the website www.biosat.net under the "Fact Sheets" tab.

2.1 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 2008a). The latest complete cycle of data for each state was used (Table 1).

Table 1. State and year of U.S. Forest Service 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 mill residue data were obtained from the USFS FIA Timber Product Output (TPO) data. All quantity data were converted to dry tons. The Subregional Timber Supply (SRTS) model was used to estimate and predict logging residues for the southeastern United States. 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 2008). Abt *et al.* (2000) noted that SRTS is a partial equilibrium market simulation model that can be used to analyze various forest resource and timber supply situations. 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).

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/). An ORACLE™ database was created for this file of FIA county level data. ZCTA level estimates were derived from the information in this database (http://www.oracle.com/database/index.html).

As ZCTAs do not account for all zip codes, files containing all possible zip codes as of January 31, 2010 were used from zip-codes.com (http://www.zip-codes.com/). 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 23,032 potential demand*

ZCTAs and 25,044 total ZCTAs the 33-state study region. Note, there were more supply ZCTAs than demand ZCTAs given that demand ZCTAs on the western edge of the 33-state study included supply ZCTAs in North Dakota, South Dakota, Nebraska, and Kansas.

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 and thus improved the accuracy of transportation cost estimates.

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

2.2 Agricultural Resource Data

County level annual crop yield and production data were obtained from the Agricultural Statistics Service 2009 annual crop survey (USDA National Agricultural Statistics Service 2009). Agricultural residue estimates were made for: barley straw, corn stover, oat straw, sorghum straw, and two categories of wheat straw (*winter wheat and wheat all*).[9]

USDA NASS reports crops sold for food in bushels and crops sold for animal feed in tons. The crops quoted in bushels were converted into dry tons using the bushel weight unique for that crop. Bushel weights were obtained from Murphy (1993). The crop residue quantities

[9] Agricultural residue is the plant material remaining after the crop is harvested, including leaves, stalks and roots. For this study, only the above ground portion of agricultural residue is considered harvestable.

were estimated using each crop's unique residue weight ratio. Residue ratios (Table 2) were obtained from Proctor (1994) and Nelson *et al.* (2004).

Table 2. Crop residue ratio from Proctor (1994) and Nelson *et al.* (2004).

Crop	Grain to Residue Ratio
Barley	1:1.2
Corn	1:1.0
Oat	1:1.3
Sorghum	1:1.4
Wheat (spring and durum)	1:1.3
Wheat (winter)	1:1.7
Wheat (all)	1:1.5*
*Average of spring/durum and winter residue ratios was used.	

The moisture content estimates for each crop (Table 3) were obtained from the United States - Canadian Tables of Composition (U.S. National Research Council 1982). Crop residues were assumed to be left to dry naturally in the field before harvesting and baling with a residue recovery rate of 60%.

Table 3. Crop moisture content from National Research Council (1982).

Crop	**Moisture Content (%)**
Barley	13
Corn	15
Oat	8
Sorghum	12
Wheat	12

Agricultural residue quantity county level data were allocated to ZCTAs by overlaying the 5-digit ZIP Code Tabulation Areas data map (Census Bureau 2000a), the County and County Equivalent Areas data map (Census Bureau 2000b), and National Land Cover Database map (Multi-Resolution Land Characteristics Consortium 2001). County-level agricultural data were allocated to each 5-digit ZCTA using the county boundary, 5-digit ZCTA, and the land cover crop (*for arable lands*) GIS spatial overlays using the technique of Pimentel *et al*. (1981). Each agricultural residue type was partitioned in the county into multiple area parts by the 5-digit ZCTA area shape unique for each 5-digit ZCTA identifier. By overlaying each area part with the land cover raster layer, the numbers of pixels in all land cover classes within each area were estimated. By aggregating the cultivate crop pixels in the unit of the county, the pixel ratio of each area part was calculated and the agricultural residue quantity in every area part was derived for this pixel ratio (Figures 9 to 11).

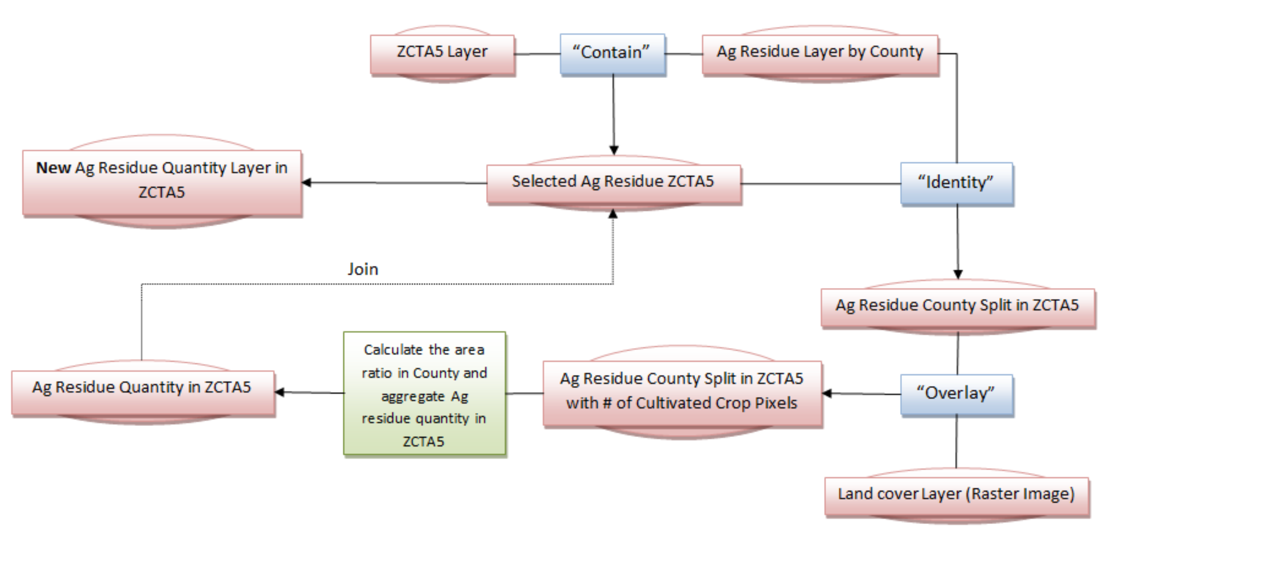

Figure 9. Flow Chart of agricultural residue quantity allocation to each 5-digit ZCTA.

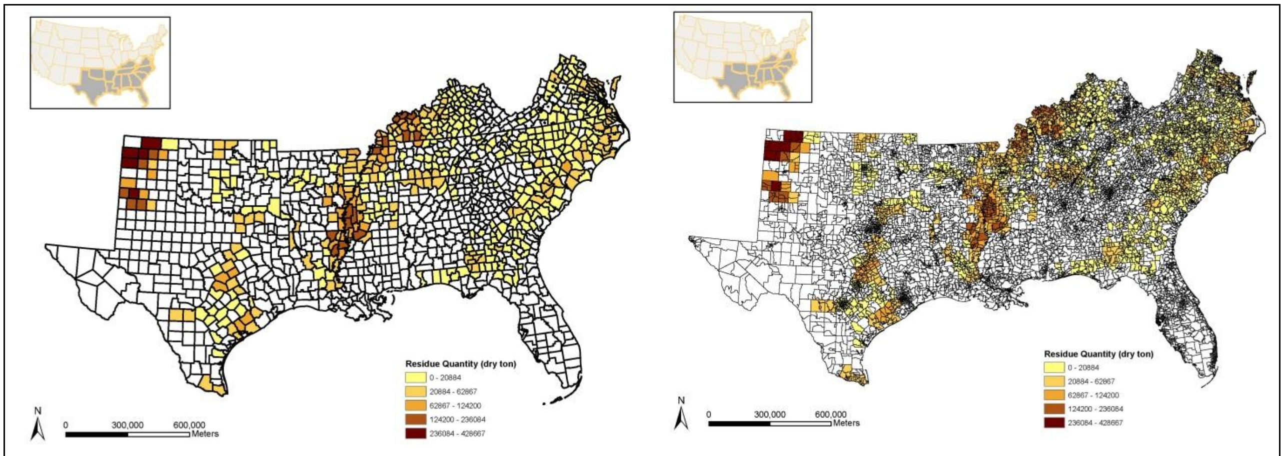

Figure 10. Agricultural residue quantity allocation by count (left image) and by 5-digit ZCTA (right image).

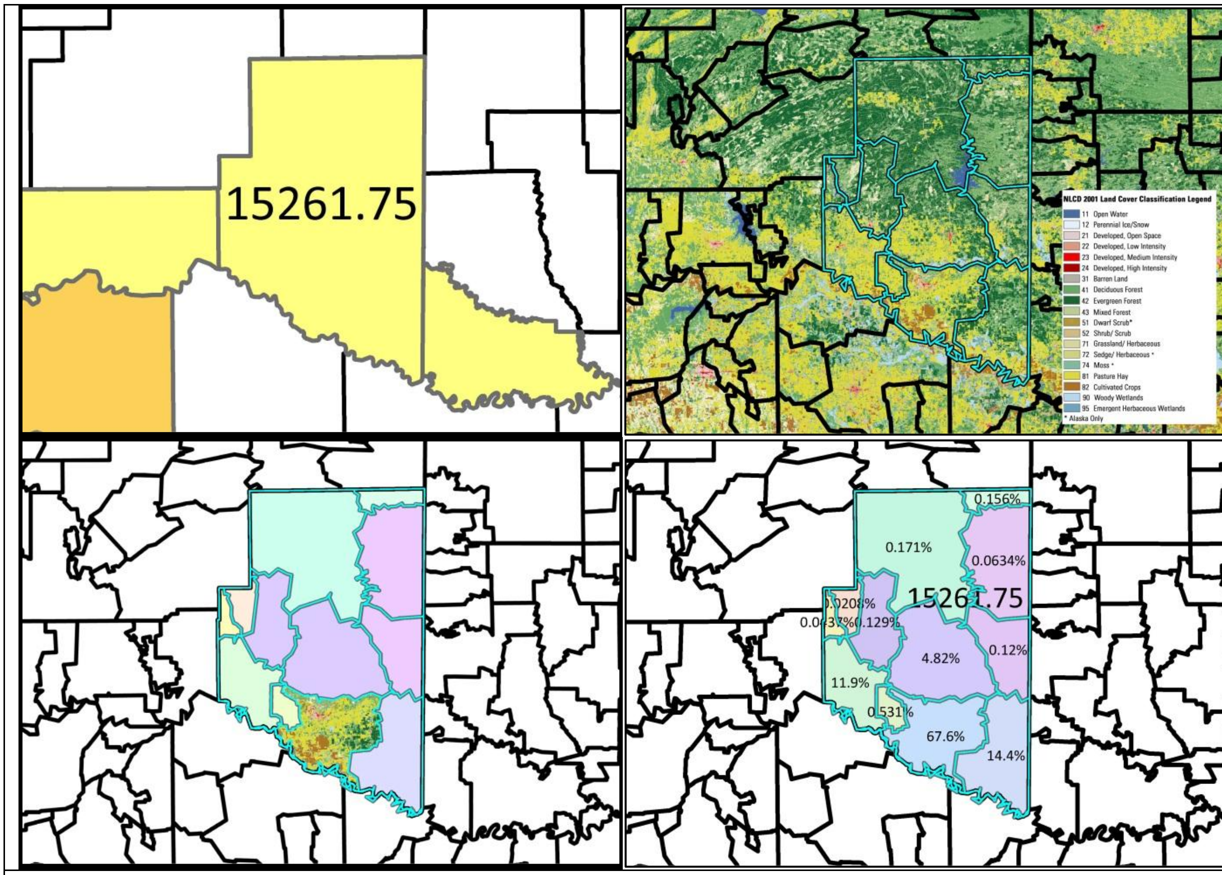

Figure 11. Illustration of county ag residue proportion (upper left), land cover map and 5-digit ZCTA boundary (upper right), land cover for 5-digit ZCTA boundary (lower left), and ag residue allocation by 5-digit ZCTA (lower right).

2.3 Feedstocks Available in BioSAT

Eighty-four feedstock types and combinations of feedstock types are available in the BioSAT model (Tables 4 and 5). Definitions and more detail of each feedstock are given on the BioSAT website under the "Biomass Sources" tab at www.biosat.net.

Table 4. Listing of residue feedstocks in the BioSAT model.

Mill Residues:			
	Total Mill Residues	Softwood Mill Residues	Hardwood Mill Residues
	Total "Clean" Mill Residues	"Clean" Softwood Mill Residues	"Clean" Hardwood Mill Residues
	Total "Unclean" Mill Residues	"Unclean" Softwood Mill Residues	"Unclean" Hardwood Mill Residues
Logging Residues:			
	Total Logging Residues	Softwood Logging Residues	Hardwood Logging Residues
	Total "At-Landing"	"At-Landing"	"At-Landing" Hardwood

	Logging Residues	Softwood Logging Residues	Logging Residues
	Total "In-Woods" Logging Residues	"In-Woods" Softwood Logging Residues	"In-Woods" Hardwood Logging Residues
Agricultural Residues:	Barley Straw		
	Corn Stover		
	Oat Straw		
	Sorghum Straw		
	Wheat Straw	All Wheat Straw	Winter Wheat Straw

Table 5. Listing of merchantable tree or roundwood feedstocks in the BioSAT model.

Total Pulpwood:					
	Lowland Hardwood	Gross Growth	Net Growth	Removals	Total Inventory
	Mixed Natural Softwood and Hardwood	Gross Growth	Net Growth	Removals	Total Inventory
	Natural Softwood	Gross Growth	Net Growth	Removals	Total Inventory
	Pine Plantation	Gross Growth	Net Growth	Removals	Total Inventory
	Upland Hardwood	Gross Growth	Net Growth	Removals	Total Inventory
Total Sawtimber:					
	Lowland Hardwood	Gross Growth	Net Growth	Removals	Total Inventory
	Mixed Natural Softwood and Hardwood	Gross Growth	Net Growth	Removals	Total Inventory
	Natural Softwood	Gross Growth	Net Growth	Removals	Total Inventory
	Pine Plantation	Gross Growth	Net Growth	Removals	Total Inventory
	Upland Hardwood	Gross Growth	Net Growth	Removals	Total Inventory
Total Pulpwood and Sawtimber:					
	Lowland Hardwood	Gross Growth	Net Growth	Removals	Total Inventory
	Mixed Natural Softwood and Hardwood	Gross Growth	Net Growth	Removals	Total Inventory
	Natural Softwood	Gross Growth	Net Growth	Removals	Total Inventory
	Pine Plantation	Gross Growth	Net Growth	Removals	Total Inventory
	Upland Hardwood	Gross Growth	Net Growth	Removals	Total Inventory

2.4 Resource Costs

Resource cost data (*e.g., stumpage, mill residue prices, etc*.) for woody cellulosic were obtained from Timber Mart South (http://www.tmart-south.com/tmart/), Timber Mart North (Michigan, Minnesota, and Wisconsin),[10] and other state-reporting sources (*e.g., Indiana, Kentucky, West Virginia, etc*.).[11] If a state did not having any resource cost or stumpage reporting system (*e.g., Oklahoma*), prices from the closest Timber Mart South regions of neighboring states (*e.g., Arkansas and Texas*) were averaged and this average was used for the entire state. The average of all Texas regions with prices from Timber Mart South was used for regions in Texas where prices were not reported. There are currently no estimates for logging residue stumpage or resources costs reported in the public domain. Logging residue stumpage was given a value of $1/dry ton. Mill residue price data (*e.g., hardwood sawdust, pine sawdust, pine shavings, etc*.) for a state were allocated equally to all ZCTAs.

Agricultural residue resource costs were included in the harvesting equation and included soil nutrient replacement costs (Gallagher *et al.* 2003). Soil nutrient replacement costs were obtained from Gallagher *et al.* (2003) and converted from 1997 dollars to 2009 dollars using the Inflation Calculator (U.S. Bureau of Labor Statistics 2009).

2.5 Transportation Costs

<u>2.5.1 Transportation Network</u>

Microsoft© MapPoint® 2006 (http://www.microsoft.com/MapPoint/en-us/default.aspx) was used in the BioSAT model to provide the shortest travel time routes between the demand and supply 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 address level geocoding, http://www.teleatlas.com/index.htm. 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

[10] http://www.prentissandcarlisle.com/content/4044/Timber_Mart_North/
[11] 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 2009).

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 U.S. 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).

2.5.2 Trucking Costs

The transportation cost model estimated fixed and variable trucking costs based on the shortest travel time from the MapPoint road network of a bio-basin and and maximum annual mileage for tractor-trailers.[12] Single-driver day cabs were assumed with a maximum one-day round-trip time of 11 hours. Contract fleet carriers contracted by the ownership of a biorefinery were assumed given feedback from a critique by major trucking companies, *i.e., contract fleet carriers would be the least expensive trucking solution*. Trailer types in the trucking cost model depended on feedstock type and were: dry-van storage (*mill residues, logging residues and some agricultural residues),* flat-bed *(baled agricultural residues*), short-log (*northern state roundwood*), and long-log (*southern states roundwood*).

Trucking costs in the BioSAT model were estimated using equations [1], [2], [3], and [4] for estimating costs between all of the potential supply $ZCTAs_{(j)}$ and a given demand $ZCTA_{(i)}$ for 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 the supply ZCTAs and demand ZCTA, and trucking fixed costs were a function of travel distance between the supply ZCTAs and demand ZCTA. Least cost solutions for a set of supply ZCTAs to meet a specified demand quantity were generally dependent on shortest travel time between a supply $ZCTA_{(j)}$ and demand $ZCTA_{(i)}$.

The trucking cost model was an adaptation of the truck transportation model by Berwack and Farooq (2003). The following cost equations were:

[12] Travel distance which influences fixed costs was allocated over the tractor-trailer's estimated annual miles which was 100,000 miles for the tractor and dry van and flatbed trailers; 80,000 miles for the long-log and short-log trailers.

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

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 $(i,)$ for all routes r, r = 1….z,
C_s = legal trailer capacity for s,
Q_i = annual capacity of demand ZCTA, i (i = 1….m),
d = round-trip travel distance (i,j),
i = demand ZCTA, i = 1…..m,
j = supply ZCTA, j = 1…..n,
m = total number of biomass supply ZCTAs,
n = total number of biomass supply ZCTAs,
r = route (i, j), r = 1….z,
s = U.S. state, q = 1….33,
t = round-trip travel time (i,j).

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

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).

$$V_{t,s(i,j)} = L_{t,s(i,j)} \quad [3]$$

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

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

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 Berwick and Farooq (2003) model were modified for the BioSAT model after a review of the model was conducted in October 2008 with seven trucking companies[13] and one large forest products company that requested anonymity.

Total trucking costs were a function of: variables costs which were a function of haul time; fixed costs which were a function of maximum annual tractor-trailer miles; and the quantity hauled between the demand ZCTA and each supply ZCTA of the bio-basin. The variable cost inputs for the trucking model (*e.g., diesel fuel, labor wages, etc*.) are updated in the BioSAT model as necessitated by changes in prices (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). Validation of the trucking cost model data for BioSAT was within two percent of actual $/ton-mile and $/ton trucking costs for a multi-state validation case study and trucking company review.

2.5.3 Intermodal Railroad Locations

Railroad locations and intermodal truck/rail locations are identified by ZCTA on BioSAT (Figure 12). Even though most transportation of cellulosic feedstocks in the eastern U.S. are assumed to be by truck, the railroad data may be useful for select users of BioSAT.

ZIPCODE	CITY	STATE	AREA_CODE	CSX	NS	BNSF	UP
35004	MOODY	AL	205	1	0	0	0
35005	ADAMSVILLE	AL	205	1	0	0	0
35007	ALABASTER	AL	205	1	0	0	0
35011	ALEXANDER CITY	AL	256	1	1	0	0
35013	ALLGOOD	AL	205	1	0	0	0
35014	ALPINE	AL	256	1	0	0	0
35015	ALTON	AL	205	1	0	0	0
35019	BAILEYTON	AL	256	1	0	0	0
35020	BESSEMER	AL	205	1	1	0	0
35021	BESSEMER	AL	205	1	1	0	0
35022	BESSEMER	AL	205	1	1	0	0
35023	BESSEMER	AL	205	1	1	0	0
35032	BON AIR	AL	256	1	0	0	0
35034	BRENT	AL	205	1	0	0	0
35035	BRIERFIELD	AL	205	1	1	0	0
35036	BROOKSIDE	AL	205	1	1	0	0
35038	BURNWELL	AL	205	1	1	0	0
35040	CALERA	AL	205	1	1	0	0
35041	CARDIFF	AL	205	1	1	0	0
35042	CENTREVILLE	AL	205	1	1	0	0
35043	CHELSEA	AL	205	1	1	0	0
35044	CHILDERSBURG	AL	256	1	1	0	0
35045	CLANTON	AL	205	1	1	0	0
35046	CLANTON	AL	205	1	1	0	0
35051	COLUMBIANA	AL	205	1	1	0	0
35052	COOK SPRINGS	AL	205	1	1	0	0

Figure 12. Railroad locations and intermodal truck/rail locations on the BioSAT website.

[13] Pemberton Truck Lines, Inc. (Knoxville, TN); Skyline Transportation, Inc. (Knoxville, TN); and Mason Dixon, Inc. (Scottsboro, AL); Patterson Chip Company (Lily, KY); GFI Transport, Inc. (Mount Joy, PA); TN Dept. of Agriculture; Flatbed Source USA; Carlen Transport Company (Hampton, ME); Gene A. Matt Trucking (Omak, IA); GCS Logging (Cambridge, NY); and May Logging (Ava, MO).

2.6 Harvesting Costs

2.6.1 Logging Residue Harvesting Costs

The Fuel Reduction Cost Simulator (FRCS) as modified for the Billion Ton Study (Perlack *et al.* 2005, U.S. Dept. of Energy 2011) 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, South, and coastal West as well as the Interior West. Logging residue costs were 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 periodically in the BioSAT model. Forest resource input data were obtained from the logging residue estimates of the SRTS model and assumed a 30% recovery rate (Abt *et al.* 2000).

2.6.2 Merchantable Tree or Roundwood Harvesting Costs

Merchantable wood harvesting costs were estimated from the Auburn Harvest Analyzer (Tufts *et al.* 1985) which was enhanced by Mr. Shawn Baker and Dr. Dale Greene (Center for Forest Business, Warnell School of Forestry and Natural Resources, University of Georgia

2009). The primary drivers for the models were quadratic mean diameter, tons per acre removed, trees per acre removed, tract size, and average height of dominant trees (*in hardwood stands only, if available*) obtained from the FIA merchantable trees estimates. The harvesting cost models generated roundwood production costs on a per ton basis for five harvesting systems for five forest stand types for the six ecoregions of the study region. The costs were calculated for sawtimber and pulpwood merchantable roundwood. The AHA models assumed each harvesting system was only utilized for specific forest types. Additionally, each forest-type and harvesting-system pair was assumed to be feasible only in certain ecoregions (Table 6, Figure 13). Detailed descriptions of USDA Forest Service ecoregions and forest types used in BioSAT are given in Appendix A.

Table 6. Ecoregion, forest type, and harvesting system feasibility.

	Wheel FB/Grapple Skidder		Chainsaw/Cable Skidder		Harvester/Forwarder		Chipper		Swing FB/Grapple Skidder	
Pine Plantation	Thinning	Clearcut	Thinning	Clearcut	Thinning	Clearcut	Thinning	Clearcut	Thinning	Clearcut
Appalachian Mtn	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Delta	13.0	12.0	-----	-----	-----	-----	14.5	13.0	-----	-----
Eastern Broadleaf	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Gulf Coastal Plain	13.0	12.0	-----	-----	-----	-----	13.5	13.0	-----	-----
Lake States	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Northeast	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Natural Pine	Thinning	Clearcut	Thinning	Clearcut	Thinning	Clearcut	Thinning	Clearcut	Thinning	Clearcut
Appalachian Mtn	-----	-----	24.0	19.5	-----	-----	-----	-----	25.5	15.0
Delta	13.0	12.0	-----	-----	-----	-----	13.5	13.0	-----	-----
Eastern Broadleaf	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Gulf Coastal Plain	13.0	12.0	-----	-----	-----	-----	14.0	13.0	-----	-----
Lake States	-----	-----	24.5	21.5	17.0	13.0	16.5	13.5	-----	-----
Northeast	13.0	12.0	24.5	21.5	16.5	13.0	14.0	13.0	-----	-----
Mixed Pine Hdwd	Thinning	Clearcut	Thinning	Clearcut	Thinning	Clearcut	Thinning	Clearcut	Thinning	Clearcut
Appalachian Mtn	-----	-----	21.0	19.5	-----	-----	-----	-----	22.0	15.0
Delta	12.0	12.0	-----	-----	-----	-----	13.0	13.0	-----	-----
Eastern Broadleaf	12.5	12.0	20.0	20.0	14.5	13.0	13.5	13.0	20.0	15.0
Gulf Coastal Plain	12.5	12.0	-----	-----	-----	-----	13.5	13.0	-----	-----
Lake States	-----	-----	21.0	19.5	15.5	12.5	13.5	13.0	-----	-----
Northeast	12.5	12.0	22.0	19.5	16.0	12.5	13.5	12.5	-----	-----
Lowland Hdwd	Thinning	Clearcut	Thinning	Clearcut	Thinning	Clearcut	Thinning	Clearcut	Thinning	Clearcut
Appalachian Mtn	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Delta	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Eastern Broadleaf	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Gulf Coastal Plain	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Lake States	-----	-----	-----	19.5	-----	12.5	-----	-----	-----	-----
Northeast	-----	-----	-----	20.0	-----	12.5	-----	-----	-----	-----
Upland Hdwd	Thinning	Clearcut	Thinning	Clearcut	Thinning	Clearcut	Thinning	Clearcut	Thinning	Clearcut
Appalachian Mtn	-----	-----	19.5	19.5	-----	-----	-----	-----	20.0	14.0
Delta	12.5	12.0	-----	-----	-----	-----	13.5	13.0	-----	-----
Eastern Broadleaf	12.5	12.0	19.5	19.5	14.5	12.5	13.5	13.0	20.0	14.0
Gulf Coastal Plain	12.0	12.0	-----	-----	-----	-----	13.5	12.5	-----	-----
Lake States	-----	-----	20.0	19.5	14.5	12.5	13.0	13.0	-----	-----
Northeast	12.0	12.0	19.5	19.5	14.5	12.5	13.0	12.5	-----	-----

The forest stand types assumed were upland hardwood, lowland hardwood, natural softwood, mixed natural and hardwood, and pine plantation. The harvesting systems assumed were feller-buncher/grapple skidder, chainsaw/cable skidder, harvester/forwarder, chipper system, and swing feller-buncher/cable.[14] The calculated cost data for each forest-type and

[14]Feller-Buncher - A heavy vehicle with a boom attachment that gathers and fells trees then places the cut trees on a stack suitable for transport and/or further processing; Swing Feller-Buncher – A feller-buncher with a tree-grabbing attachment designed for maximum reach and maneuverability so the vehicle base can be moved less often; Chainsaw – A motorized saw with a cutting element consisting of a continuous chain that is pulled around a bar at high speed; Cable Skidder – A heavy vehicle with a main winch cable and choker attachment that is manually secured to a load of felled trees then drags the cut trees out of the forest. The process is more labor intensive than with a grapple skidder, but the cable allows it reach trees that the vehicle base cannot drive to; Grapple Skidder - A heavy vehicle with a boom or bottom-opening jaws attachment that assembles a load of felled trees then carries or drags the cut trees out of the forest. The process is less labor intensive than with a cable skidder, but the vehicle base must be able to drive closer to the trees; Harvester – A heavy vehicle with a boom attachment that fells, delimbs, cuts and bucks trees then places the cut trees on a stack suitable for transport and/or further processing. When combined with a forwarder it is referred to as a cut-to-length system; Forwarder – A heavy vehicle with a boom

harvesting-system pair were allocated equally to all ZCTAs contained within the ecoregions where the harvesting system is feasible.

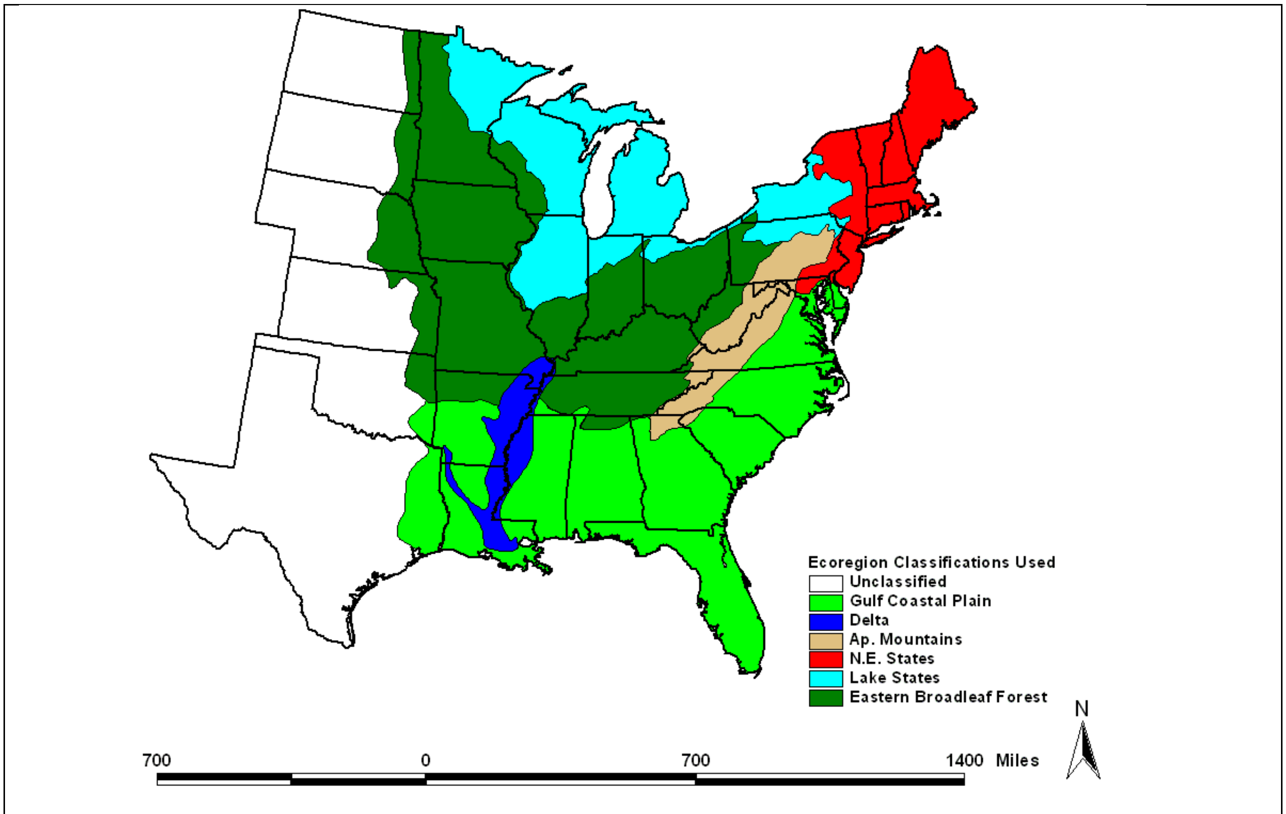

Figure 13. Ecoregions used in AHA merchantable tree harvesting.

attachment that pulls a flat bed or log trailer. The boom assembles a load of felled, cut trees then places them on the trailer and transports them out of the forest. The forwarder combined with a harvester is called a cut-to-length system; Chipper – A machine that chops cut trees into high quality wood chips then blows the chips into a pile suitable for transport and/or further processing or directly into a transport trailer or vehicle.

2.6.3 Agricultural Residue Harvesting Costs

The harvesting cost model [5] for agricultural residues was an adaptation of the harvest cost equation from the Biomass from Crop Residues Cost and Supply Estimates report (Gallagher *et al.* 2003). The harvesting operations assumed were chopping, baling, and on-farm transport of the residue, where the labor requirements for the chopper and the baler were the same, and the bales were of the large round variety. The operating equipment and soil nutrient replacement costs were obtained from Gallagher *et al.* (2003) and converted from 1997 dollars to 2010 dollars using the Inflation Calculator (U.S. Department of Labor Bureau of Labor Statistics, 2010). The calculated cost data for a county were allocated equally to all ZCTAs. The harvest equation is:

Ag. Residue Harvest cost ($/dry ton) = ($15.93 per acre /crop residue recoverable dry tons per acre) + (fertilizer replacement cost per dry ton) + (on-farm transport cost per dry ton) [5]

3. Results

The results and discussion section are organized for the southern and northern regions of the study area. Given that 84 possible cellulosic feedstocks are available in BioSAT, for the sake of brevity, only ten cellulosic feedstock types are illustrated for the southern region and nine feedstock types are illustrated for the northern region. A complete of listing feedstock types was given in Tables 4 and 5 of the Methods section.

For the southern region summary statistics and bio-basin illustrations are presented for the following feedstocks: total mill residues, hardwood mill residues, softwood mill residues, total logging residues, "*at-landing*" logging residues, "*in-woods*" logging residues, corn stover agricultural residues, sorghum straw agricultural residues, wheat straw agricultural residues, and natural softwood pulpwood. For the northern region summary statistics and bio-basin illustrations are presented for the following feedstocks: total mill residues, hardwood mill residues, softwood mill residues, total logging residues, "*at-landing*" logging residues, "*in-woods*" logging residues, corn stover agricultural residues, wheat straw agricultural residues, and upland hardwood pulpwood.

3.1 Southern Region

3.1.1 Mill Residues

The mill residue categories included in the BioSAT model were total mill residues, hardwood mill residues, softwood mill residues, clean hardwood mill residues, unclean hardwood mill residues, clean softwood mill residues, and unclean softwood mill residues. The maximum quantity available in a bio-basin and the associated total cost (TC), average total cost (ATC), and median marginal cost (MC) in $/dry ton were estimated for this report assuming an annual consumption of one million dry tons and a maximum 160-mile one-way truck haul distance (with dry van trailer storage). Total hardwood and softwood mill residues are illustrated in this section.

3.1.1.1 Total Mill Residues. -- The top ten ZCTA locations in the southern region for softwood and hardwood mill residues combined were located in central Mississippi, eastern Georgia, eastern Mississippi, western Alabama, and northeastern Georgia (Figure 14). ATC for all available total mill residues ranged from $43.35 to $45.72/dry ton. The median of the MC ranged from $45.65/dry ton to $47.24 (Table 7, Figure 15).

Table 7. Top ten locations in the southern region for total mill residues based on average total cost (median marginal costs also presented).

Rank	Zip Code/ ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	39092	Scott	MS	Lake	6,003,503	$265,306,358	$44.19	$46.31
2	39192	Holmes	MS	West	4,800,023	$208,267,898	$43.39	$45.65
3	30206	Pike	GA	Concord	4,431,630	$192,106,633	$43.35	$47.24
4	39074	Scott	MS	Forest	6,179,269	$269,099,517	$43.55	$46.04
5	39080	Scott	MS	Harperville	6,240,425	$271,635,689	$43.53	$46.73
6	30285	Lamar	GA	The Rock	4,616,576	$200,749,768	$43.48	$46.65
7	39338	Jasper	MS	Louin	6,609,373	$293,250,307	$44.37	$45.76
8	35464	Sumter	AL	Gainesville	7,294,648	$333,530,427	$45.72	$46.27
9	30256	Pike	GA	Meansville	4,669,203	$205,131,079	$43.93	$46.53
10	30671	Oglethorpe	GA	Maxeys	4,366,887	$194,708,896	$44.59	$46.92

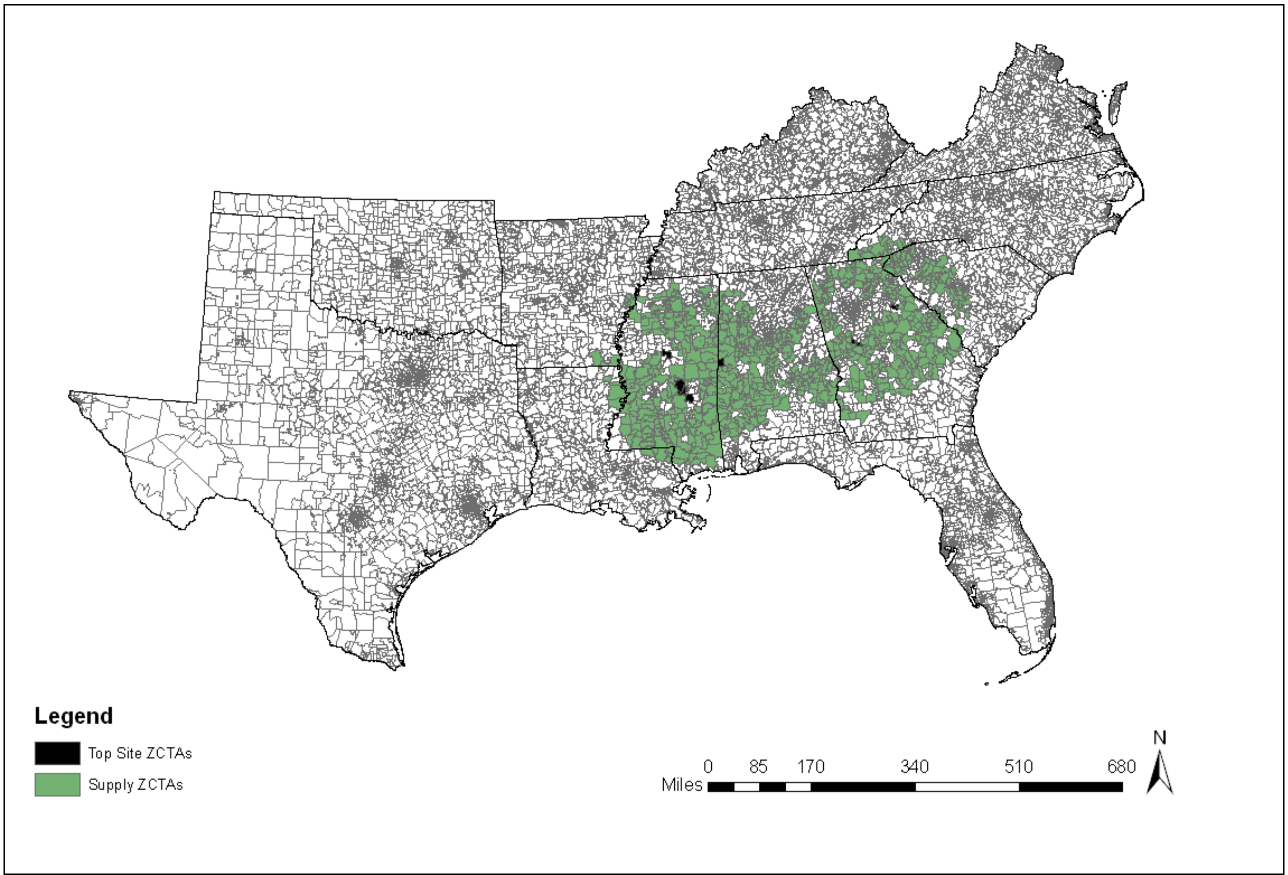

Figure 14. Least cost bio-basins for total mill residues for the southern region.

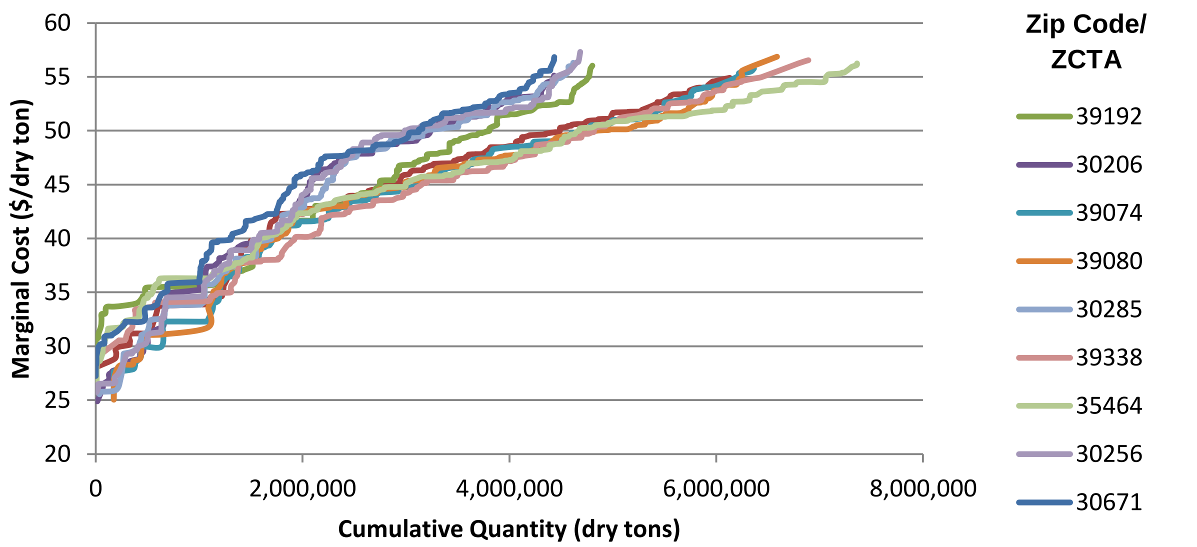

Figure 15. Marginal cost curves for the top ten locations in the southern region for total mill residues.

3.1.1.2 Hardwood Mill Residues. -- The top ten ZCTA locations in the southern region for hardwood mill residues were located in central Mississippi, southwestern Alabama, western Alabama, north western Louisiana, and eastern Mississippi (Figure 16). ATC for all available hardwood mill residues ranged from $40.29 to $46.41/dry ton. The median MC ranged from $44.42 to $46.86/dry ton (Table 8, Figure 17).

Table 8. Top ten locations in southern region for hardwood mill residues based on average total cost (median marginal costs also presented).

Rank	Zip Code/ ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	39767	Montgomery	MS	Stewart	2,696,361	$115,399,408	$42.80	$46.64
2	39752	Webster	MS	Mathiston	3,061,387	$131,423,303	$42.93	$45.98
3	36470	Monroe	AL	Perdue Hill	3,792,951	$152,817,008	$40.29	$44.72
4	36462	Monroe	AL	Monroeville	3,793,228	$153,158,160	$40.38	$44.69
5	36461	Monroe	AL	Monroeville	3,792,951	$152,817,008	$40.29	$44.72
6	36460	Monroe	AL	Monroeville	3,686,646	$150,166,097	$40.73	$45.22
7	35442	Pickens	AL	Aliceville	4,557,099	$209,186,013	$45.90	$45.76
8	71066	Natchitoches	LA	Powhatan	4,893,054	$209,408,381	$42.80	$44.42
9	39355	Clarke	MS	Quitman	5,121,172	$237,689,197	$46.41	$46.86
10	39422	Jasper	MS	Bay Springs	4,780,777	$221,655,666	$46.36	$46.73

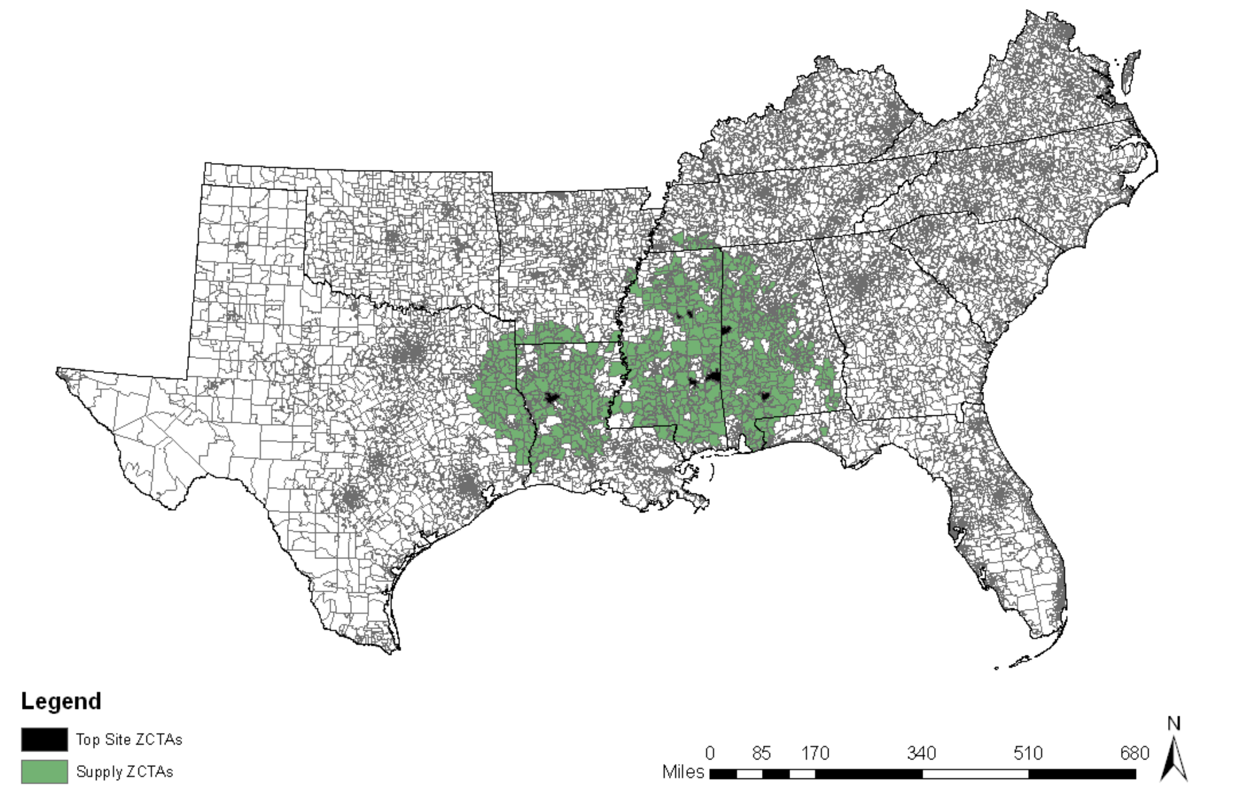

Figure 16. Least cost bio-basins for hardwood mill residues for the southern region.

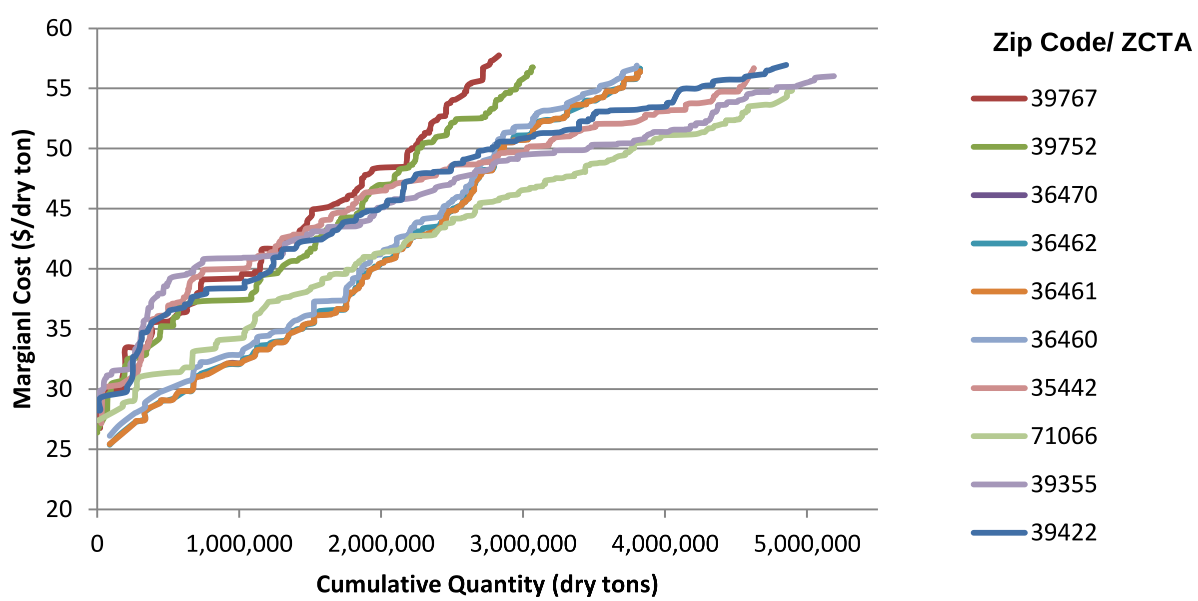

Figure 17. Marginal cost curves for the top ten locations for hardwood mill residues in the southern region.

3.1.1.3 Softwood Mill Residues. -- The top ten ZCTA locations in the southern region for softwood mill residues were located in southeastern Mississippi, central Mississippi, southern Arkansas, eastern Georgia, central Louisiana, and southern Mississippi (Figure 18). ATC for all available softwood mill residues ranged from $41.06 to $44.88/dry ton. The median MC ranged from $43.19 to $48.89/dry ton (Table 9, Figure 19).

Table 9. Top ten locations in the southern region for softwood mill residues based on average total cost (median marginal costs also presented).

Rank	Zip Code/ ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	39116	Smith	MS	Mize	2,124,976	$90,276,837	$42.48	$44.81
2	39443	Jones	MS	Laurel	2,607,883	$116,882,562	$44.82	$45.39
3	39288	Rankin	MS	Pearl	2,194,386	$94,702,782	$43.16	$44.44
4	71759	Union	AR	Norphlet	2,799,114	$124,148,814	$44.35	$48.89
5	31035	Washington	GA	Harrison	2,018,240	$86,412,213	$42.82	$45.84
6	39440	Jones	MS	Laurel	2,580,502	$113,923,143	$44.15	$44.80
7	71483	Winn	LA	Winnfield	2,710,986	$119,385,972	$44.04	$45.85
8	71764	Ouachita	AR	Stephens	2,843,378	$127,326,116	$44.78	$48.32
9	71858	Nevada	AR	Rosston	2,968,398	$133,217,590	$44.88	$47.33
10	39652	Pike	MS	Magnolia	1,701,445	$69,854,831	$41.06	$43.19

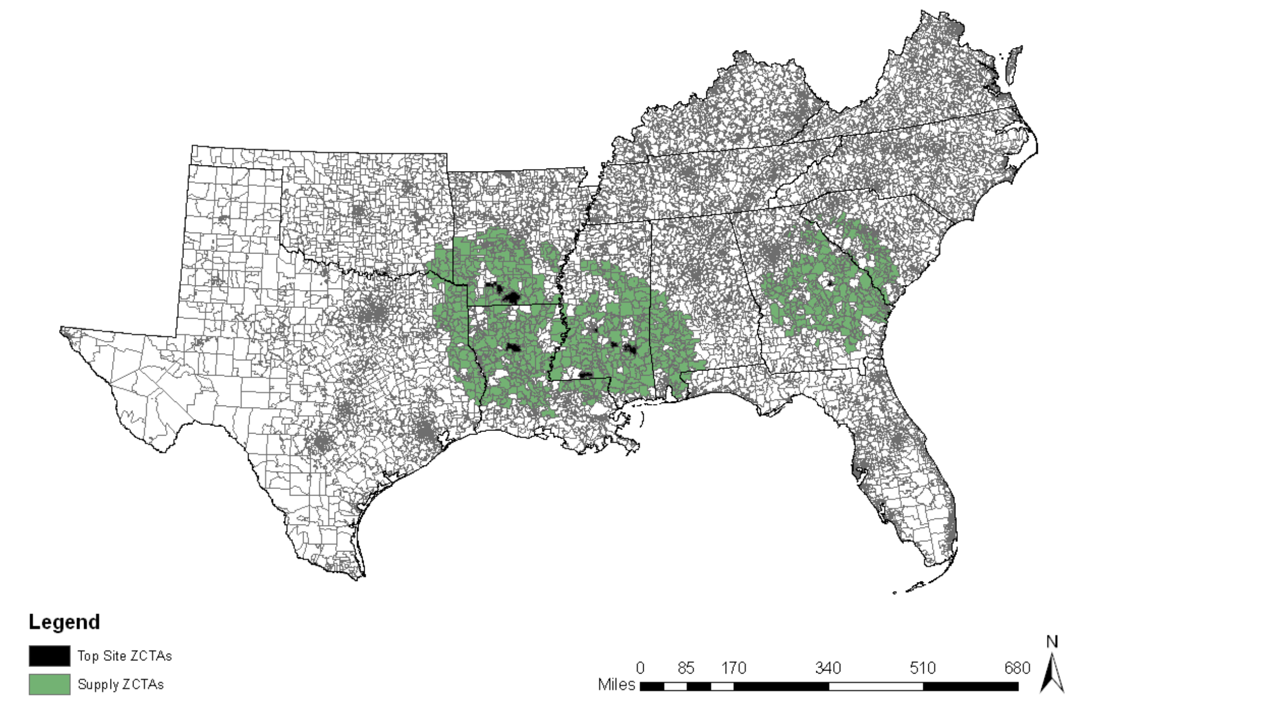

Figure 18. Least cost bio-basins for softwood mill residues for the southern region.

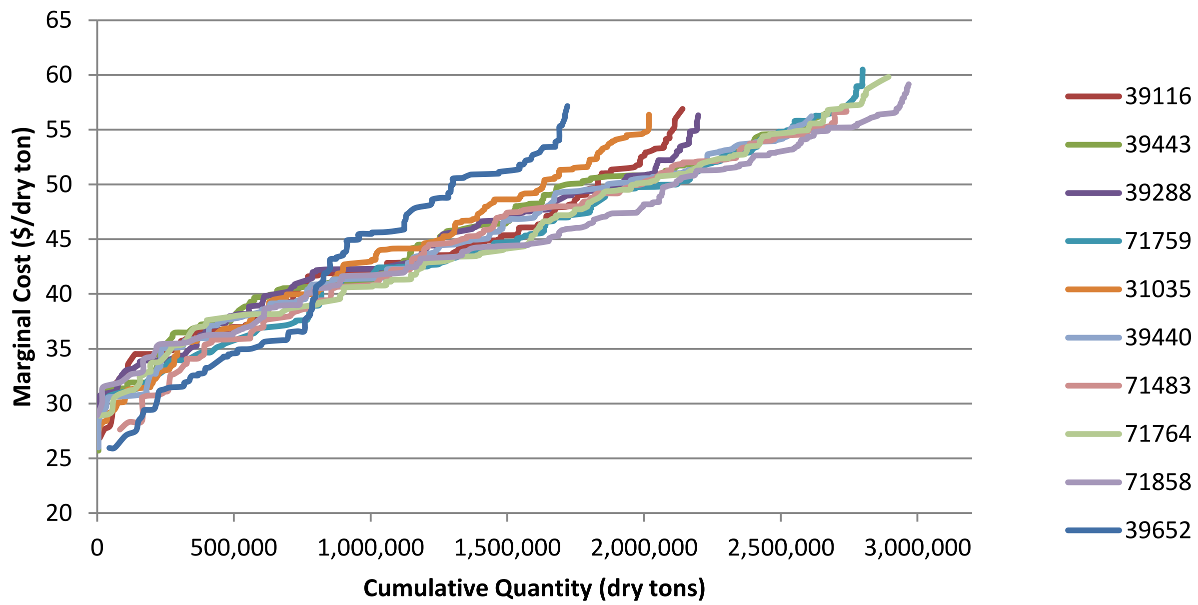

Figure 19. Marginal cost curves for the top ten locations for softwood mill residues in the southern region.

3.1.2 Logging Residues

The logging residues categories included in the BioSAT model were total logging residues, total *"at-landing"* logging residues, total *"in-woods"* logging residues, hardwood *"at-landing"* logging residues, hardwood *"in-woods"* logging residues, softwood *"at-landing"* logging residues, and softwood *"in-woods"* logging residues. For illustration purposes, the maximum quantity available in a bio-basin and the associated total cost (TC), average total cost (ATC), and median marginal cost (MC) in $/dry ton were estimated for total logging residues, total *"at-landing"* logging residues, and total *"in-woods"* logging residues assuming an annual consumption of one million dry tons and a maximum 160-mile one-way truck haul distance (with dry van trailer storage).

3.1.2.1 Total Logging Residues. -- The top ten ZCTA locations in the southern region for total logging residues (*i.e., all softwood/hardwood and "at-landing" and "in-woods"*) were located in northern and eastern Kentucky (Figure 20). ATC for all available total logging ranged from $75.34 to $87.08/dry ton. The median MC ranged from $36.14 to $77.47/dry ton (Table 10, Figure 21). The large disparity between ATC and MC is caused by the kinked MC curves which affected the estimate of the median MC (Figure 21).

Table 10. Top ten locations in southern region for total logging residues based on average total cost (median marginal costs also presented).

Rank	Zip Code/ ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	41143	Carter	KY	Grayson	1,190,140	$91,955,363	$77.26	$76.71
2	41653	Floyd	KY	Prestonsburg	1,183,449	$97,529,397	$82.41	$38.08
3	41601	Floyd	KY	Allen	1,187,103	$97,922,931	$82.49	$38.08
4	41502	Pike	KY	Pikeville	1,331,468	$115,941,751	$87.08	$36.14
5	41642	Floyd	KY	Ivel	1,245,267	$104,077,866	$83.58	$37.54
6	41267	Martin	KY	Warfield	1,204,062	$95,803,931	$79.57	$39.42
7	41129	Boyd	KY	Catlettsburg	1,175,465	$88,784,152	$75.53	$76.87
8	41101	Boyd	KY	Ashland	1,170,413	$88,177,741	$75.34	$75.66
9	41168	Boyd	KY	Rush	1,148,437	$87,013,296	$75.77	$77.47
10	41659	Floyd	KY	Stanville	1,249,827	$104,843,093	$83.89	$36.88

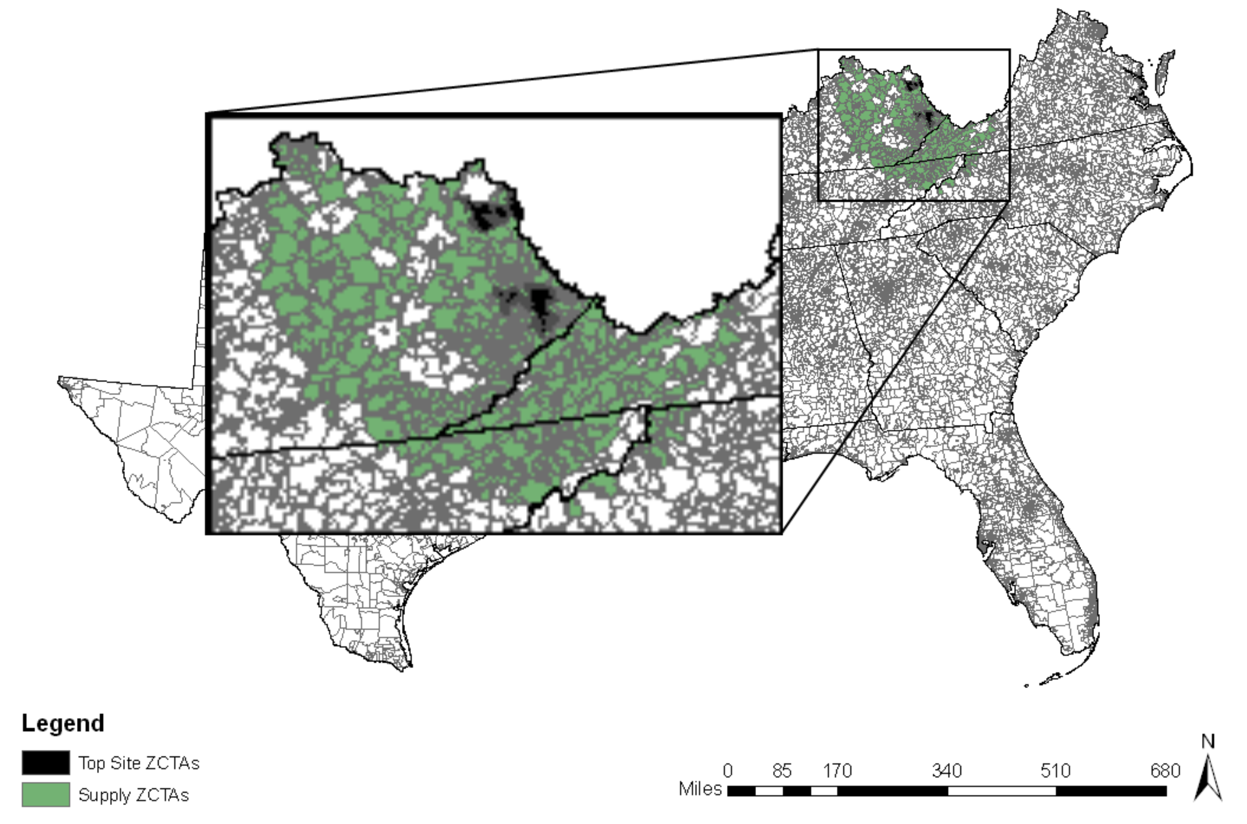

Figure 20. Least cost bio-basins for total logging residues for the southern region.

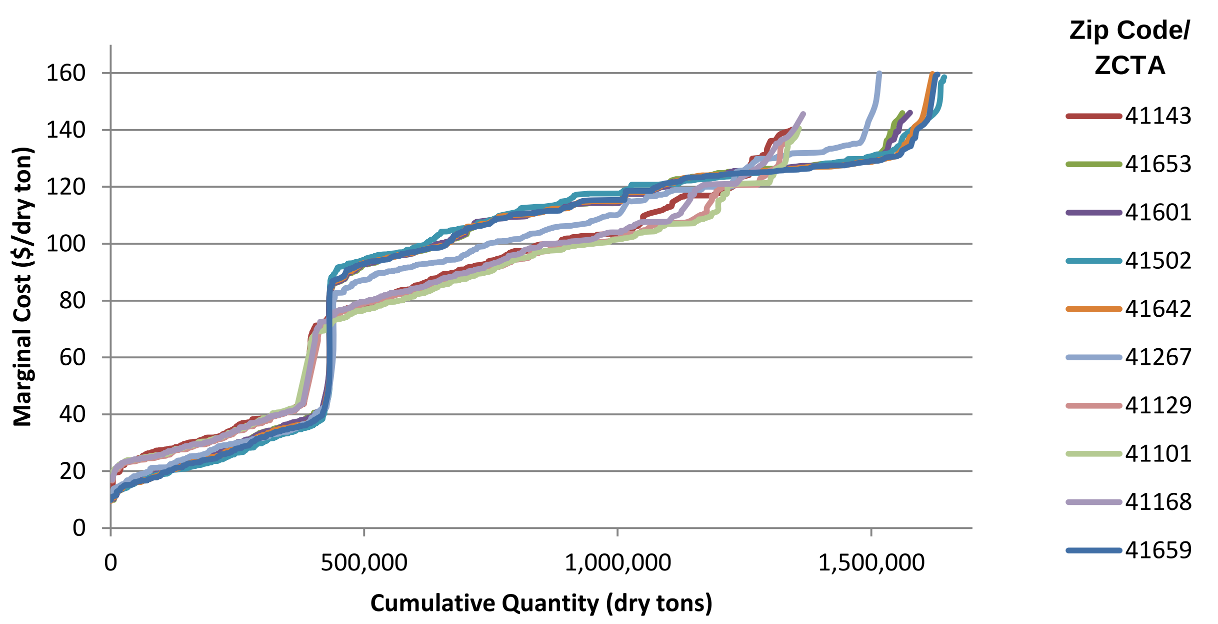

Figure 21. Marginal cost curves for the top ten locations for total logging residues in the southern region.

<u>3.1.2.2 "At-Landing" Logging Residues</u>. -- The top ten ZCTA locations in the southern region for *"at-landing"* logging residues (*i.e., softwood and hardwood combined*) were located in southern Arkansas, northeastern North Carolina, northern Louisiana, and eastern Mississippi (Figure 22). ATC for *"at-landing"* logging residues ranged from $37.59 to $40.58/dry ton. The median MC ranged from $37.47 to $35.84/dry ton (Table 11, Figure 23).

Table 11. Top ten locations in southern region for "at landing" logging residues based on average total cost (median marginal costs also presented).

Rank	Zip Code/ ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Median MC ($/dry ton)	Average Total Cost ($/dry ton)
1	71730	Union	AR	El Dorado	2,444,559	$84,962,615	$39.24	$34.76
2	71731	Union	AR	El Dorado	2,444,559	$84,830,379	$39.23	$34.70
3	27855	Hertford	NC	Murfreesboro	1,723,213	$57,485,735	$39.29	$33.36
4	27897	Northampton	NC	Woodland	1,729,111	$57,292,018	$39.30	$33.13
5	71270	Lincoln	LA	Ruston	2,565,285	$89,989,801	$36.76	$35.08
6	71021	Webster	LA	Cullen	2,502,861	$88,662,362	$37.47	$35.42
7	39304	Lauderdale	MS	Meridian	2,548,797	$90,388,731	$37.29	$35.46
8	27910	Hertford	NC	Ahoskie	1,657,082	$54,562,290	$39.77	$32.93
9	71040	Claiborne	LA	Homer	2,541,781	$88,377,041	$37.64	$34.77
10	71651	Bradley	AR	Jersey	2,277,877	$81,645,194	$40.58	$35.84

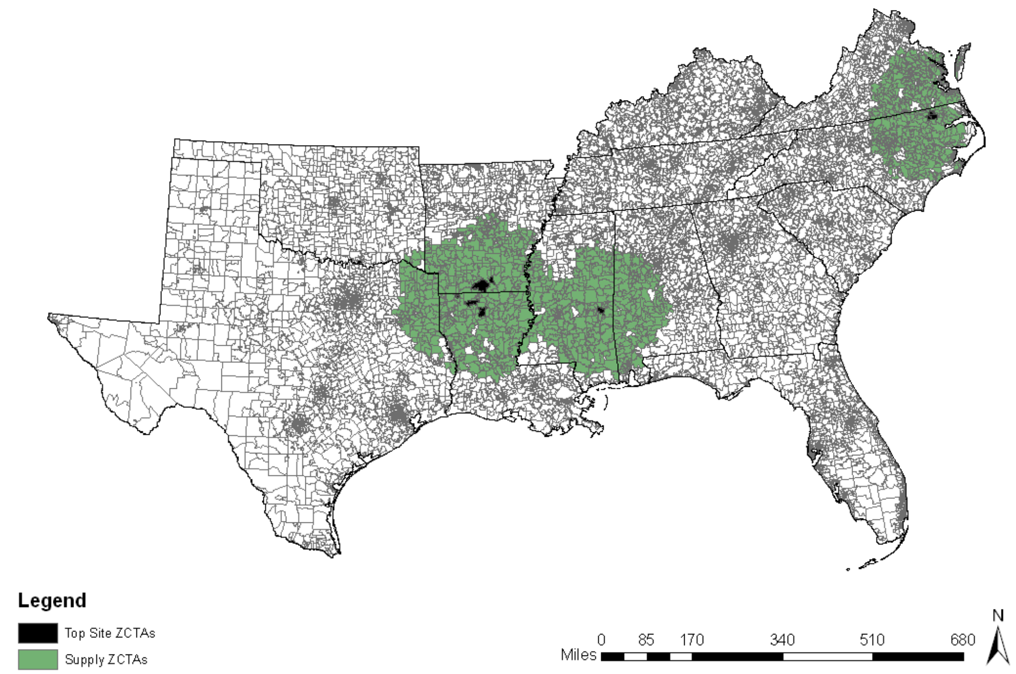

Figure 22. Least cost bio-basins for “at-landing” logging residues for the southern region.

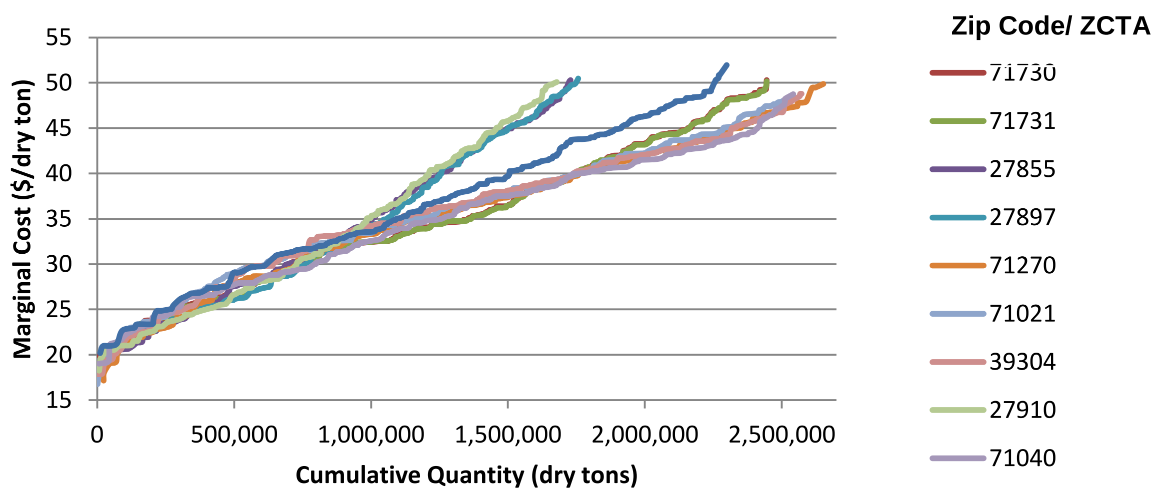

Figure 23. Marginal cost curves for the top ten locations in the southern region for “at-landing” logging residues.

<u>3.1.2.3 "In-Woods" Logging Residues</u>. -- The top ten ZCTA locations in the southern region for *"in-woods"* logging residues (*i.e., softwood and hardwood combined*) were located in southeastern Georgia and northeastern Florida (Figure 24). ATC for these least cost bio-basins ranged from $164.53to $181.94/dry ton. The median MC ranged from $164.30 to $176.81/dry ton (Table 12, Figure 25). The higher costs of harvesting small trees and forest floor residuals contributed to the higher costs of *"in-woods"* harvesting as estimated from the FRCS model.

Table 12. Top ten locations in southern region for "in-woods" logging residues based on average total cost (median marginal costs also presented).

Rank	Zip Code/ ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Median MC ($/dry ton)	Average Total Cost ($/dry ton)
1	31305	McIntosh	GA	Darien	1,481,687	$255,941,937	$171.77	$172.74
2	31309	Liberty	GA	Fleming	1,762,724	$311,668,896	$181.94	$176.81
3	31310	Liberty	GA	Hinesville	1,843,326	$324,982,385	$181.79	$176.30
4	31502	Ware	GA	Waycross	1,824,131	$310,728,895	$169.05	$170.34
5	32256	Duval	FL	Jacksonville	1,019,761	$168,873,258	$164.98	$165.60
6	32046	Nassau	FL	Hilliard	1,363,780	$228,673,243	$166.99	$167.68
7	31319	McIntosh	GA	Meridian	1,455,378	$254,256,550	$173.87	$174.70
8	31524	Glynn	GA	Brunswick	1,398,767	$239,649,868	$167.49	$171.33
9	32232	Duval	FL	Jacksonville	1,160,687	$190,699,195	$164.78	$164.30
10	32204	Duval	FL	Jacksonville	1,167,845	$192,343,563	$164.53	$164.70

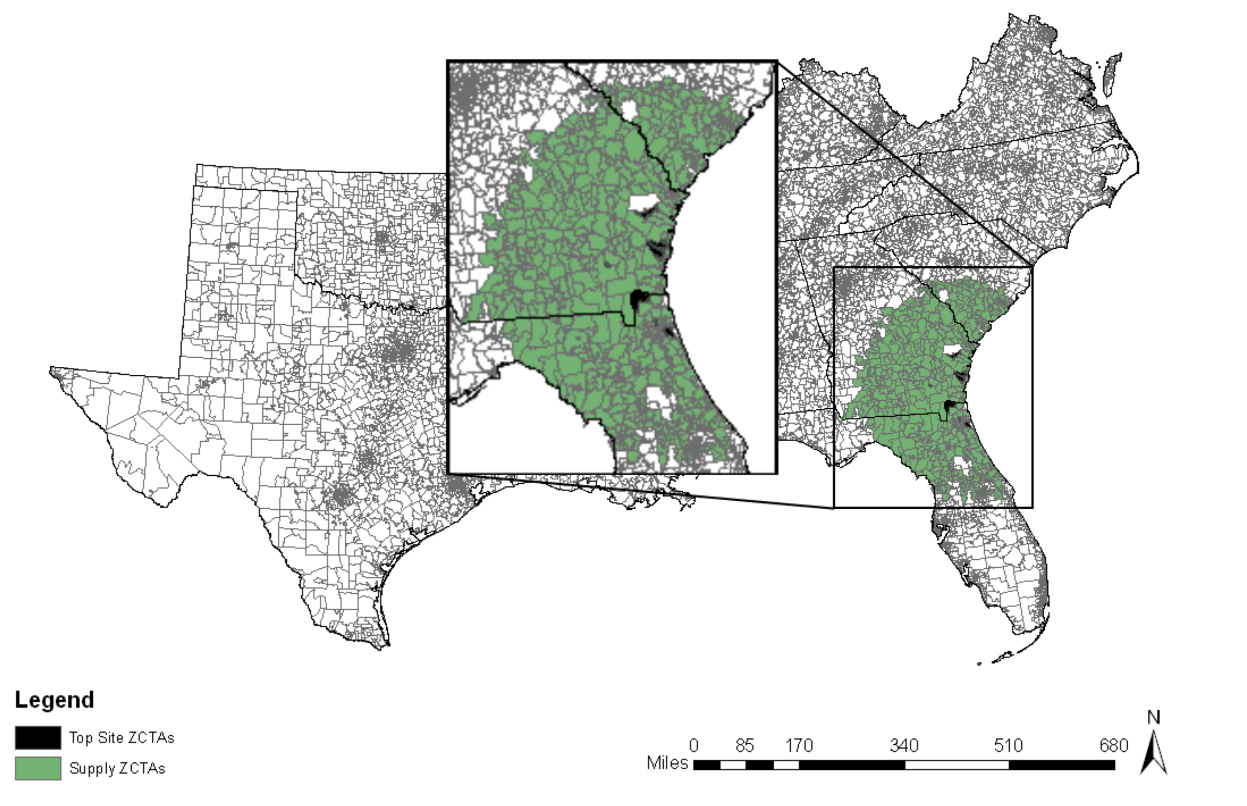

Figure 24. Least cost bio-basins for "in-woods" logging residues for the southern region.

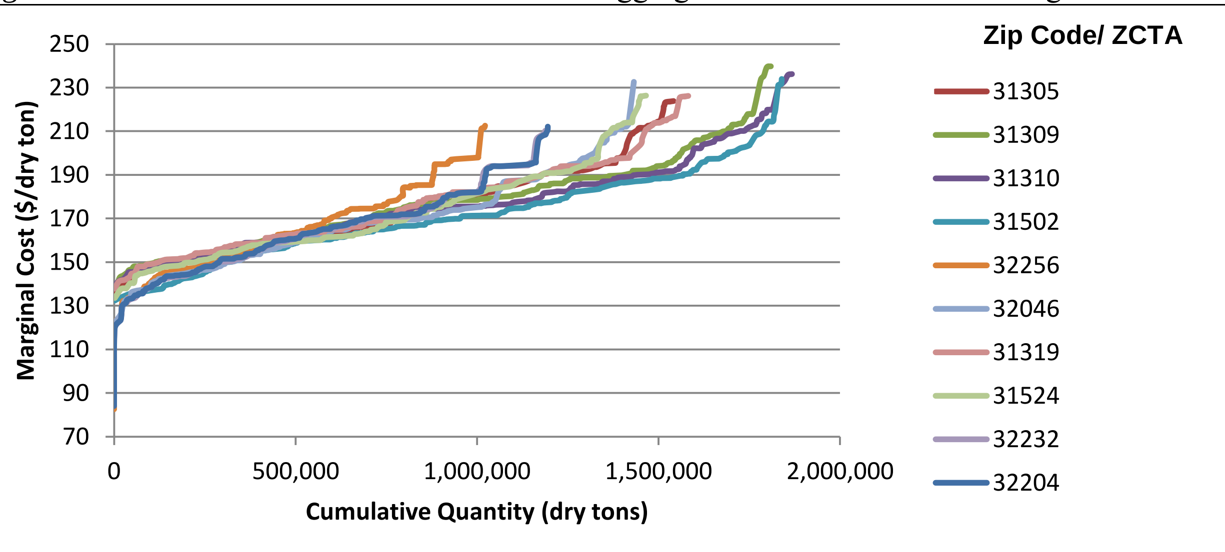

Figure 25. Marginal cost curves for the top ten locations for "in-woods" logging residues in the southern region.

3.1.3 Agricultural Residues

3.1.3.1 Corn Stover

The top ten ZCTA locations in the southern region for corn stover were all located in northwest Texas (Figure 26). ATC for corn stover ranged from $23.05 to $26.13/dry ton. The median MC ranged from $24.01 to $27.68/dry ton (Table 13, Figure 27).

Table 13. Top ten locations in southern region for corn stover based on average total cost (median marginal costs also presented).

Rank	Zip Code/ ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	79013	Moore	TX	Cactus	2,778,981	$64,050,591	$23.05	$24.01
2	79078	Hutchinson	TX	Sanford	3,043,287	$74,796,388	$24.58	$25.99
3	79036	Hutchinson	TX	Fritch	3,096,123	$77,088,705	$24.90	$26.17
4	79044	Hartley	TX	Hartley	2,727,770	$69,234,202	$25.38	$26.82
5	79018	Hartley	TX	Channing	2,820,602	$68,006,941	$24.11	$25.69
6	79007	Hutchinson	TX	Borger	3,037,796	$79,390,929	$26.13	$27.68
7	79116	Potter	TX	Amarillo	3,196,184	$79,099,131	$24.75	$24.77
8	79106	Potter	TX	Amarillo	3,196,184	$79,281,623	$24.81	$24.69
9	79159	Potter	TX	Amarillo	3,189,526	$79,302,636	$24.86	$24.71
10	79102	Potter	TX	Amarillo	3,196,184	$79,430,651	$24.85	$24.73

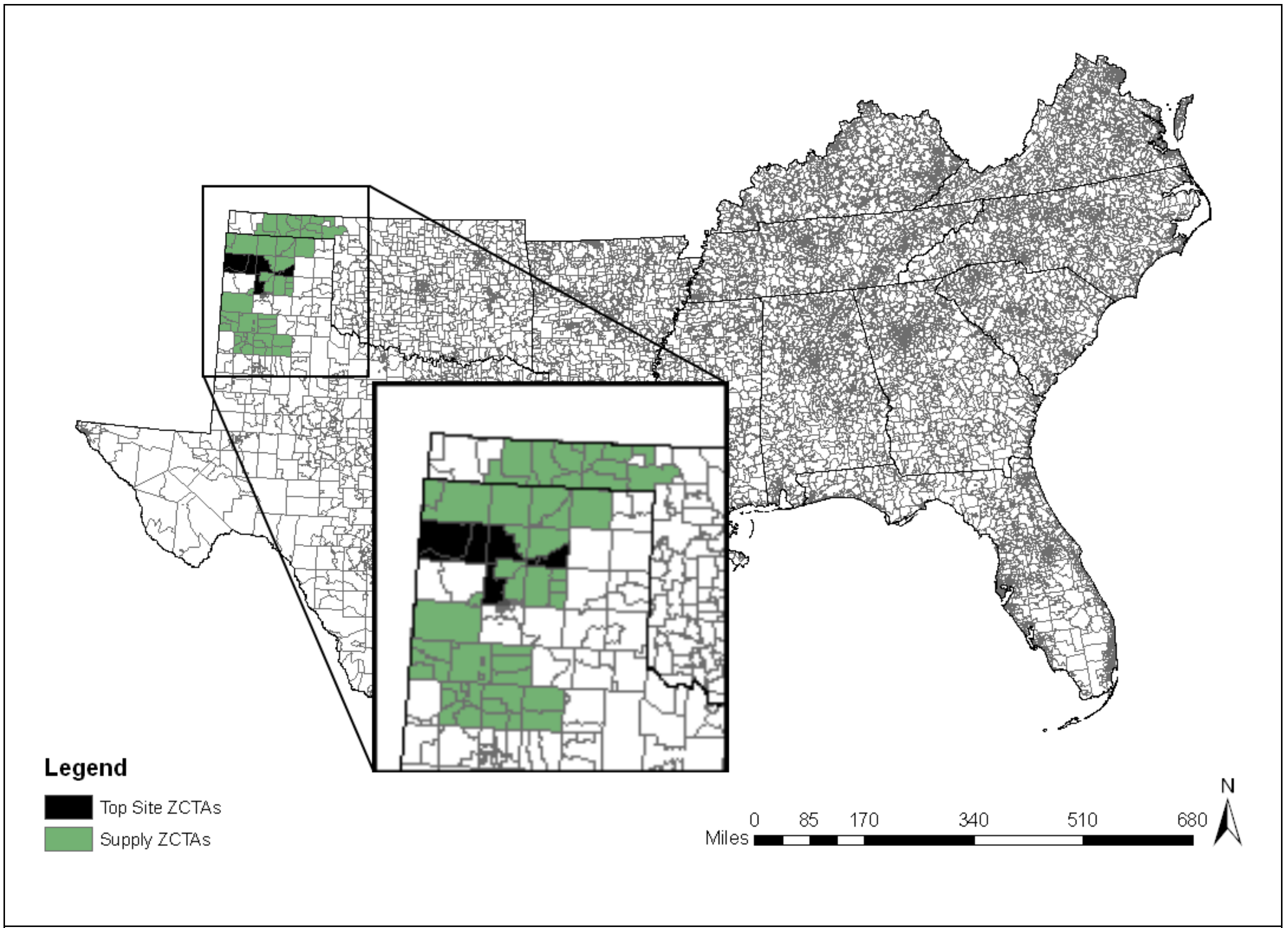

Figure 26. Least cost bio-basins for corn stover for the southern region.

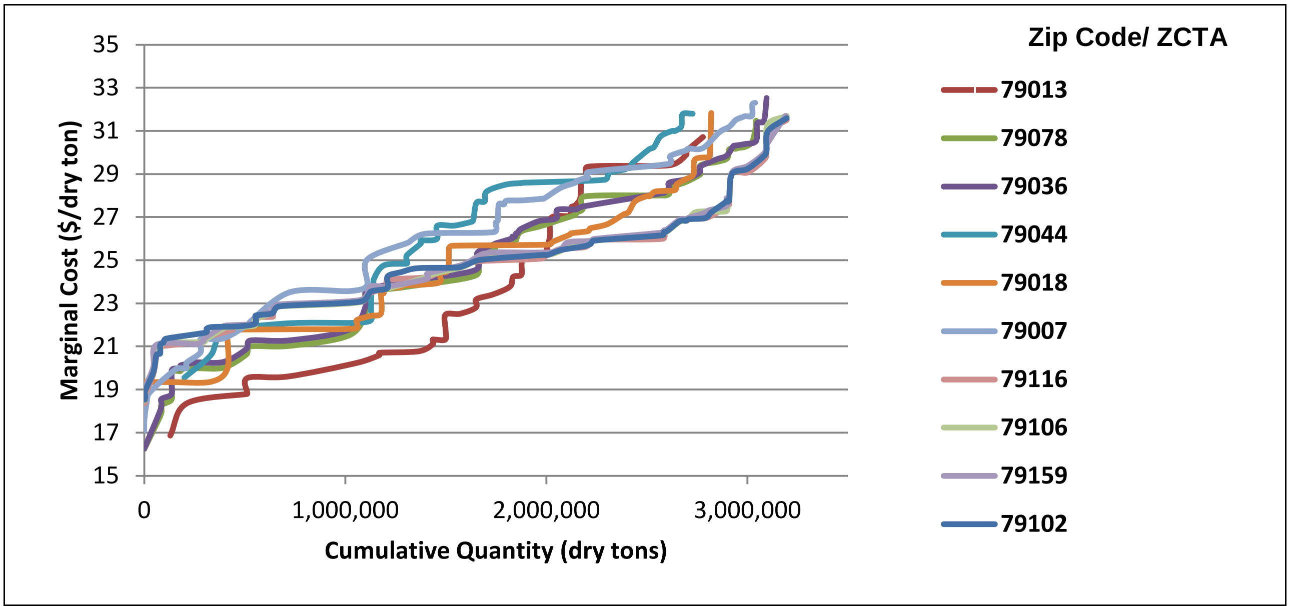

Figure 27. Marginal cost curves for the top ten locations for corn stover in the southern region.

3.1.3.2 Sorghum Straw

The top ten ZCTA locations in the southern region were located in southern Texas near the coast (Figure 28). ATC for sorghum straw ranged from $30.25 to $31.04/dry ton. The median MC ranged from $34.27 to $36.27/dry ton (Table 14, Figure 29).

Table 14. Top ten locations in the southern region for sorghum straw based average total cost (median marginal costs also presented).

Rank	Zip Code/ ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	78351	Nueces	TX	Driscoll	1,060,279	$32,071,568	$30.25	$35.74
2	78410	Nueces	TX	Corpus Christi	1,091,525	$33,572,650	$30.76	$35.17
3	78426	Nueces	TX	Corpus Christi	1,058,732	$32,239,652	$30.45	$35.24
4	78409	Nueces	TX	Corpus Christi	1,056,002	$32,706,477	$30.97	$35.36
5	78339	Nueces	TX	Banquete	1,032,864	$31,403,356	$30.40	$36.27
6	78364	Kleberg	TX	Kingsville	1,034,149	$31,333,067	$30.30	$34.51
7	78405	Nueces	TX	Corpus Christi	1,062,074	$32,897,176	$30.97	$34.46
8	78416	Nueces	TX	Corpus Christi	1,064,304	$33,038,781	$31.04	$34.73
9	78408	Nueces	TX	Corpus Christi	1,063,174	$32,612,756	$30.67	$34.27
10	78467	Nueces	TX	Corpus Christi	1,049,094	$32,452,252	$30.93	$34.43

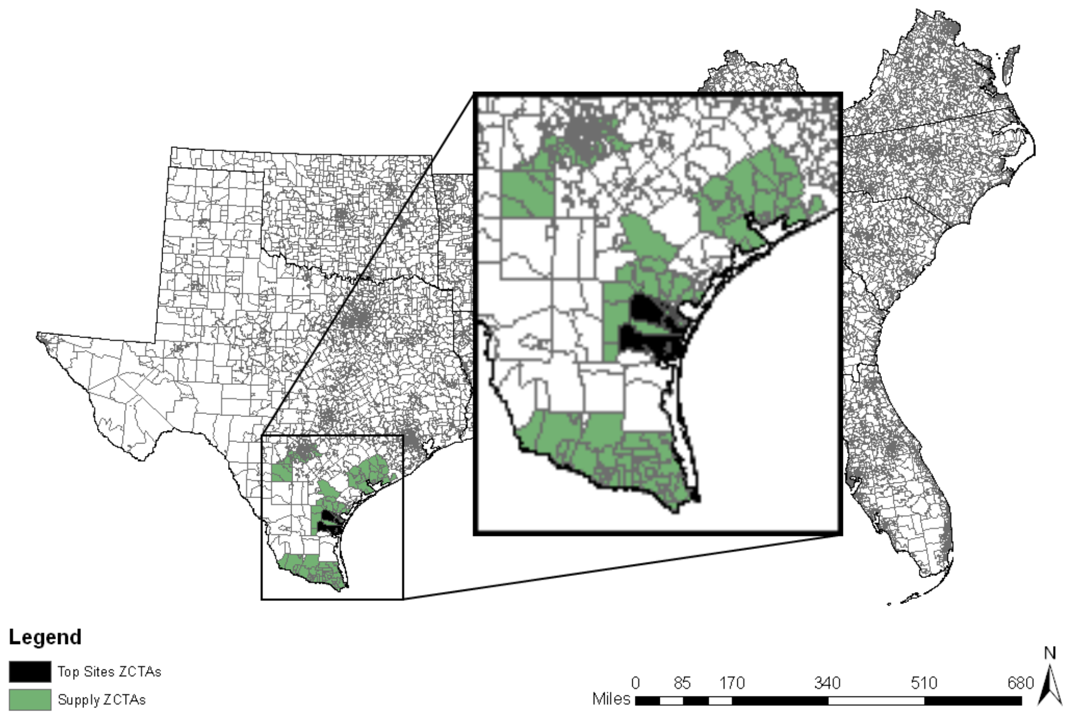

Figure 28. Least cost bio-basins for sorghum straw for the southern region.

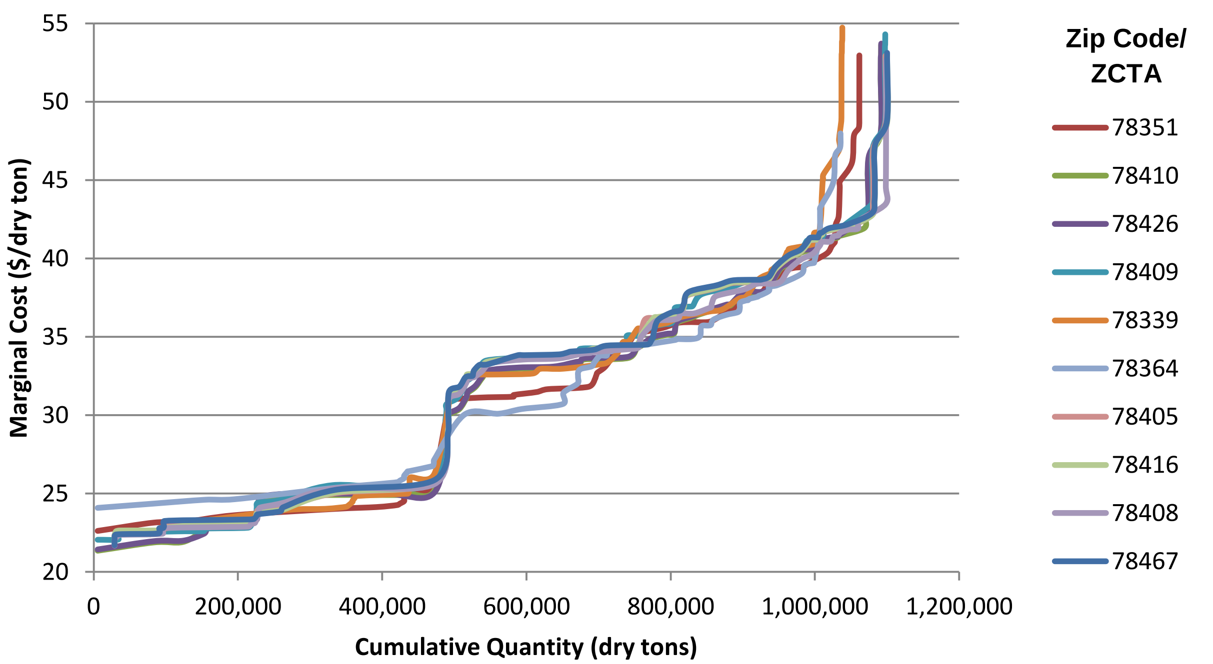

Figure 29. Marginal cost curves for the top ten locations for sorghum straw in the southern region.

3.1.3.3 Wheat Straw

The top ten ZCTA locations for wheat straw were located in northwestern Mississippi, eastern Arkansas, and southwestern Kentucky (Figure 30). ATC for wheat straw ranged from $27.27 to $30.80/dry ton. The median MC ranged from $29.74 to $32.45/dry ton (Table 15, Figure 31).

Table 15. Top ten locations in southern region for wheat straw based on average total cost (median marginal costs also presented).

Rank	Zip Code/ ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	38645	Coahoma	MS	Lyon	1,836,837	$55,400,397	$30.16	$31.74
2	72312	Lee	AR	Barton	1,881,327	$55,388,999	$29.44	$31.45
3	42241	Christian	KY	Hopkinsville	1,098,616	$29,964,241	$27.27	$29.74
4	42040	Graves	KY	Farmington	1,250,369	$35,923,126	$28.73	$30.39
5	42221	Todd	KY	Fairview	1,070,168	$29,391,703	$27.46	$29.85
6	72352	Lee	AR	La Grange	1,841,804	$54,642,392	$29.67	$31.65
7	38644	Coahoma	MS	Lula	1,889,270	$56,059,900	$29.67	$31.10
8	38767	Coahoma	MS	Rena Lara	1,815,854	$55,840,338	$30.75	$31.87
9	72355	Lee	AR	Lexa	1,851,448	$54,811,266	$29.60	$31.67
10	72346	St. Francis	AR	Heth	1,775,681	$54,691,902	$30.80	$32.45

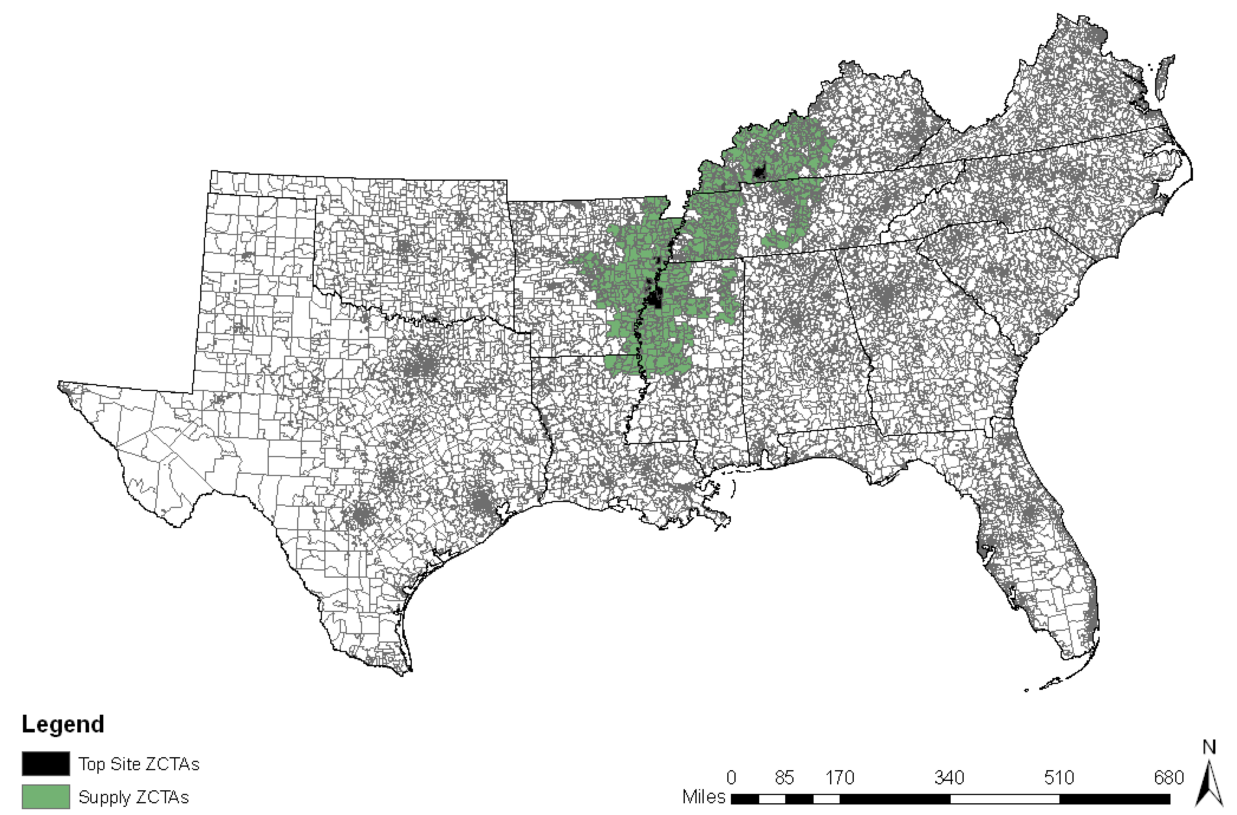

Figure 30. Least cost bio-basins for wheat straw for the southern region.

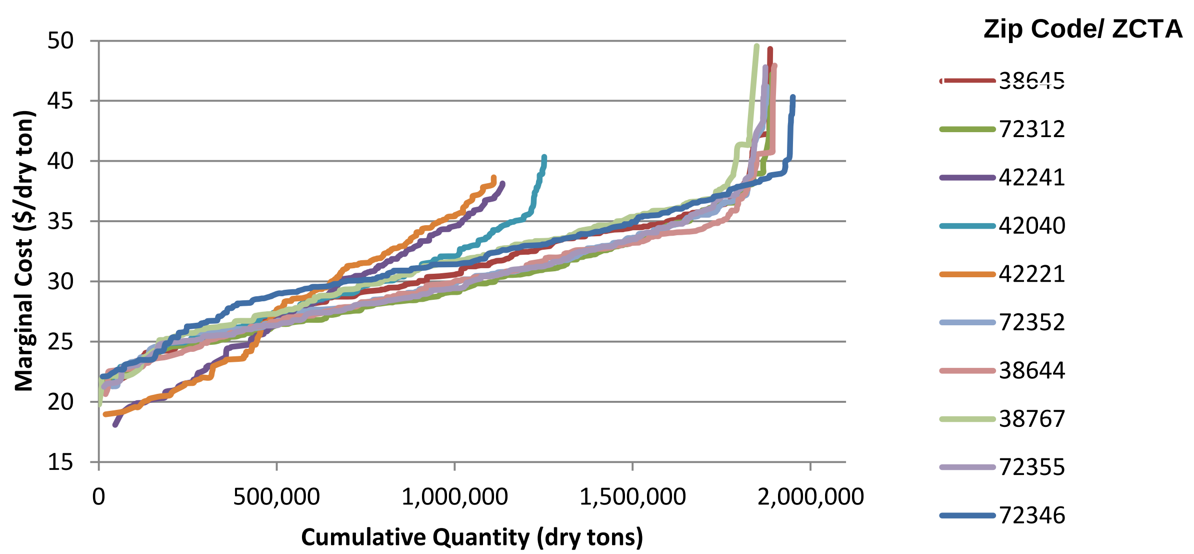

Figure 31. Marginal cost curves for the top ten locations for wheat straw in the southern region.

3.1.4 Merchantable Trees (Roundwood)

The merchantable trees (roundwood) categories for pulpwood and sawtimber included in the BioSAT model were: mixed natural softwood and hardwood, natural softwood, pine plantation, and upland hardwood. For illustration purposes, the maximum quantity available in a bio-basin and the associated total cost (TC), average total cost (ATC), and median marginal cost (MC) in $/dry ton were estimated for the southeast for "*natural softwood pulpwood" for "gross growth."* The costs estimates were derived assuming a minimum annual consumption of pulpwood of at least 0.5 million dry tons. The bio-basins were constructed using a maximum 80-mile one-way truck haul distance with long-log trailers. Kentucky and Tennessee did not have any bio-basins with sufficient quantity of 0.5 million dry tons for the *natural softwood pulpwood* and are not presented in the discussion below. More detail for all possible categories and combinations of harvesting and haul distance scenarios are available on the website www.biosat.net under the "Guided Assessment" link.

Least cost bio-basins for *"natural softwood pulpwood"* were in North Carolina, South Carolina, Oklahoma, and Virginia. The median MC ranged from $47.43 to $60.47/dry ton (Table 16, Figure 32). Bio-basins with the largest concentrations of *"natural softwood pulpwood"* were in Alabama, Florida, and Oklahoma (Figures 33 to 43).

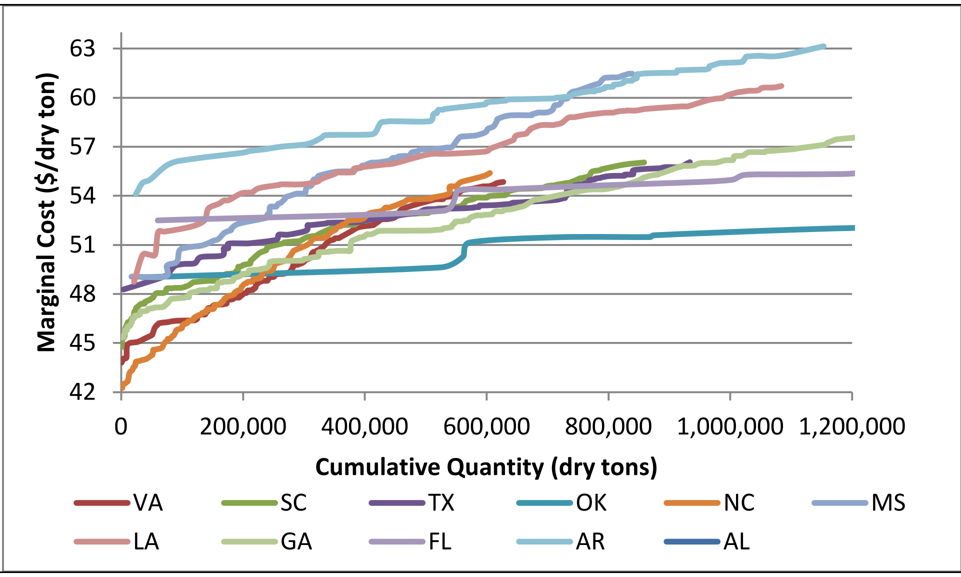

Figure 32. Marginal cost curves for least cost bio-basins for natural softwood pulpwood for each state in the southern region.

Table 16. Least cost bio-basins for natural softwood pulpwood for each state in the southern region based average total cost (median marginal costs also presented).

State and Zip Code/ ZCTA	County	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median Marginal Total Cost ($/dry ton)
Alabama						
36257	Calhoun	De Armanville	2,147,369	$23,078,683	$43.26	$51.45
Arkansas						
71748	Dallas	Ivan	1,152,994	$24,865,603	$48.31	$60.47
Florida						
32565	Santa Rosa	Jay	7,157,330	$363,377,644	$50.77	$57.62
Georgia						
30273	Clayton	Rex	1,315,306	$21,111,913	$41.51	$49.46
Louisiana						
70639	Vernon	Evans	1,083,733	$24,676,179	$48.70	$57.44
Mississippi						
39109	Neshoba	Madden	839,156	$24,624,016	$49.21	$56.41
North Carolina						
28147	Rowan	Salisbury	605,068	$22,572,374	$44.75	$47.43
Oklahoma						
74939	Le Flore	Hodgen	957,539	$45,747,686	$43.37	$59.07
South Carolina						
29742	York	Sharon	858,293	$21,445,282	$42.19	$49.44
Texas						
77326	Polk	Ace	933,670	$23,010,329	$45.08	$53.49
Virginia						
24586	Pittsylvania	Ringgold	627,201	$23,094,398	$46.12	$48.72

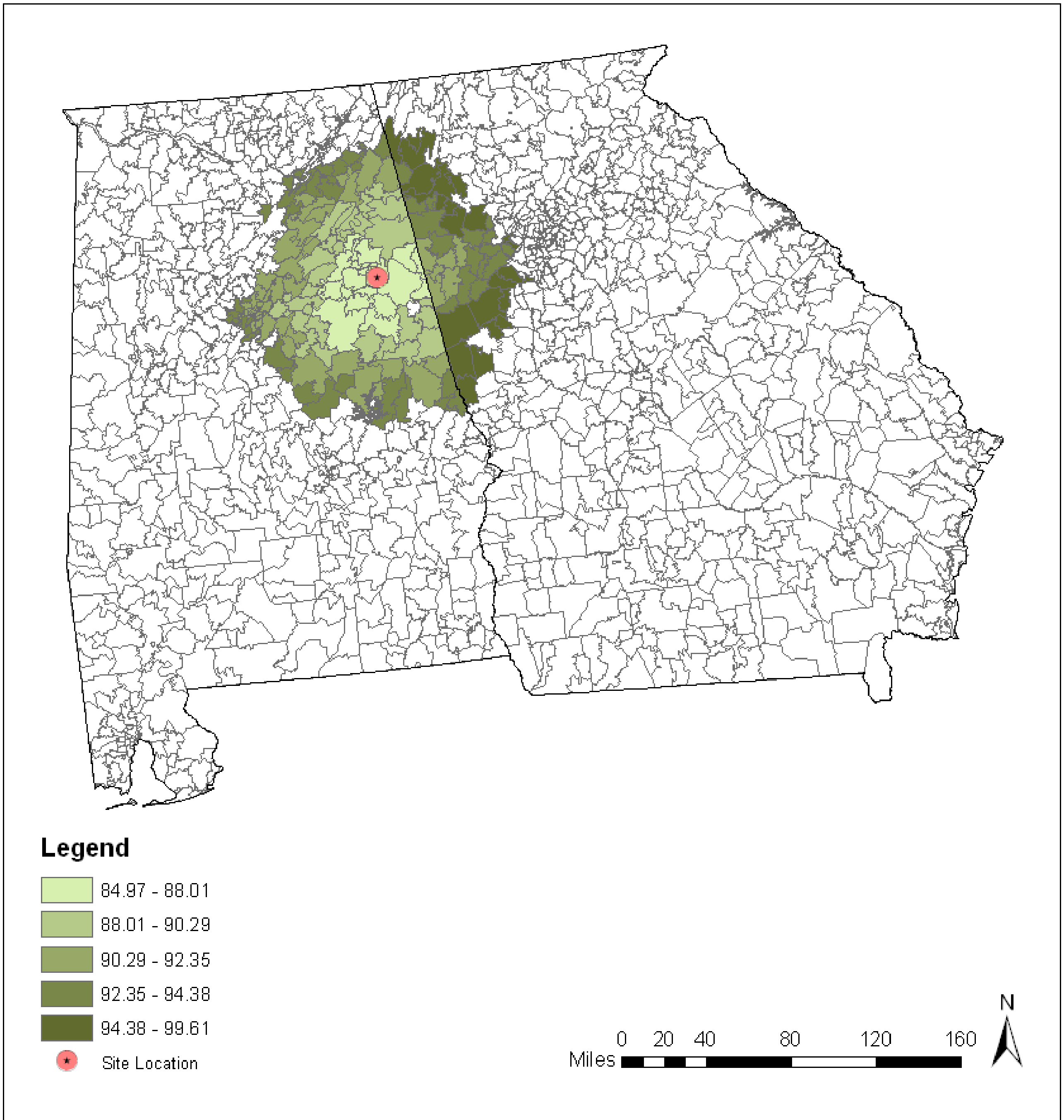

Figure 33. Bio-basin for least cost natural softwood pulpwood in AL (DeArmanville, AL, 36257 zip code, ZCTA 36207).

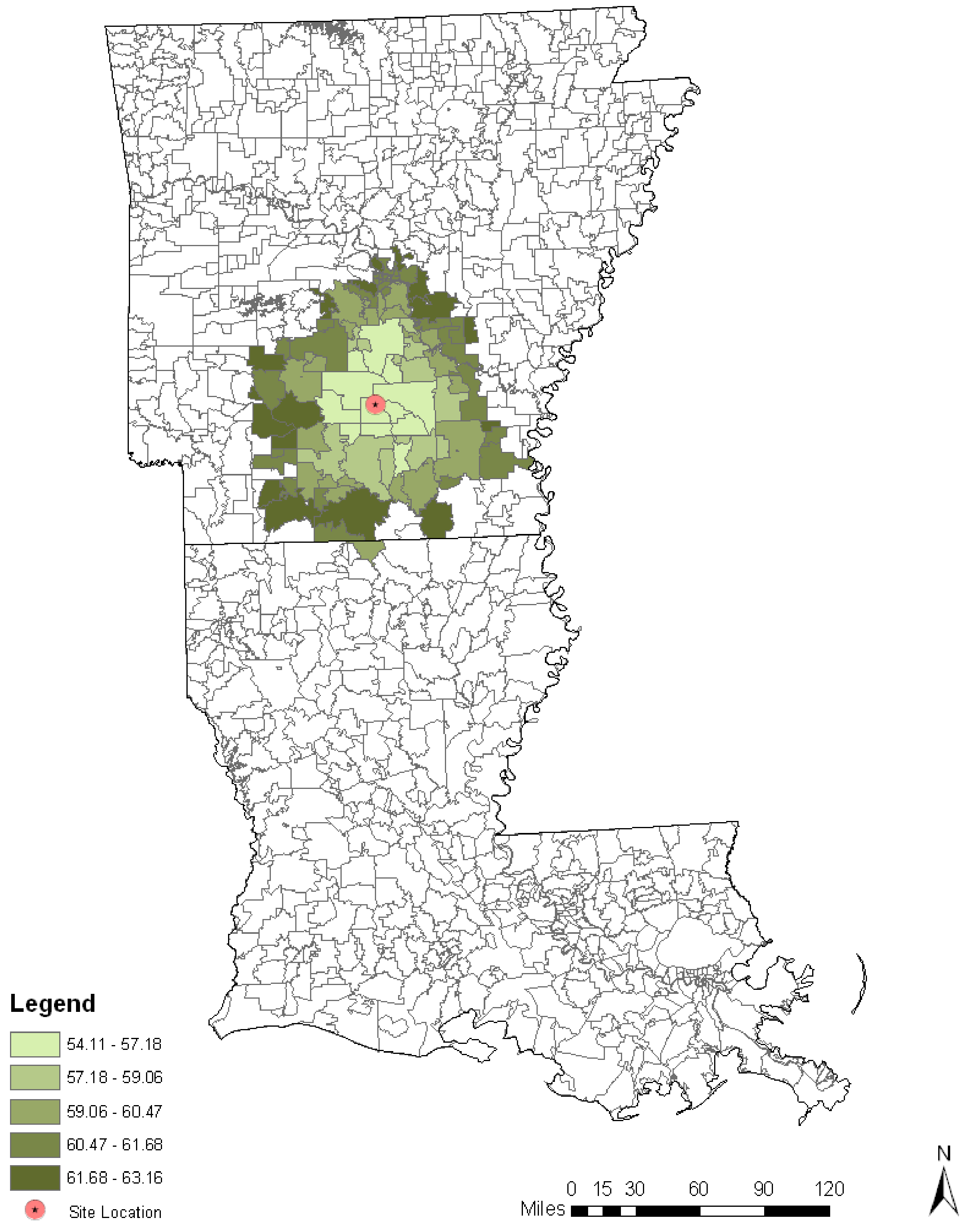

Figure 34. Bio-basin for least cost natural softwood pulpwood in AR (Ivan, AR, 71748 zip code).

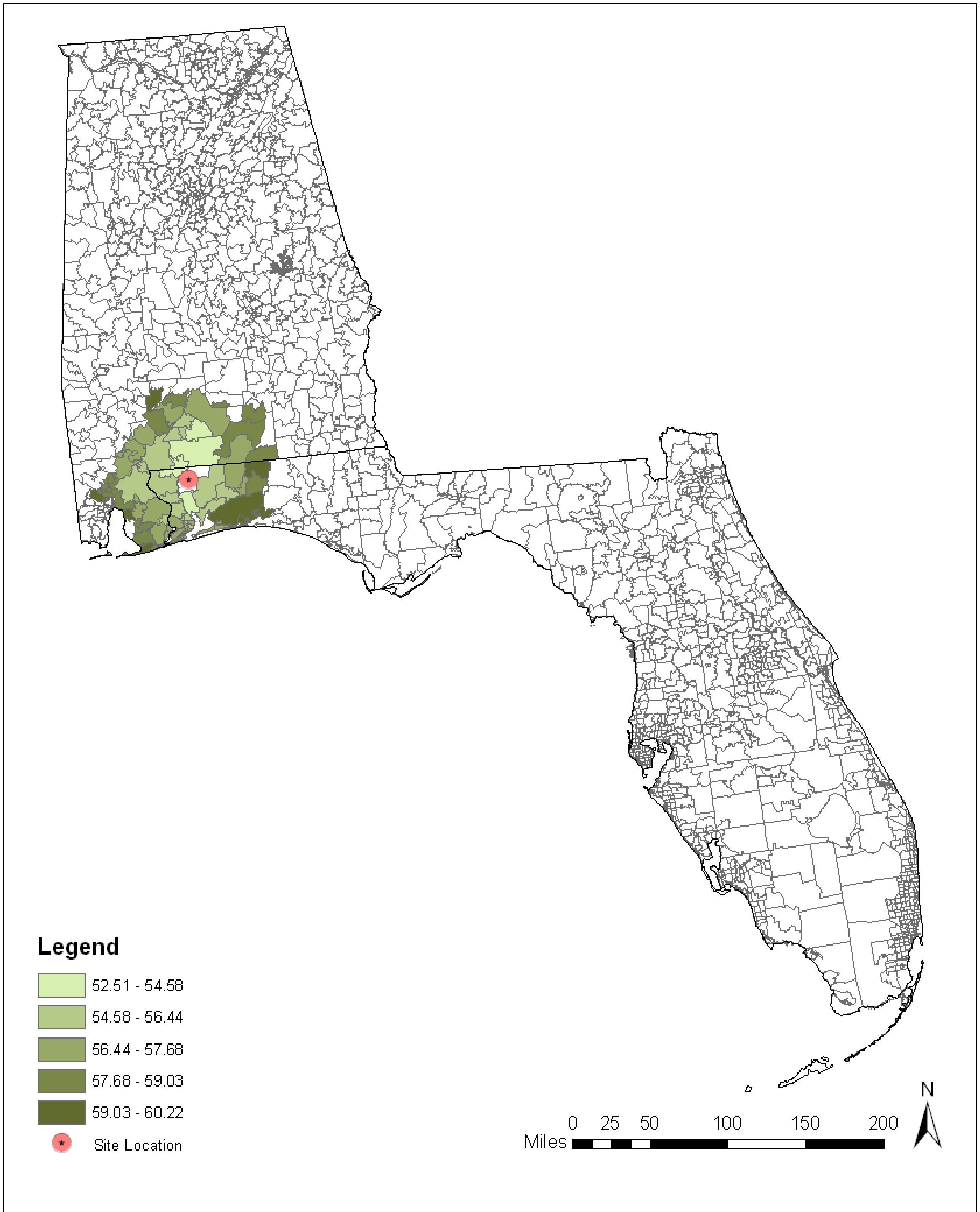

Figure 35. Bio-basin for least cost natural softwood pulpwood in FL (Jay, FL, 32565 zip code).

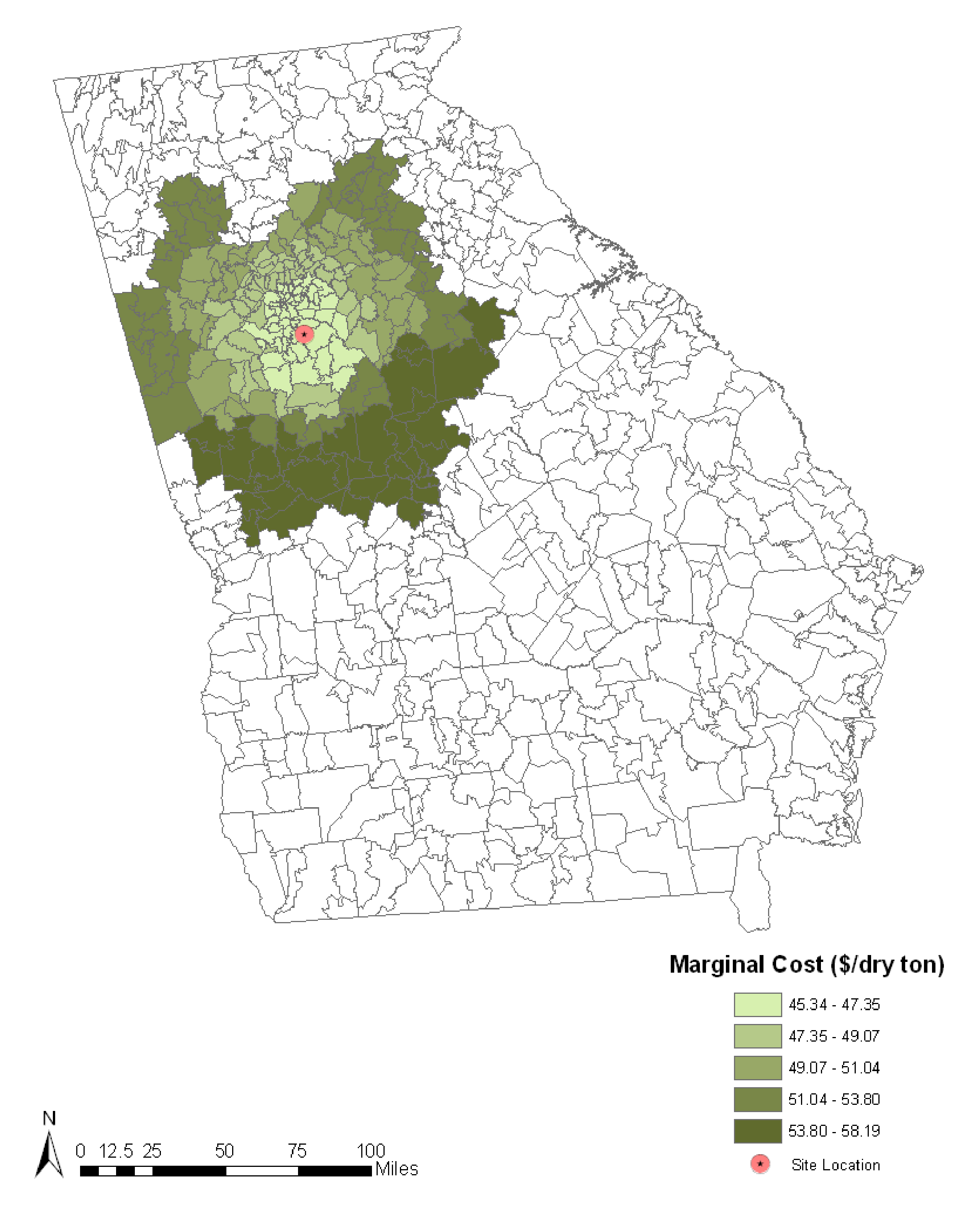

Figure 36. Bio-basin for least cost natural softwood pulpwood in GA (Rex, GA 30273 zip code).

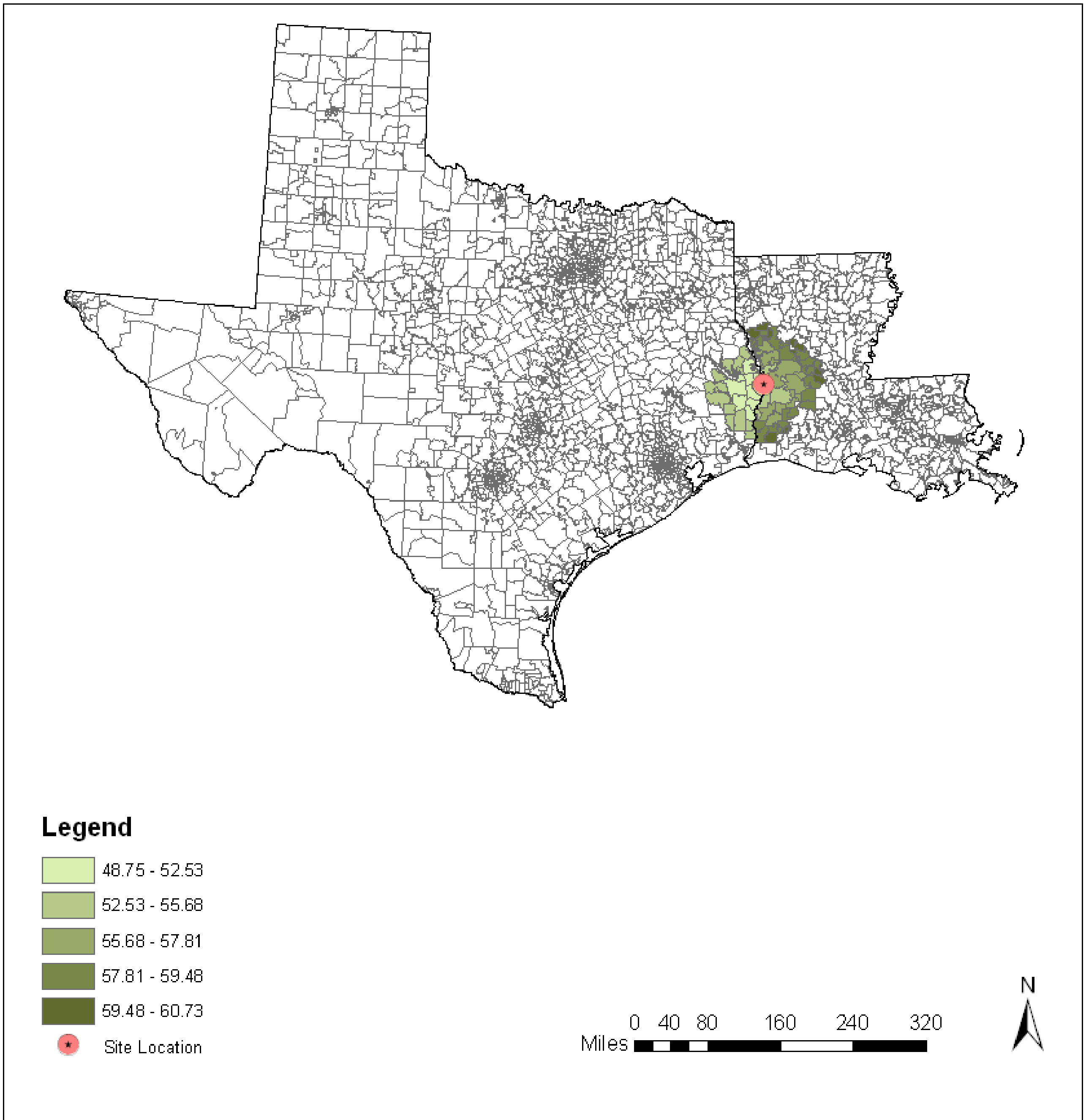

Figure 37. Bio-basin for least cost natural softwood pulpwood in LA (Evans, LA, 70639 zip code).

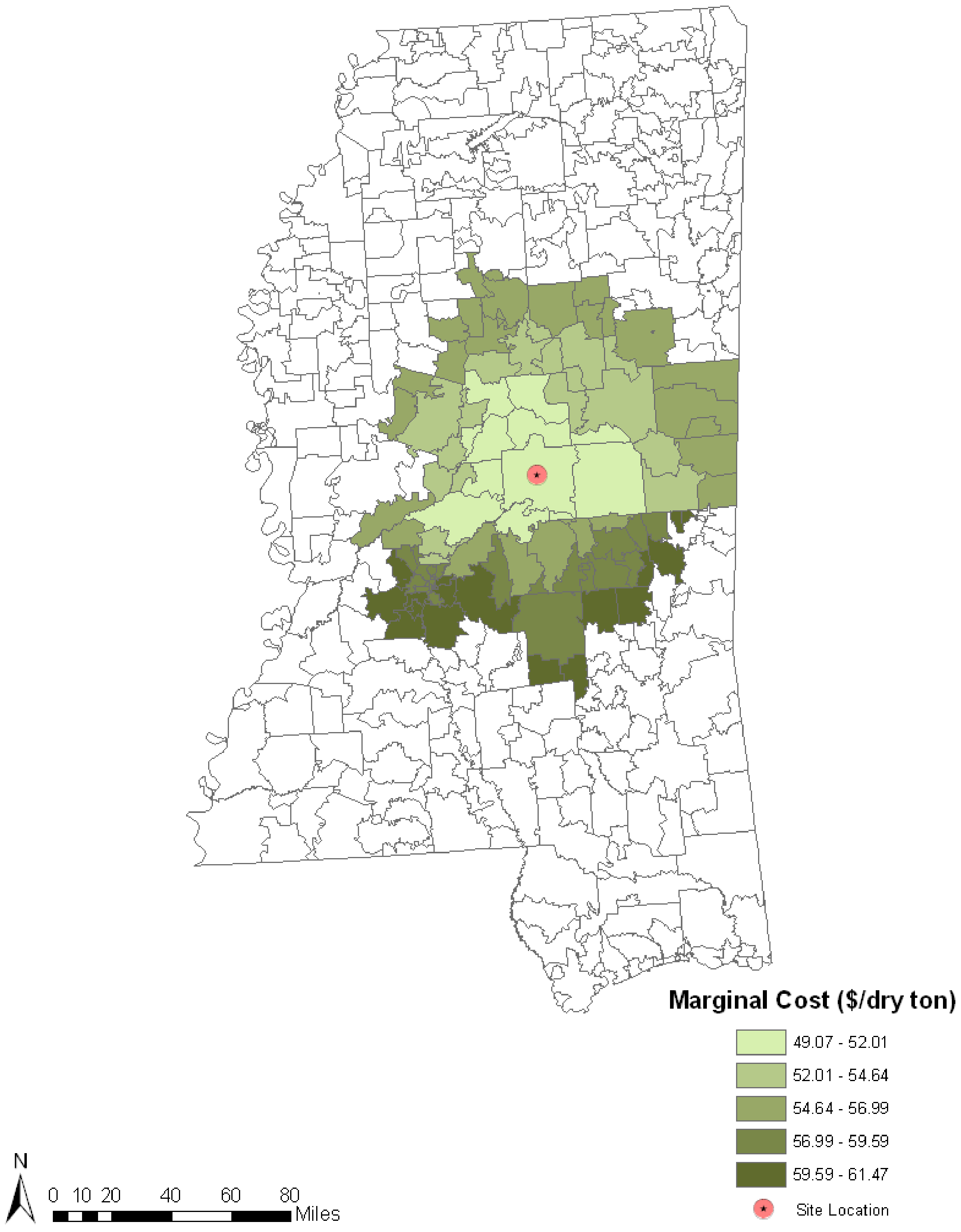

Figure 38. Bio-basin for least cost natural softwood pulpwood in MS (Madden, MS, 39109 zip code, ZCTA 39051).

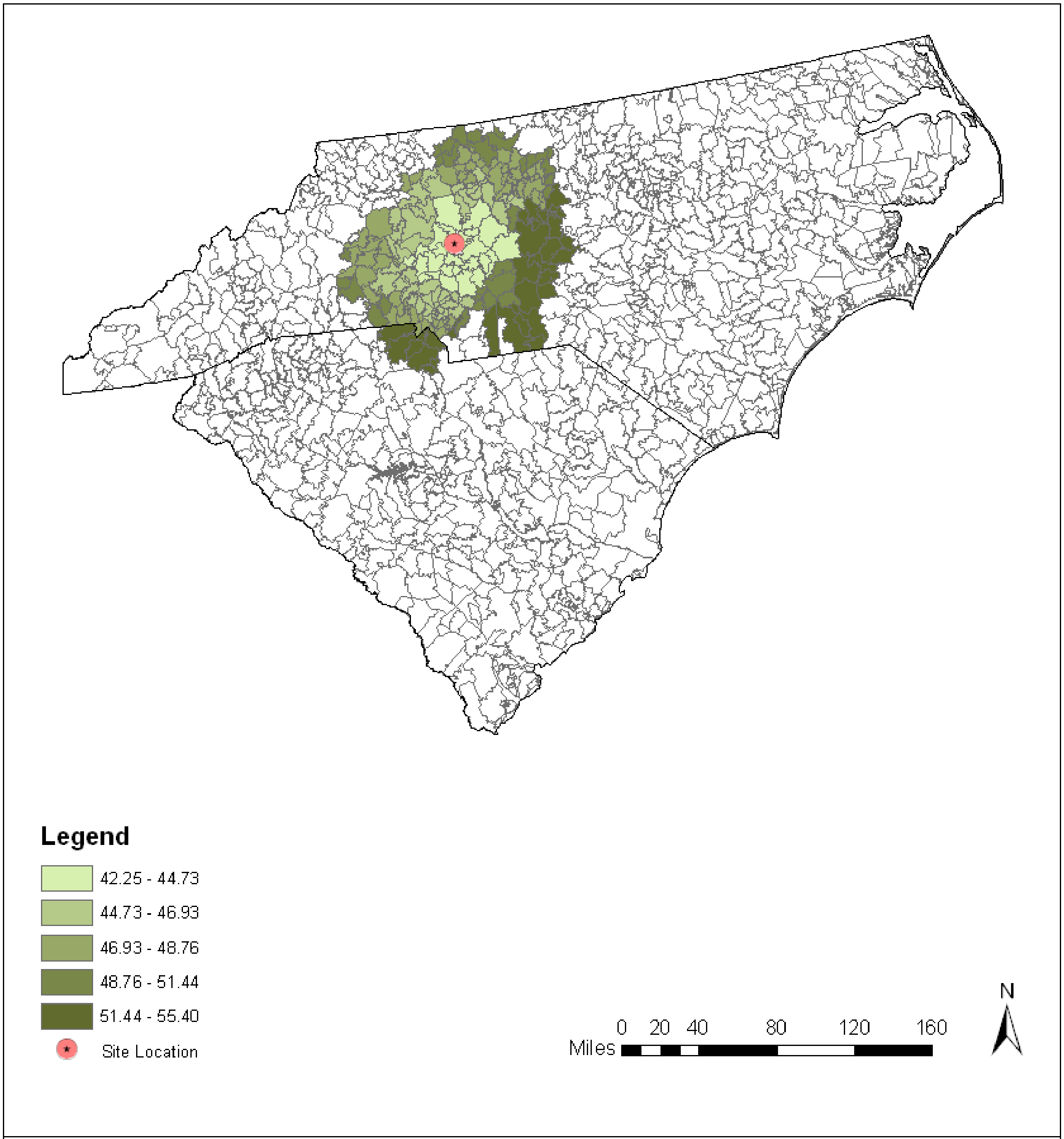

Figure 39. Bio-basin for least cost natural softwood pulpwood in NC (Salisbury, NC, 28147 zip code).

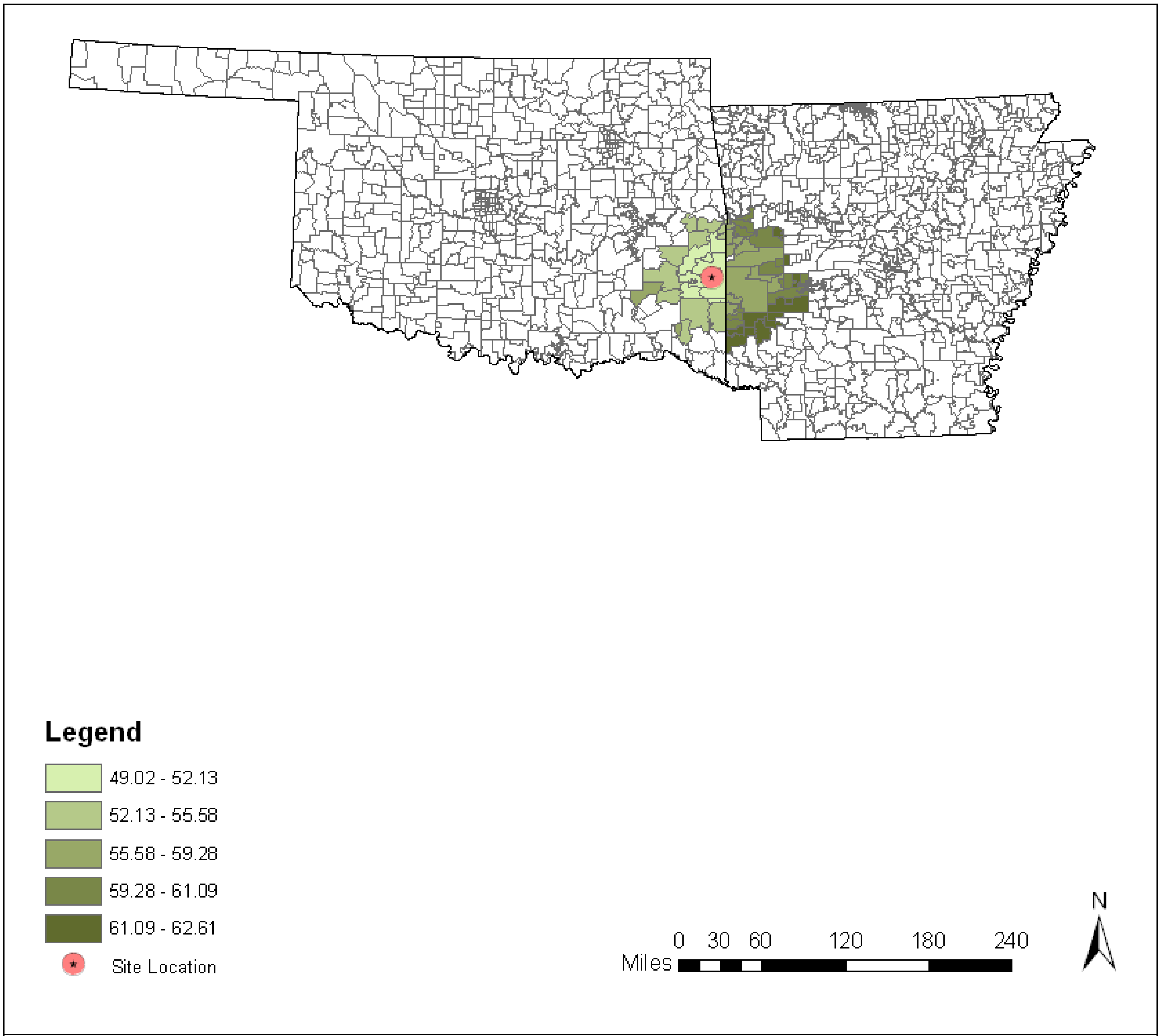

Figure 40. Bio-basin for least cost natural softwood pulpwood in OK (Hodgen, OK, 74939 zip code).

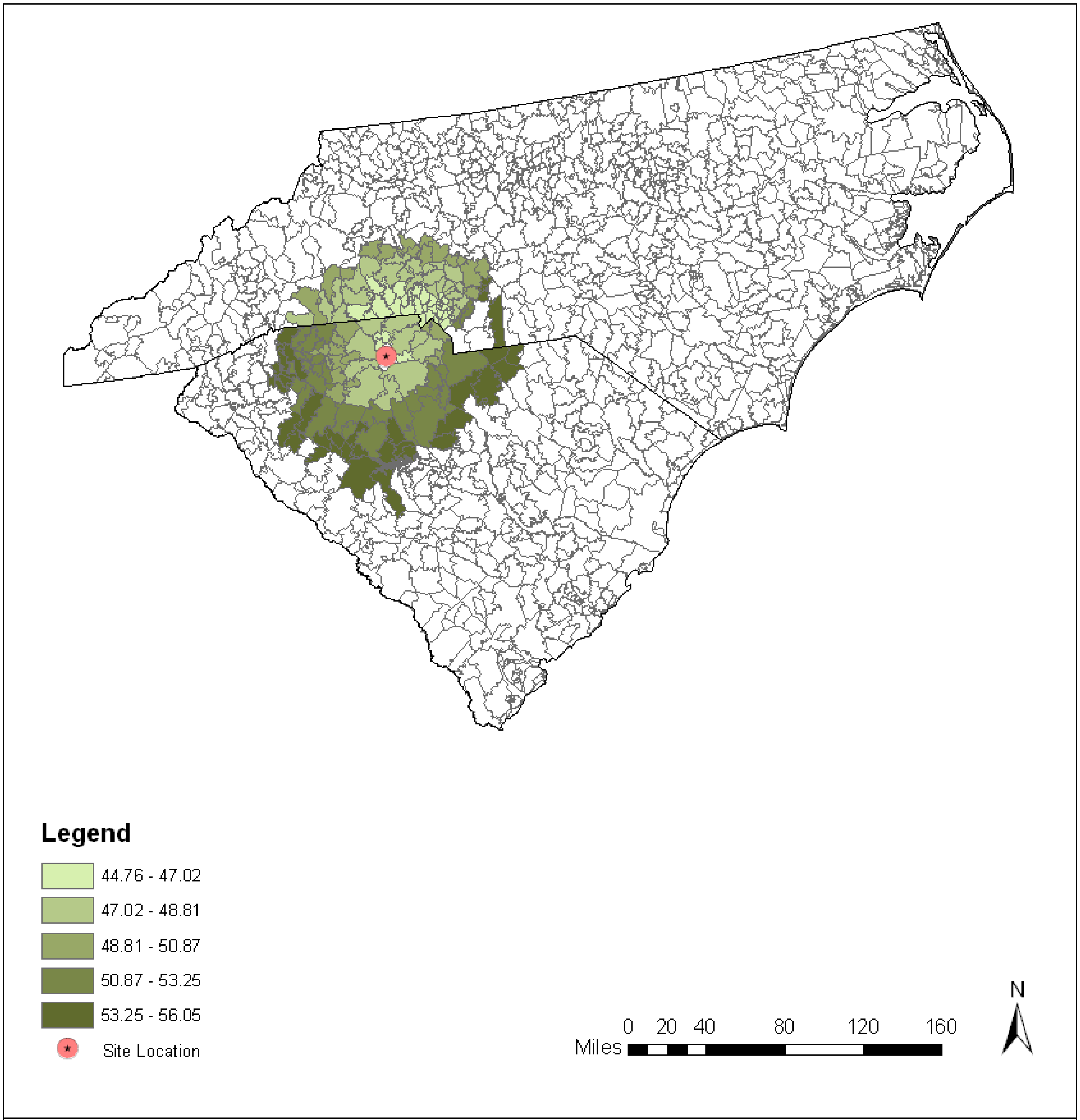

Figure 41. Bio-basin for least cost natural softwood pulpwood in SC (Sharon, SC, 29742 zip code).

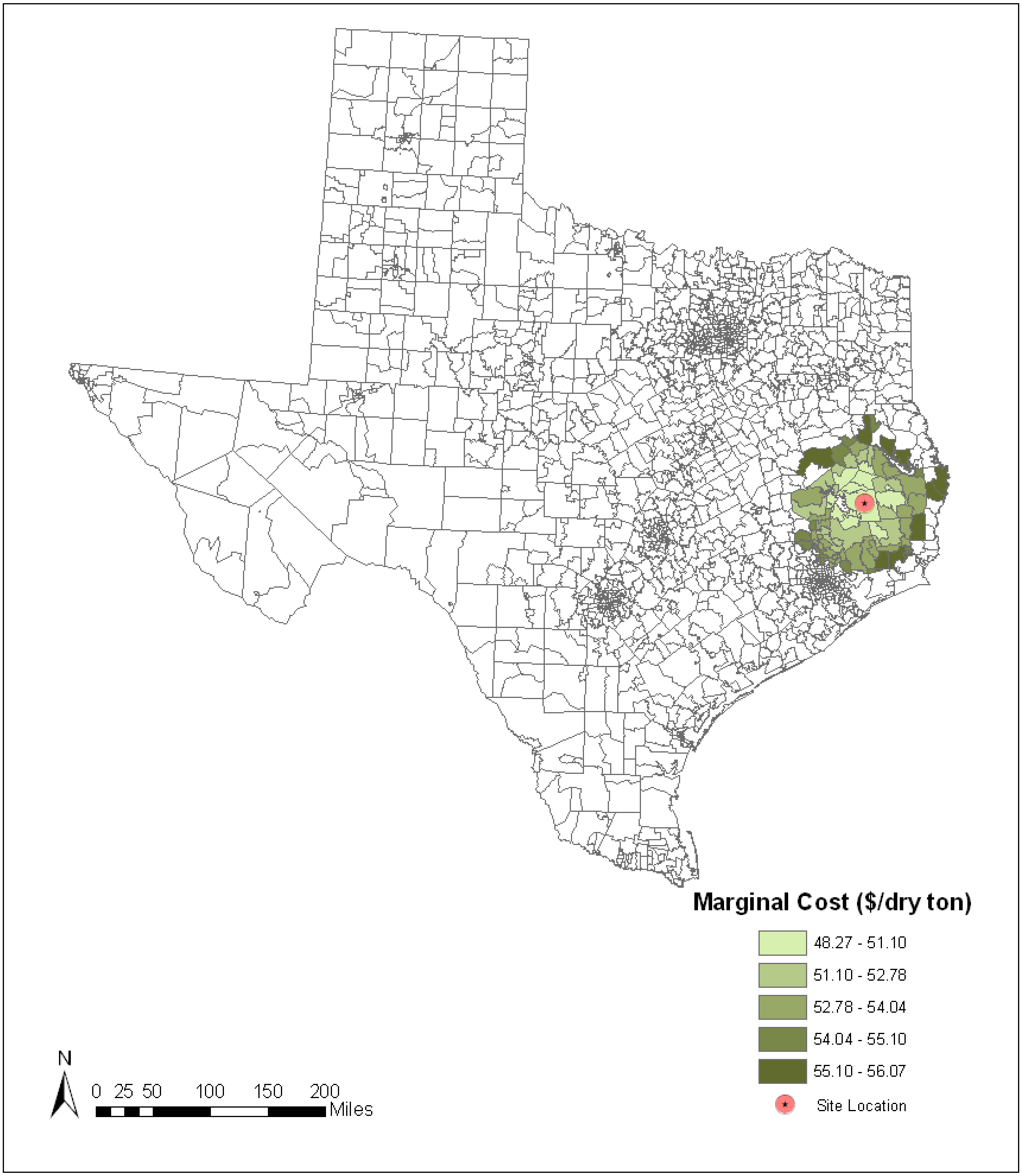
Marginal Cost ($/dry ton)
48.27 - 51.10
51.10 - 52.78
52.78 - 54.04
54.04 - 55.10
55.10 - 56.07
Site Location
N
0 25 50 100 150 200
Miles

Figure 42. Bio-basin for least cost natural softwood pulpwood in TX (Livingston, TX, ZCTA 77351).

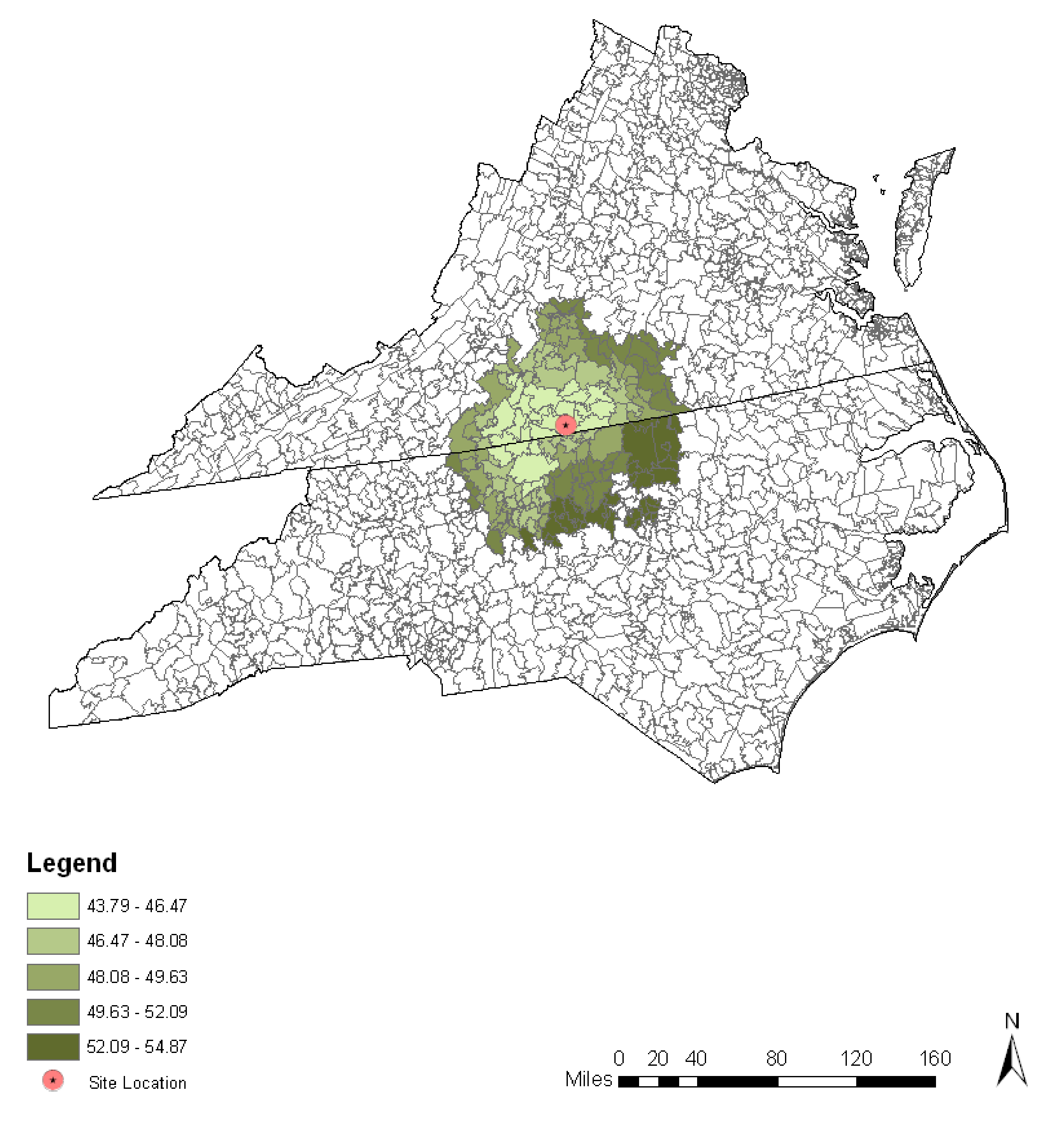

Figure 43. Bio-basin for least cost natural softwood pulpwood in VA (Ringgold, VA, 24586 zip code).

3.2 Northern Region

3.2.1 Mill Residues

The mill residues categories included in this report for the northern regions were total mill residues, hardwood mill residues, and softwood mill residues. The maximum quantity, total costs (TC), average total costs (ATC), and median marginal cost (MC) with MC curves associated with available quantities are presented for least cost bio-basins in this region. Bio-basins were constructed assuming a minimum annual consumption of 0.5 million dry tons and a maximum 120-mile one-way truck haul distance (with dry van trailer storage).

3.2.1.1 Total Mill Residues. -- The top ten ZCTA locations based on least average total cost for total mill residues (*softwood and hardwood combined*) in the northern region were all located in West Virginia (Figure 44). ATC for up to 0.5 million annual dry tons ranged from $30.90 to $32.76/dry ton. The median of the MC for up to 0.5 million annual dry tons ranged from $49.48 to $53.89/dry ton (Table 17, Figure 45).

Table 17. Top ten northern locations for total mill residues based on average total cost (median marginal costs also presented).

Rank	Zip Code/ ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	26250	Barbour	WV	Belington	1,070,654	$15,450,603	$30.90	$51.26
2	26416	Barbour	WV	Philippi	967,547	$15,591,291	$31.18	$50.88
3	26349	Barbour	WV	Galloway	1,062,105	$15,697,946	$31.40	$49.79
4	26275	Barbour	WV	Junior	1,155,972	$15,708,437	$31.42	$51.87
5	26435	Barbour	WV	Simpson	1,068,360	$15,868,371	$31.74	$49.48
6	26285	Randolph	WV	Norton	1,068,344	$16,150,008	$32.30	$53.89
7	26347	Barbour	WV	Flemington	1,062,859	$16,164,990	$32.33	$49.87
8	26405	Barbour	WV	Moatsville	1,072,583	$16,211,501	$32.42	$50.50
9	26408	Harrison	WV	Mount Clare	1,061,351	$16,314,211	$32.63	$49.90
10	26238	Barbour	WV	Volga	894,117	$16,377,698	$32.76	$51.59

Figure 44. Least cost bio-basins for total mill residues for the northern region.

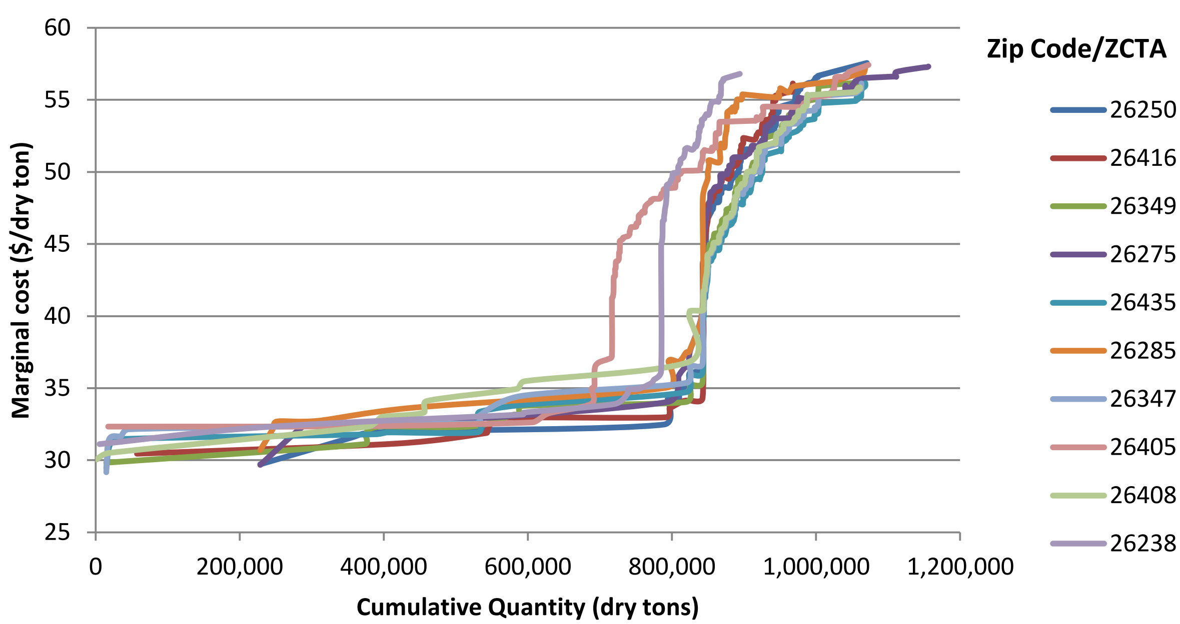

Figure 45. Marginal cost curves for the top ten locations for total mill residues in the northern region.

3.2.1.2 Hardwood Mill Residues. – The top ten ZCTA locations based on least average total cost for hardwood mill residues for the northern region were also located in West Virginia (Figure 46). ATC ranged from $30.74 to $32.58/dry ton. The median MC ranged from $49.29 to $53.67/dry ton (Table 18, Figure 47).

Table 18. Top ten locations in northern region for hardwood mill residues based on average total cost (median marginal costs also presented).

Rank	Zip Code/ ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	26250	Barbour	WV	Belinton	998,777	$15,370,518	$30.74	$51.00
2	26416	Barbour	WV	Philippi	929,932	$15,505,699	$31.01	$50.70
3	26349	Barbour	WV	Galloway	991,561	$15,613,977	$31.23	$49.58
4	26275	Barbour	WV	Junior	1,044,071	$15,635,080	$31.27	$51.69
5	26435	Barbour	WV	Simpson	997,566	$15,779,593	$31.56	$49.29
6	26347	Barbour	WV	Flemington	992,120	$16,076,570	$32.15	$49.68
7	26285	Randolph	WV	Norton	977,890	$16,077,389	$32.15	$53.67
8	26405	Barbour	WV	Moatsville	951,764	$16,122,747	$32.25	$50.20
9	26408	Harrison	WV	Mount Clare	990,878	$16,238,948	$32.48	$49.62
10	26238	Barbour	WV	Volga	864,658	$16,290,381	$32.58	$51.41

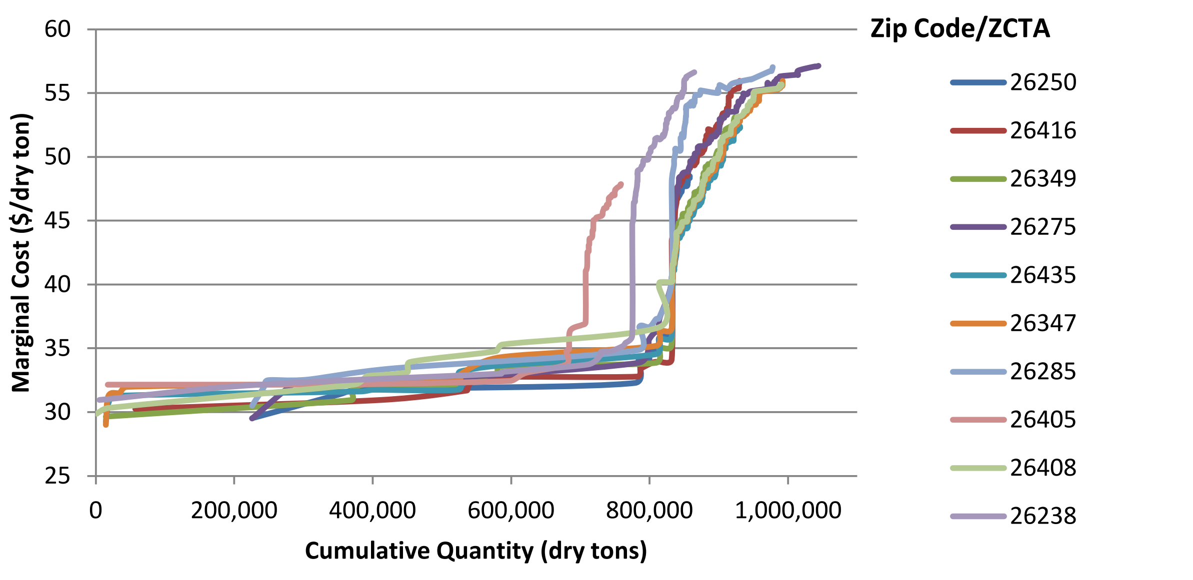

Figure 46. Marginal cost curves for the top ten locations for hardwood mill residues in the northern region.

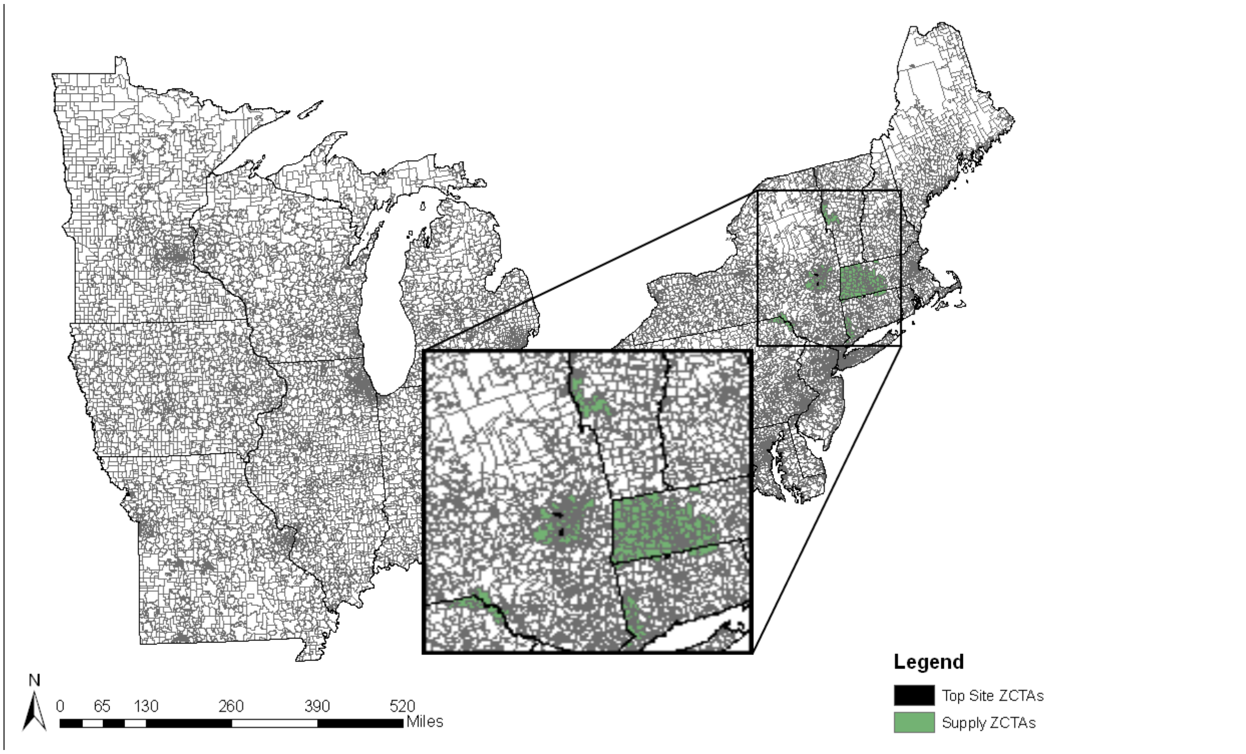

Figure 47. Least cost bio-basins for hardwood mill residues for the northern region.

3.2.1.3 Softwood Mill Residues. -- The top ten ZCTA locations based on least average total cost for the northern region were located in southern Maine and southeastern New Hampshire (Figure 48). ATC ranged from $78.86 to $81.21/dry ton. The median MC ranged from $81.96 to $82.84/dry ton (Table 17, Figure 49).

Table 19. Top ten locations in the northern region for softwood mill residues based average total cost (median marginal costs also presented).

Rank	Zip Code/ ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	04090	York	ME	Wells	503,078	$39,431,286	$78.86	$82.07
2	04054	York	ME	Moody	506,932	$39,775,970	$79.55	$82.60
3	03907	York	ME	Ogunquit	507,634	$40,096,972	$80.19	$82.84
4	03902	York	ME	Cape Neddick	509,666	$40,416,978	$80.83	$82.52
5	03908	York	ME	South Berwick	504,166	$40,427,665	$80.86	$82.35
6	03805	Strafford	NH	Newington	509,183	$40,460,033	$80.92	$82.04
7	03909	York	ME	York	517,479	$40,477,989	$80.96	$82.38
8	03911	York	ME	York Harbor	513,097	$40,544,009	$81.09	$82.56
9	03878	Strafford	NH	Somersworth	508,007	$40,561,301	$81.12	$82.14
10	03869	Strafford	NH	Rollinsford	509,666	$40,606,494	$81.21	$81.96

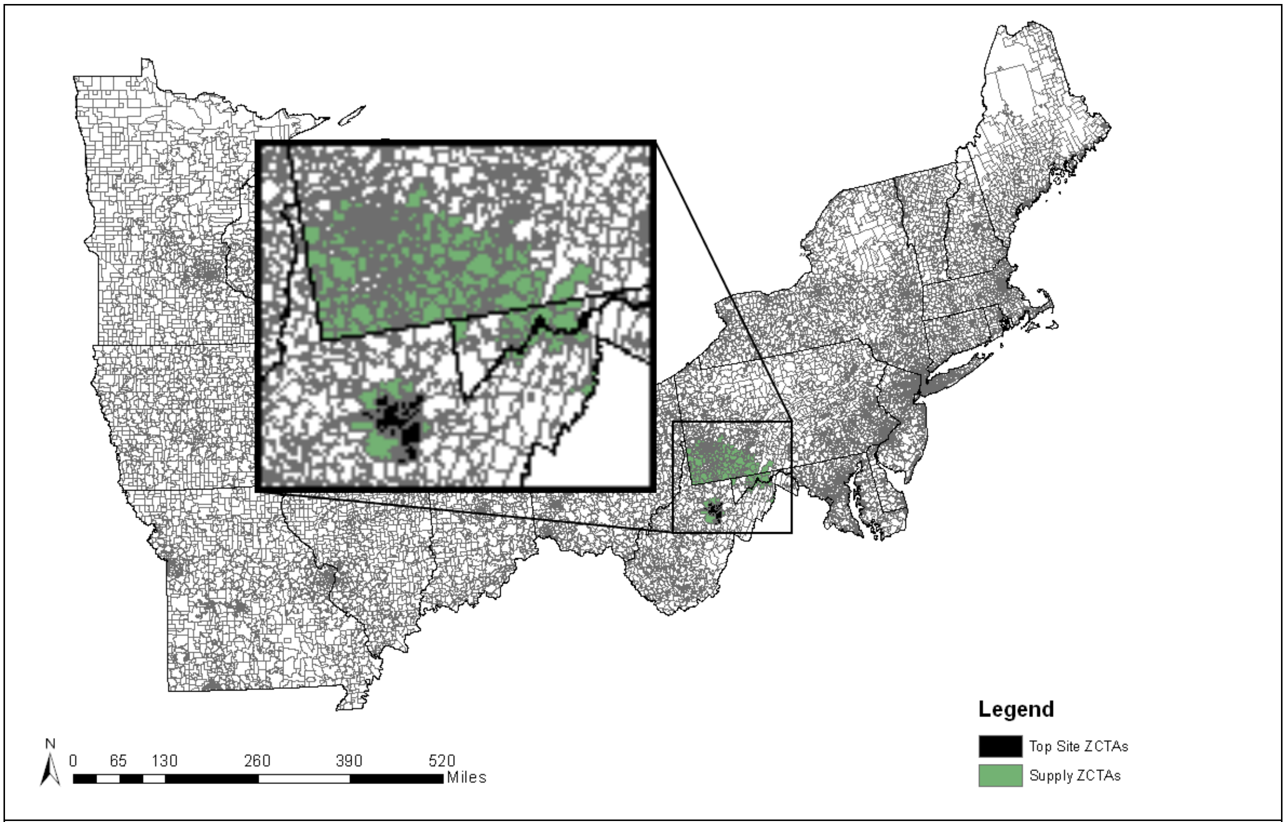

Figure 48. Least cost bio-basins for softwood mill residues for the northern region.

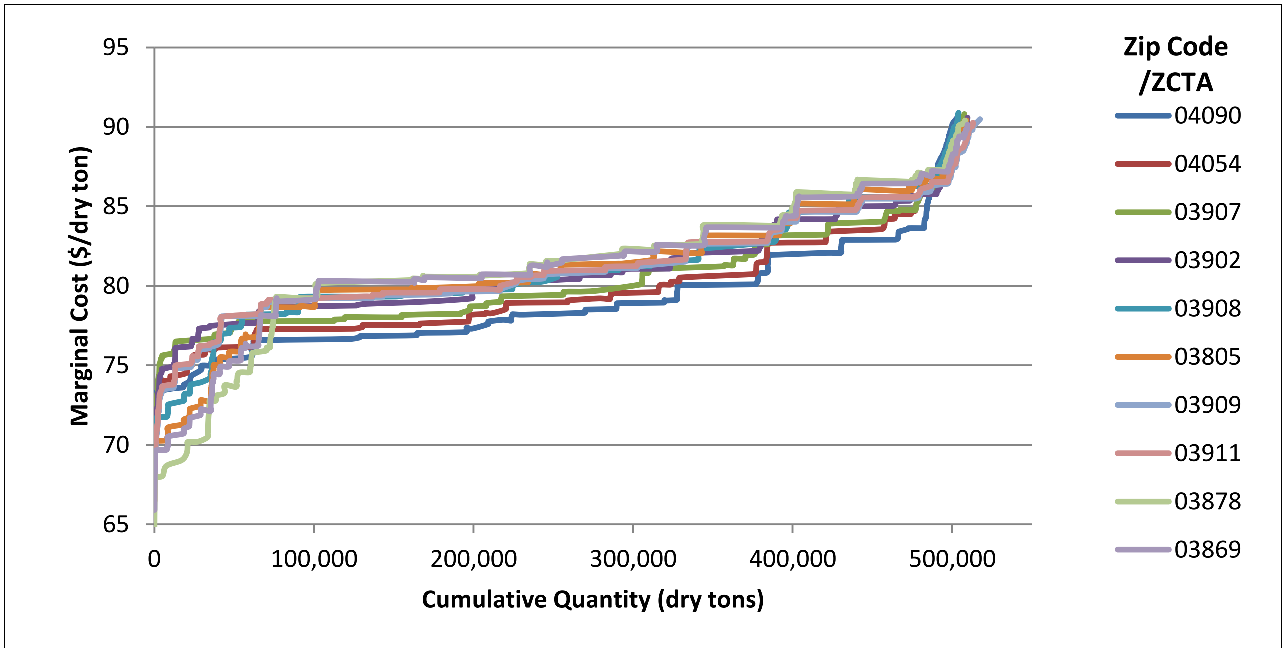

Figure 49. Marginal cost curves for the top ten locations for softwood mill residues in the northern region.

3.2.2 Logging Residues

The logging residues categories included in this BioSAT model final report were total logging residues, total *"at-landing"* and total *"in-woods"* logging residues. For illustration purposes, the maximum quantity available in a bio-basin and the associated total cost (TC), average total cost (ATC), and median marginal cost (MC) in $/dry ton were estimated assuming an annual consumption of one million dry tons and a maximum 160-mile one-way truck haul distance (with dry van trailer storage).

3.2.2.1 Total Logging Residues. -- The top ten ZCTA locations based on least ATC for the northern region total were located in southern West Virginia, southwestern West Virginia, and western New York (Figure 50). ATC ranged from $45.86 to $57.36/dry ton. The median MC ranged from $93.63 to $112.80/dry ton (Table 20, Figure 51).

Table 20. Top ten locations in the northern region for total logging residues based on average total cost (median marginal costs also presented).

Rank	Zip Code/ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	25682	Mingo	WV	Meador	1,448,333	$52,206,806	$52.09	$112.67
2	07890	Sussex	NJ	Branchville	1,086,723	$52,727,017	$45.86	$100.63
3	25608	Mingo	WV	Baisden	1,518,844	$53,122,707	$51.00	$112.80
4	25672	Mingo	WV	Edgarton	1,492,593	$53,749,180	$51.28	$111.80
5	14556	Livingston	NY	Sonyea	1,009,227	$55,945,945	$54.58	$93.63
6	14462	Livingston	NY	Groveland	1,023,830	$56,957,258	$53.45	$93.93
7	25669	Wayne	WV	Crum	1,406,108	$57,493,283	$56.32	$106.51
8	25650	Mingo	WV	Verner	1,718,815	$57,960,034	$57.36	$111.01
9	25688	Mingo	WV	North Matewan	1,515,607	$58,677,521	$52.62	$111.40
10	25678	Mingo	WV	Matewan	1,499,982	$58,718,839	$52.72	$111.30

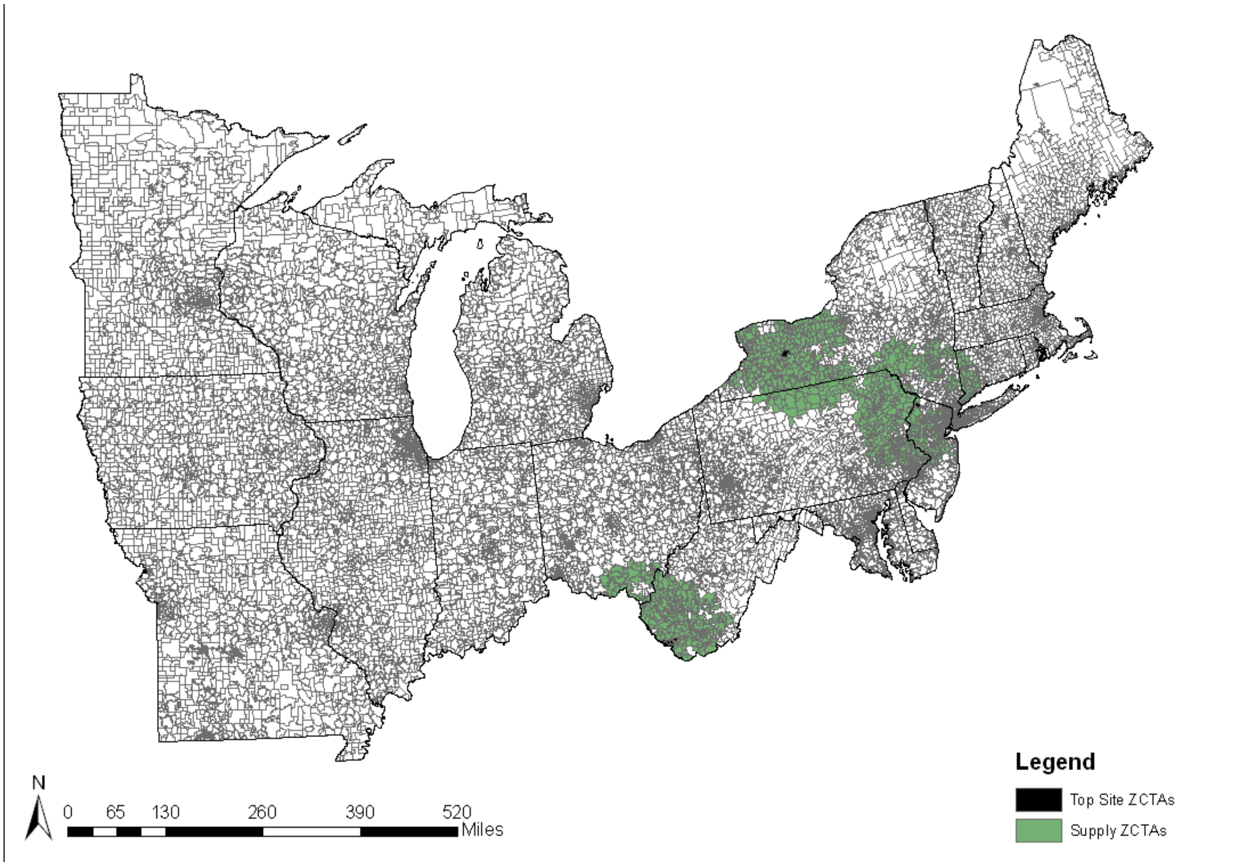

Figure 50. Least cost bio-basins for total logging residues for the northern region.

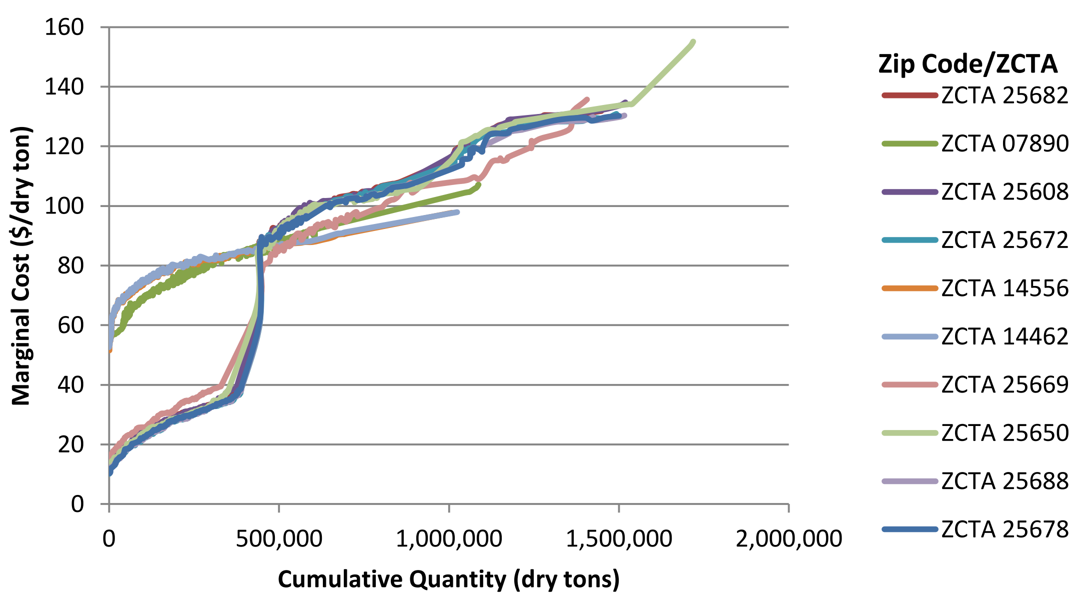

Figure 51. Marginal cost curves for the top ten locations for total logging residues in the northern region.

3.2.2.2 "At-Landing" Logging Residues. -- The top ten ZCTA locations in the northern region for *"at-landing"* logging residues were located in southern West Virginia (Figure 52). ATC ranged from $29.85 to $31.34/dry ton. The median MC ranged from $33.61 to $37.50/dry ton (Table 21, Figure 53).

Table 21. Top ten locations in the northern region for "at-landing" logging residues based on average total cost (median marginal costs also presented).

Rank	Zip Code/ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	25193	Boone	WV	Sylvester	501,035	$14,925,425	$29.85	$34.85
2	25844	Raleigh	WV	Glen Daniel	515,012	$15,096,635	$30.19	$33.72
3	25009	Boone	WV	Ashford	538,218	$15,152,146	$30.30	$34.38
4	25024	Boone	WV	Bloomingrose	531,422	$15,170,799	$30.34	$34.11
5	25181	Boone	WV	Seth	522,498	$15,439,760	$30.88	$34.92
6	25214	Kanawha	WV	Winifrede	514,987	$15,457,175	$30.91	$34.90
7	25067	Kanawha	WV	East Bank	541,601	$15,461,500	$30.92	$33.61
8	25140	Raleigh	WV	Naoma	510,326	$15,605,265	$31.21	$34.93
9	24850	McDowell	WV	Jolo	514,187	$15,647,703	$31.30	$37.50
10	25165	Boone	WV	Racine	543,334	$15,669,798	$31.34	$34.50

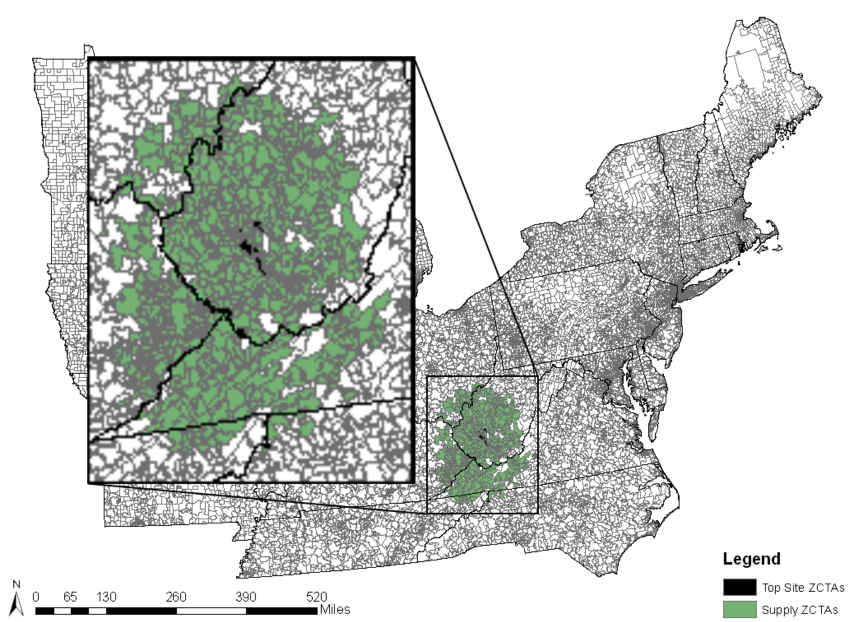

Figure 52. Least cost bio-basins for "at-landing" logging residues for the northern region.

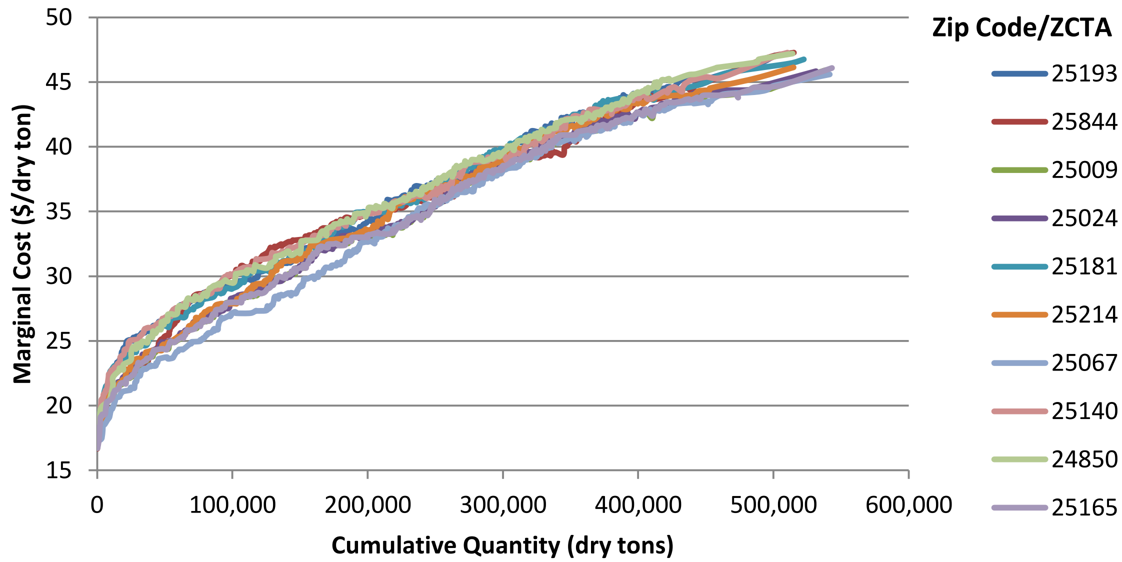

Figure 53. Marginal cost curves for the top ten locations for "at-landing" logging residues in the northern region.

<u>3.2.2.3 "In-Woods" Logging Residues</u>. – The top ten ZCTA locations based on least average total cost in the northern region were located in western Pennsylvania (Figure 54). ATC for *"in-woods"* logging residues ranged from $111.94 to $117.37/dry ton. The median MC ranged from $167.16 to $218.42/dry ton (Table 20, Figure 55).

Table 22. Top ten locations in the northern region for "in-woods" logging residues based on average total cost (median marginal costs also presented).

Rank	Zip Code/ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	15072	Westmoreland	PA	Pricedale	1,000,500	$112,521,521	$112.38	$169.29
2	16695	Bedford	PA	Woodbury	1,037,589	$112,638,041	$111.94	$215.81
3	15695	Westmoreland	PA	Wyano	1,001,177	$114,733,463	$114.40	$170.49
4	15539	Bedford	PA	Fishertown	1,039,020	$115,930,419	$115.52	$216.07
5	16670	Bedford	PA	Queen	1,038,430	$117,457,587	$112.91	$218.42
6	15534	Bedford	PA	Buffalo Mills	1,029,396	$117,720,931	$116.40	$218.16
7	15927	Cambria	PA	Colver	1,016,006	$117,723,836	$116.89	$167.28
8	15960	Cambria	PA	Twin Rocks	1,001,483	$117,788,866	$117.37	$168.32
9	15957	Indiana	PA	Strongstown	1,003,654	$118,033,416	$116.99	$168.19
10	15490	Fayette	PA	White	1,025,566	$118,041,730	$114.54	$167.16

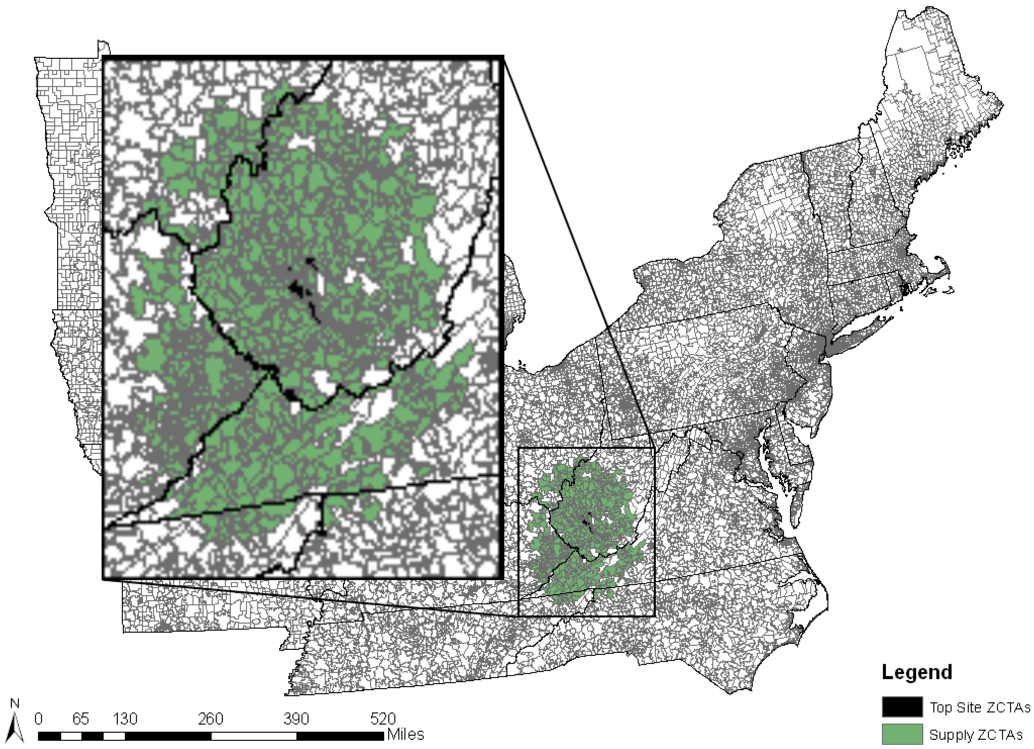

Figure 54. Least cost bio-basins for “in-woods” logging residues for the northern region.

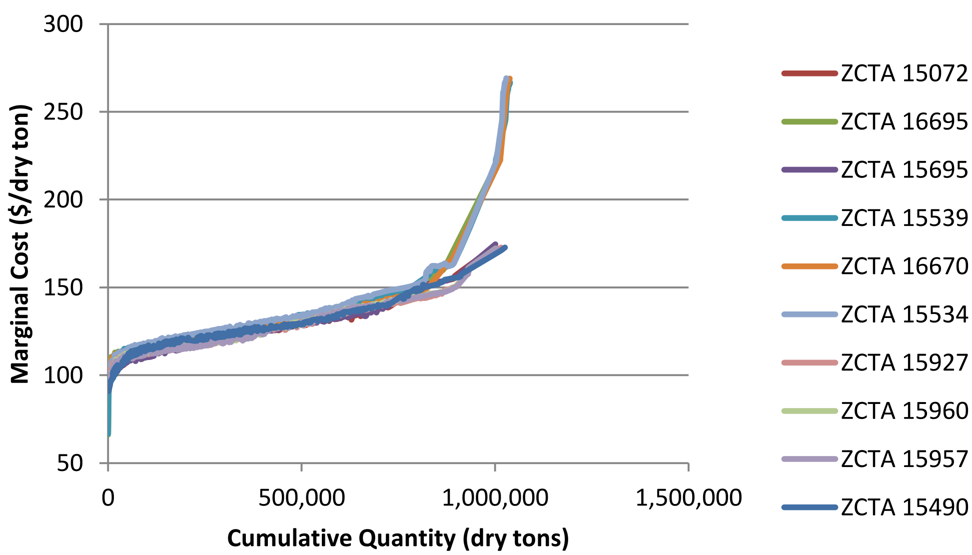

Figure 55. Marginal cost curves for the top ten locations for “in-woods” logging residues in the northern region.

3.2.3 Agricultural Residues

Potential agricultural residues in the northern region of the 33-state study region are presented in this section of the report for corn stover and wheat straw with an annual consumption of at least one million dry tons within a 120-mile one-way truck haul distance (with flatbed trailer). The total cost (TC), average total cost (ATC), and median marginal cost (MC) in $/dry ton were estimated.

<u>3.2.3.1 Corn Stover</u>. -- The top ten ZCTA locations in the northern region for corn stover were located in southern Minnesota, western Indiana, southwestern Minnesota, northwestern Illinois, northeastern Illinois, and northeastern Iowa (Figure 56). Costs for corn stover in the northern region were generally lower than costs for this same feedstock in the southern region. ATC ranged from $14.03 to $15.14/dry ton. The median MC ranged from $18.33 to $20.10/dry ton (Table 23, Figure 57).

Table 23. Top ten locations in the northern region for corn stover based on average total cost (median marginal costs also presented).

Rank	Zip Code/ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	56145	Cottonwood	MN	Jeffers	20,824,309	$14,848,883	$14.79	$18.94
2	47902	Tippecanoe	IN	Lafayette	19,200,489	$14,883,108	$14.03	$19.15
3	47903	Tippecanoe	IN	Lafayette	19,200,489	$14,883,108	$14.03	$19.15
4	56271	Swift	MN	Murdock	12,633,908	$14,888,581	$14.21	$20.10
5	61345	Bureau	IL	Neponset	23,518,928	$15,003,064	$14.79	$19.05
6	56162	Martin	MN	Ormsby	22,294,841	$15,069,111	$14.23	$19.30
7	60420	Livingston	IL	Dwight	22,882,272	$15,339,978	$15.14	$19.25
8	52043	Clayton	IA	Elkader	16,672,148	$15,422,703	$15.07	$18.71
9	56074	Nicollet	MN	Nicollet	19,660,219	$15,465,966	$14.96	$19.16
10	52168	Winneshiek	IA	Spillville	18,999,284	$15,477,308	$14.97	$18.33

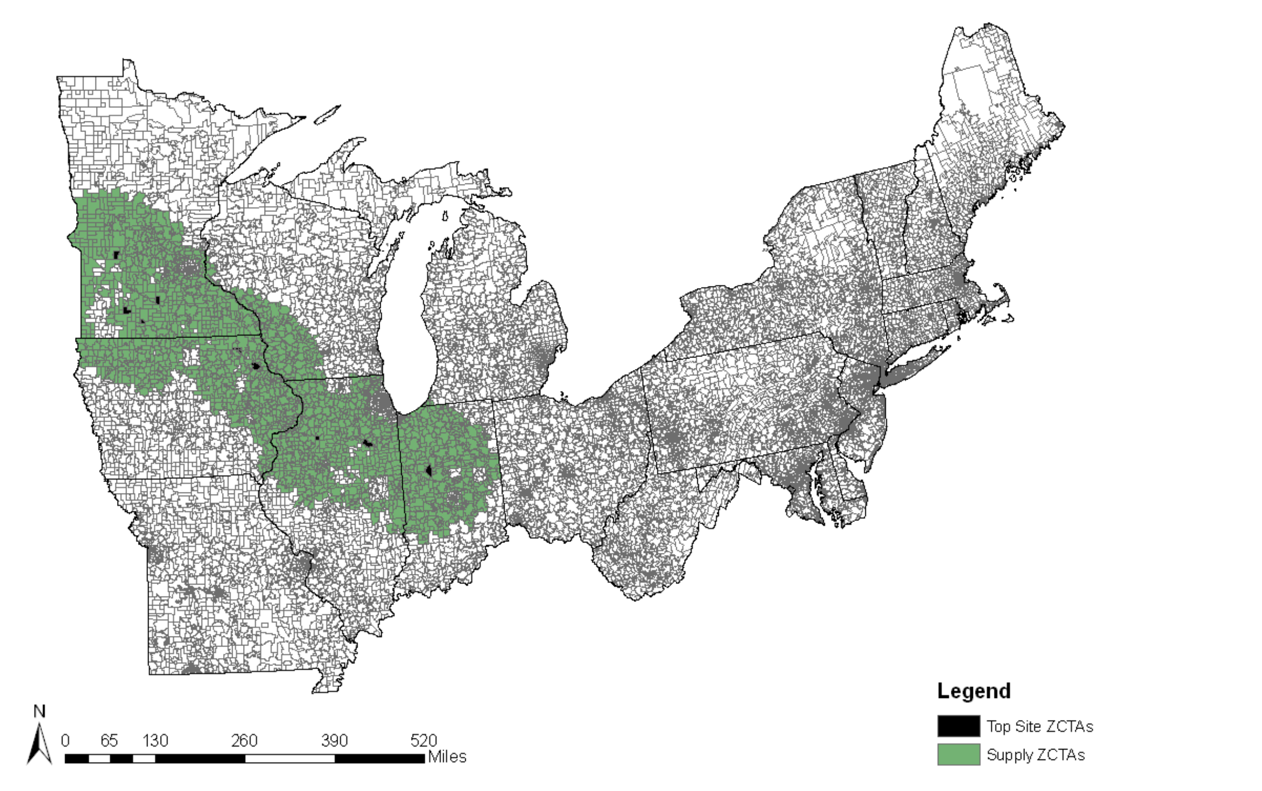

Figure 56. Least cost bio-basins for corn stover for the northern region.

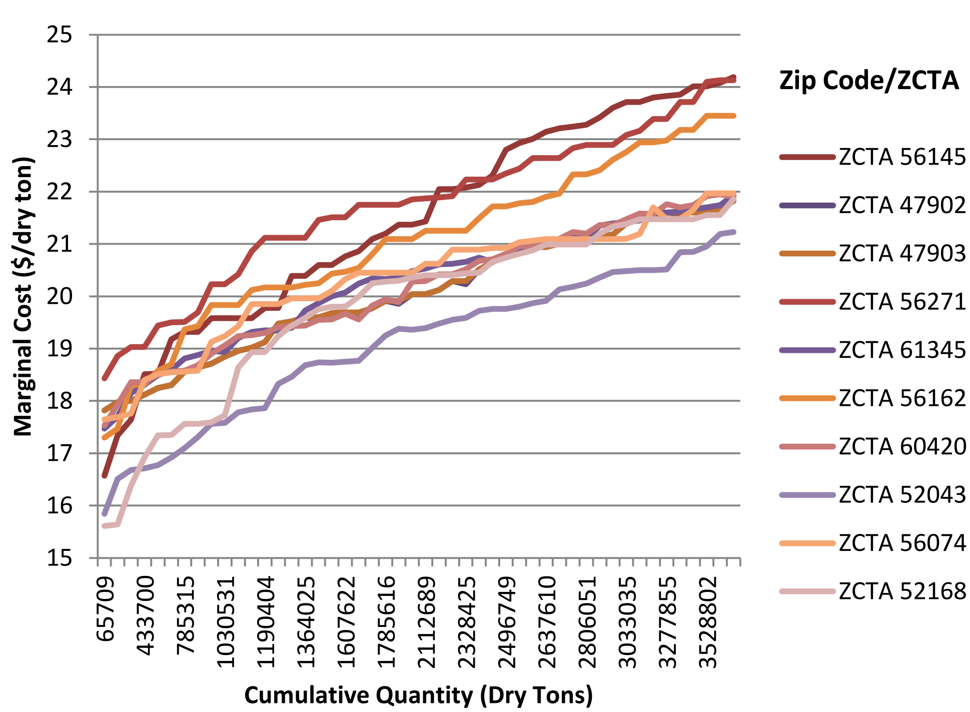

Figure 57. Marginal cost curves for least cost bio-basins for each state for corn stover in the northern region.

<u>3.2.3.2 Wheat Straw</u>. -- The top ten ZCTA locations in the northern region for wheat straw were located in southern Missouri, northwestern Indiana, southern Ohio, eastern Michigan, western Michigan, and northern Minnesota (Figure 58). ATC for wheat straw ranged from $30.82 to $39.78/dry ton. The median MC ranged from $35.57 to $46.71/dry ton (Table 24, Figure 59).

Table 24. Top ten locations in the northern region for wheat straw based on average total cost (median marginal costs also presented).

Rank	Zip Code/ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
1	65555	Texas	MO	Raymondville	1,035,240	$14,820,986	$33.01	$46.71
2	65548	Howell	MO	Mountain View	1,146,306	$17,310,428	$33.47	$43.51
3	47943	Jasper	IN	Fair Oaks	1,023,654	$17,659,731	$36.86	$40.57
4	45681	Ross	OH	South Salem	1,049,089	$19,969,070	$37.22	$38.82
5	48759	Huron	MI	Sebewaing	1,010,671	$20,065,511	$39.78	$37.94
6	65564	Texas	MO	Solo	1,196,450	$20,222,939	$30.91	$46.03
7	49315	Kent	MI	Byron Center	1,331,318	$20,934,869	$30.82	$35.66
8	65775	Howell	MO	West Plains	1,094,543	$21,190,654	$39.07	$42.74
9	56636	Itasca	MN	Deer River	1,147,877	$21,887,543	$33.79	$40.97
10	49516	Kent	MI	Grand Rapids	1,470,735	$23,477,510	$32.61	$35.57

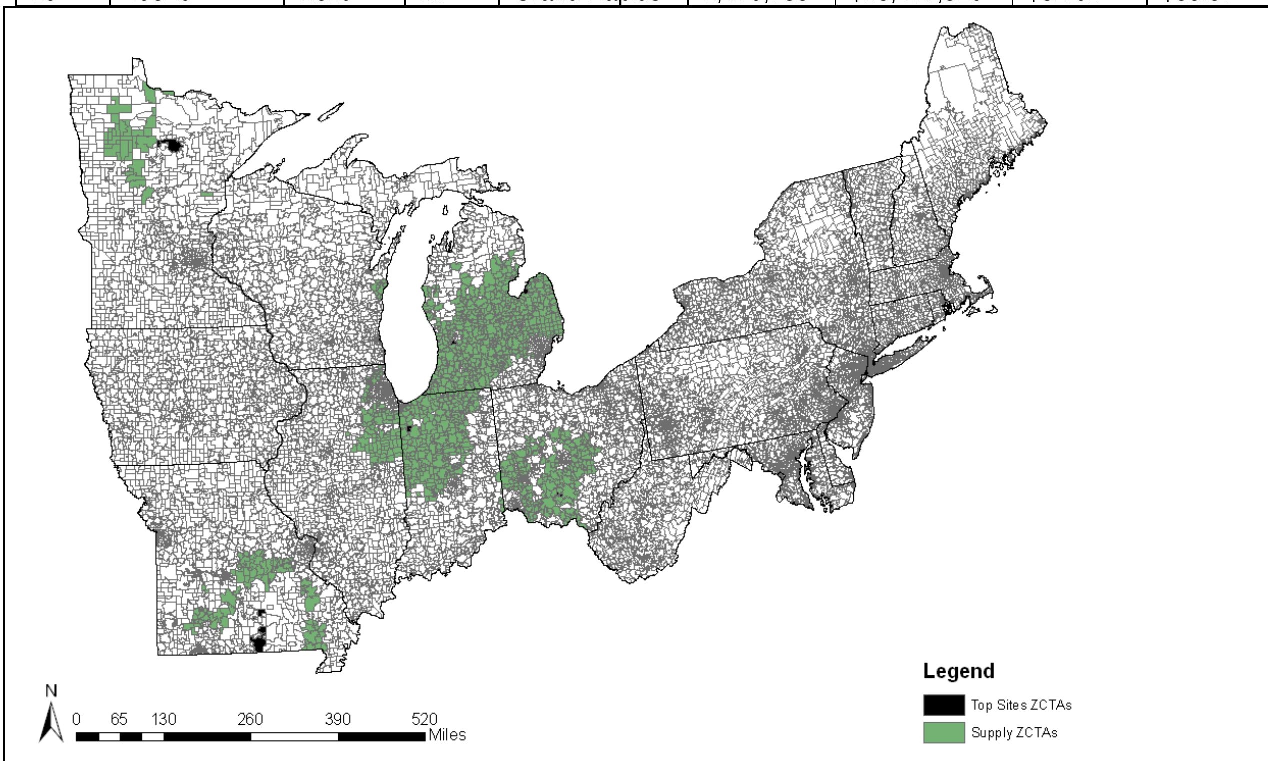

Figure 58. Least cost bio-basins for wheat straw for the northern region.

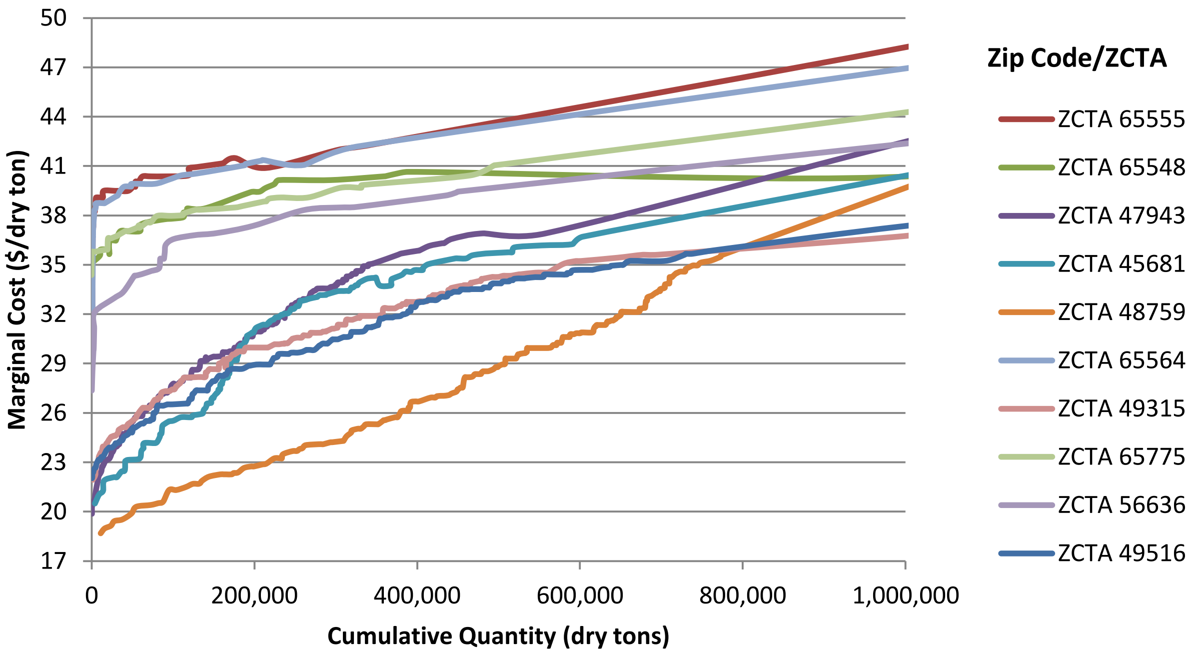

Figure 59. Marginal cost curves for least cost bio-basins for each state for wheat straw in the northern region.

3.2.4 Merchantable Trees (Roundwood)

The merchantable trees (roundwood) categories for pulpwood and sawtimber in the northern region available in the BioSAT model were: lowland hardwood, mixed natural softwood and hardwood, natural softwood, pine plantation, and upland hardwoods. As an illustration for this report, the maximum quantity available in a bio-basin and the associated total cost (TC), average total cost (ATC), and median marginal cost (MC) in $/dry ton were estimated for the northern region for "*upland hardwood pulpwood*" for *"gross growth."* The costs estimates were derived assuming a minimum annual consumption of pulpwood of at least 0.5 million dry tons. The bio-basins were constructed using a maximum 80-mile one-way truck haul distance with short-log trailers. Illinois, Maine, Massachusetts, and Rhode Island did not have any bio-basins with sufficient upland hardwood pulpwood trees quantity with an annual consumption of up to 0.5 million dry tons and are not illustrated in this report. More detail for the 60 possible combinations of roundwood feedstock types with combinations of harvesting and haul distance scenarios are available on the website www.biosat.net under the "Guided Assessment" link.

Least cost bio-basins in the northern region for "*upland hardwood pulpwood"* occurred in Delaware, Indiana, Ohio and Pennsylvania. The median MC ranged ranged from $28.73 to $56.01/dry ton (Table 25). Bio-basins with the largest concentrations of pulpwood in the upland hardwood pulpwood category were in Maryland, Missouri, and Wisconsin. Not all states for this feedstock type had feasible annual consumptions of to 0.5 million dry tons (Figure 60). Missouri had a large concentration of upland hardwood pulpwood but also had the most expensive MC relative to other states in the northern region. Many of the bio-basins in the northern region were non-concentric (Figures 61 to 75).

Table 25. Least cost bio-basins for upland hardwood pulpwood for each state in the northern region based average total cost (median marginal costs also presented).

Zip Code/ZCTA	County	State	City	Annual Quantity Available (dry tons)	Total Cost	Average Total Cost ($/dry ton)	Median MC ($/dry ton)
Connecticut							
06794	Litchfield	CT	Washington Depot	217,914	$7,185,183	$32.61	$41.27
Delaware							
19701	New Castle	DE	Bear	326,083	$9,965,220	$30.56	$34.33
Indiana							
46160	Brown	IN	Morgantown	421,815	$13,849,509	$32.83	$34.69
Iowa							
52101	Winneshiek	IA	Decorah	469,100	$17,024,031	$36.72	$47.18
Maryland							
21788	Frederick	MD	Thurmont	569,833	$13,522,822	$28.73	$35.81
Minnesota							
55932	Wabasha	MN	Elgin	433,766	$15,088,638	$34.79	$44.19
Missouri							
65717	Wright	MO	Norwood	1,117,378	$60,283,801	$53.95	$56.01
New Hampshire							
03467	Cheshire	NH	Westmoreland	20,685	$823,298	$39.80	$42.28
New Jersey							
07461	Sussex	NJ	Sussex	244,295	$8,019,163	$32.83	$38.67
New York							
12771	Orange	NY	Port Jervis	247,403	$8,233,389	$33.28	$38.54
Ohio							
43725	Guernsey	OH	Cambridge	503,010	$16,280,270	$32.37	$34.99
Pennsylvania							

17004	Mifflin	PA	Belleville	43,944	$1,150,995	$26.19	$36.21
Vermont							
05775	Rutland	VT	West Pawlet	109,046	$3,704337	$33.97	$37.81
West Virginia							
25699	Wayne	WV	Wilsondale	514,639	$21,562,458	$41.90	$42.96
Wisconsin							
54602	La Crosse	WI	La Crosse	660,420	$26,641,492	$40.34	$46.29

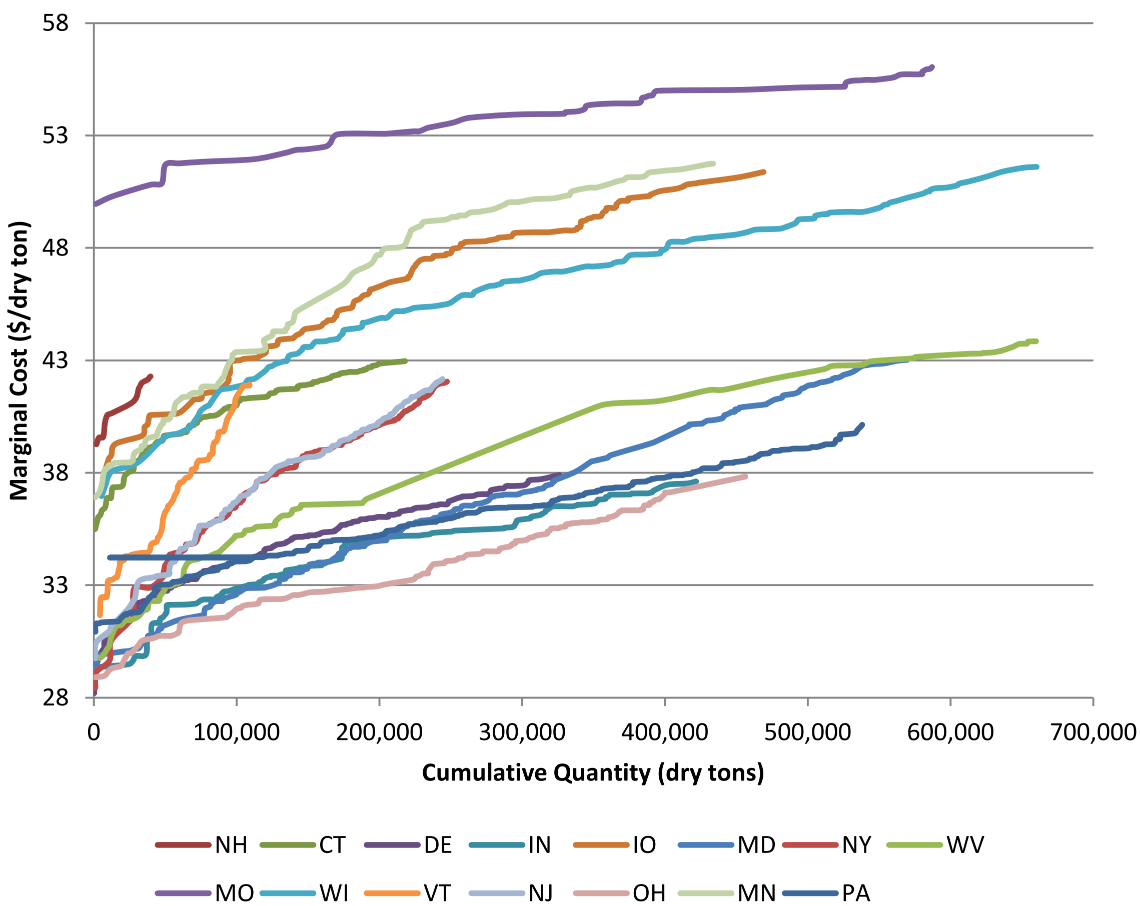

Figure 60. Marginal cost curves for least cost bio-basins for each state for upland hardwoods in the northern region.

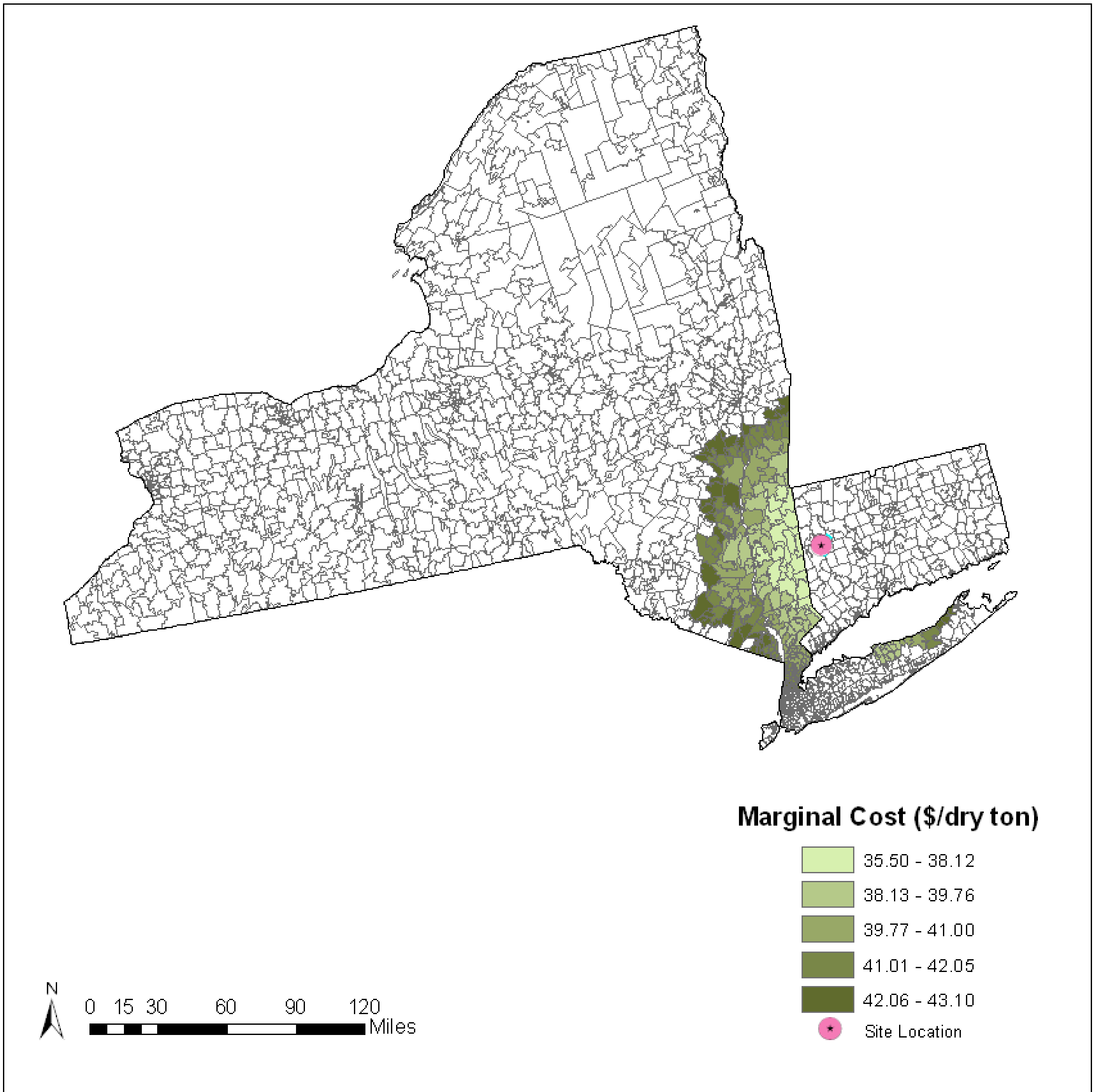

Figure 61.Marginal cost by ZCTA for upland hardwood pulpwood in CT (Washington Depot CT, 06794 zip code).

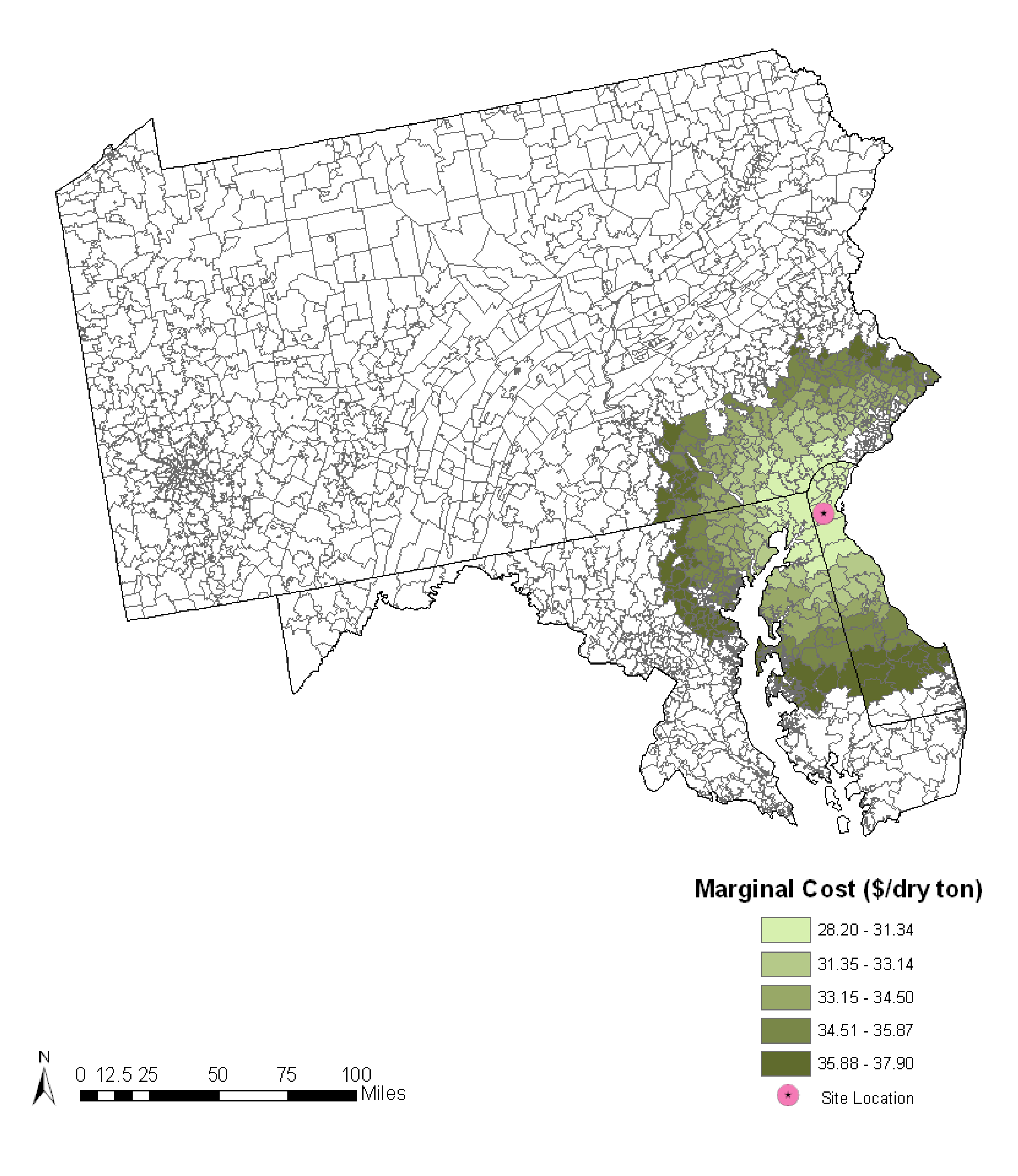

Figure 62. Marginal cost by ZCTA for upland hardwood pulpwood in DE (Bear, DE, 19701 zip code).

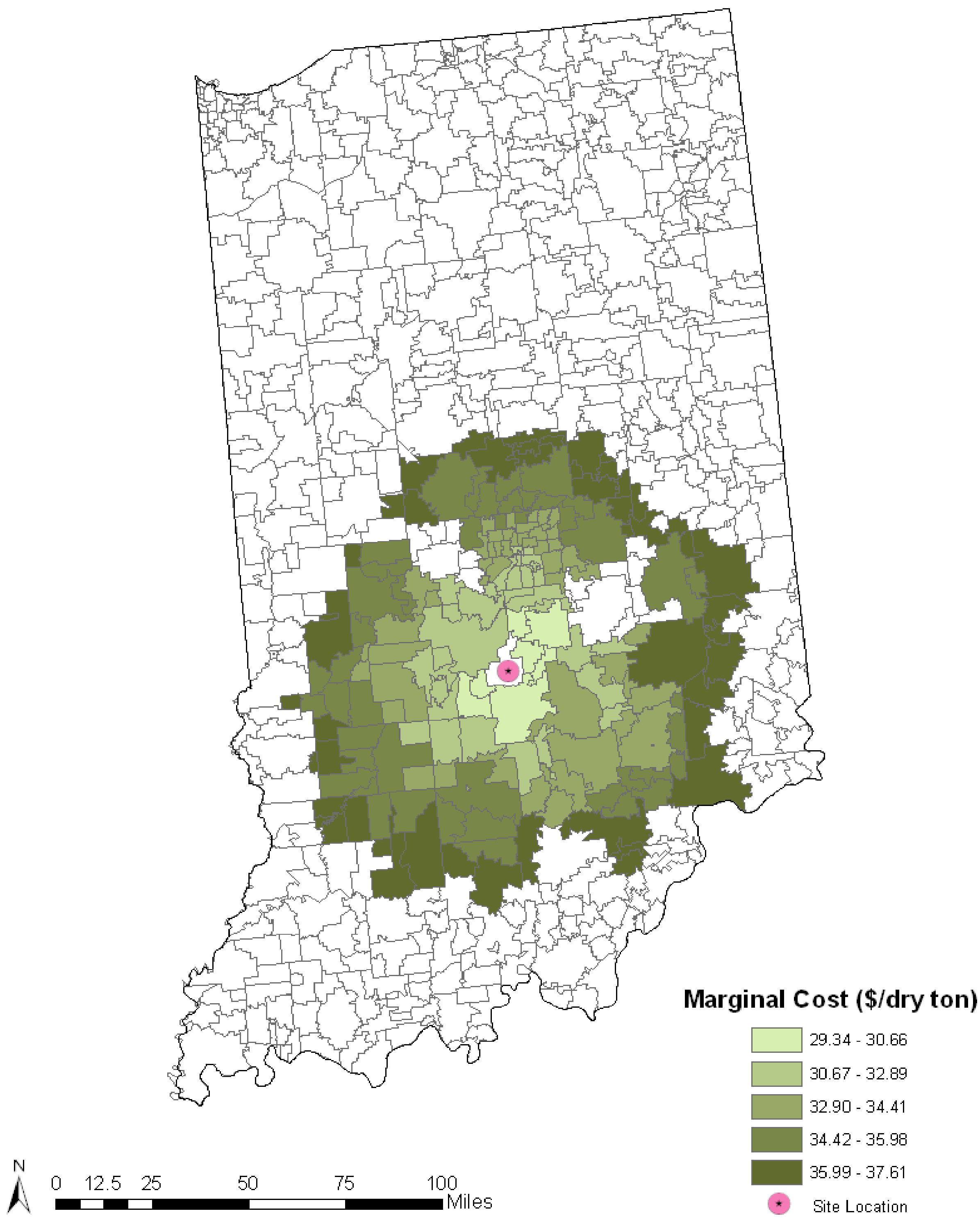

Figure 63. Marginal cost by ZCTA for upland hardwood pulpwood in IN (Morgantown, IN, 46160 zip code).

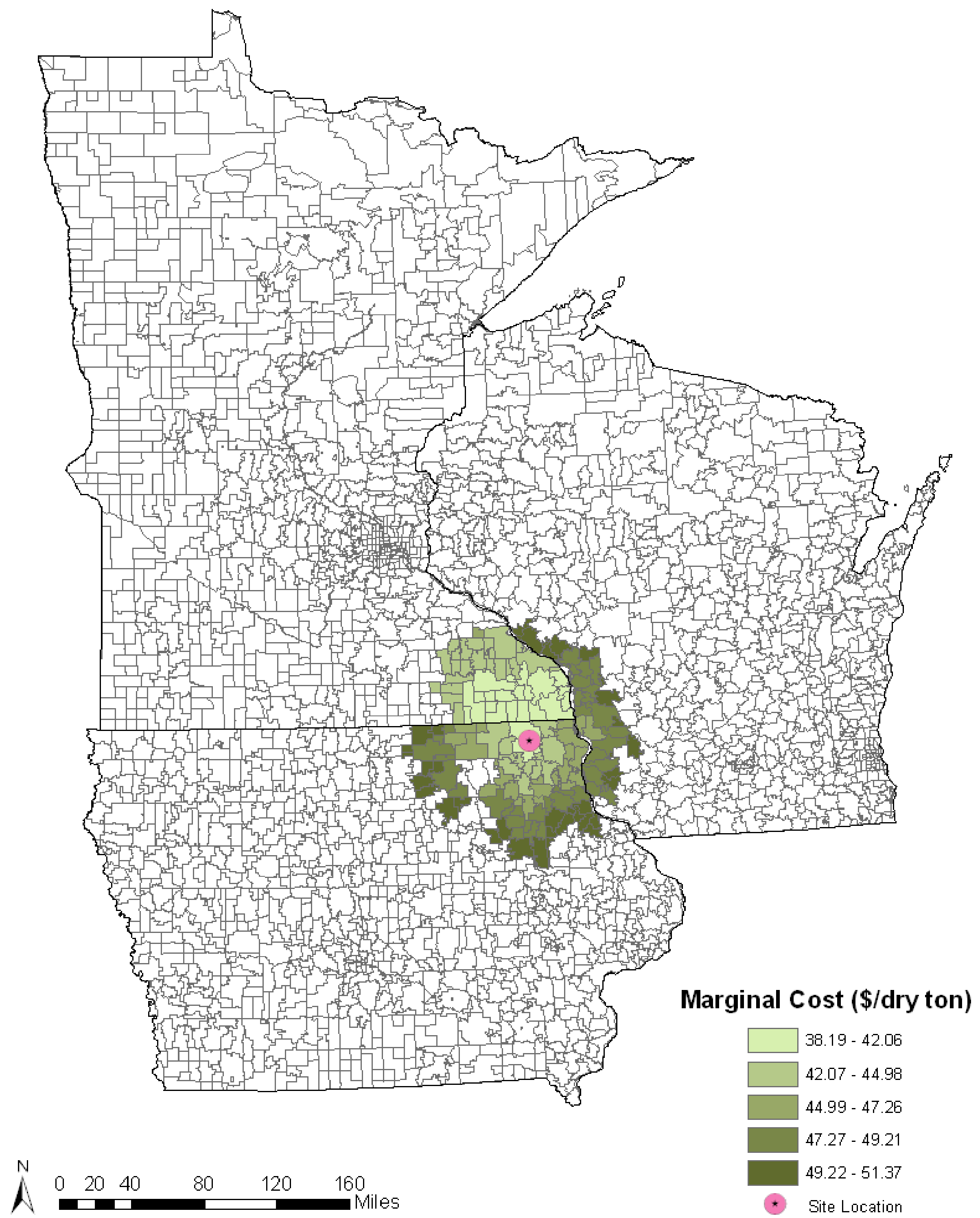

Figure 64. Marginal cost by ZCTA for upland hardwood pulpwood in IA (Decorah, IA, 52101 zip code).

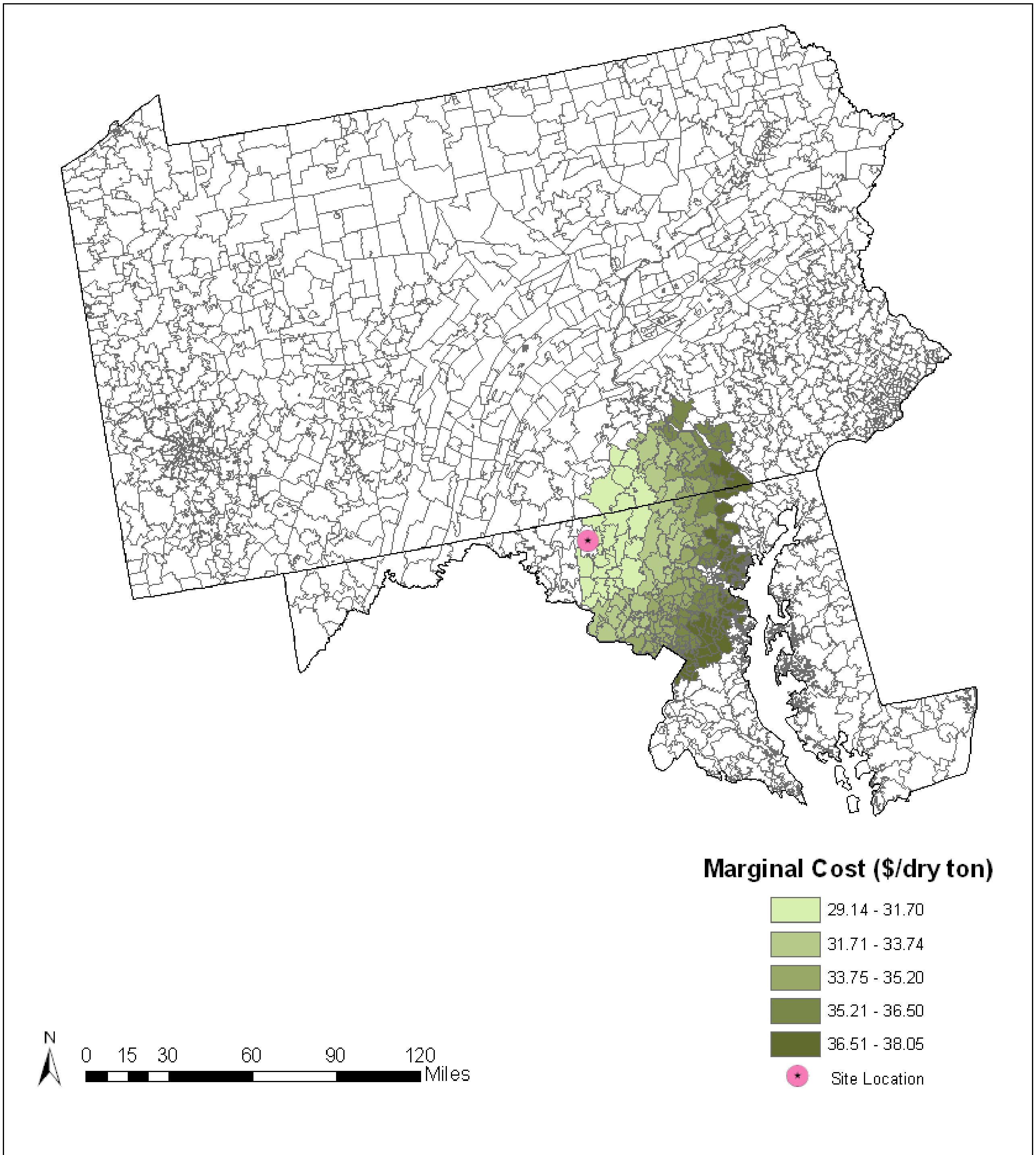

Figure 65. Marginal cost by ZCTA for upland hardwood pulpwood in MD (Thurmont, MD, 21788 zip code).

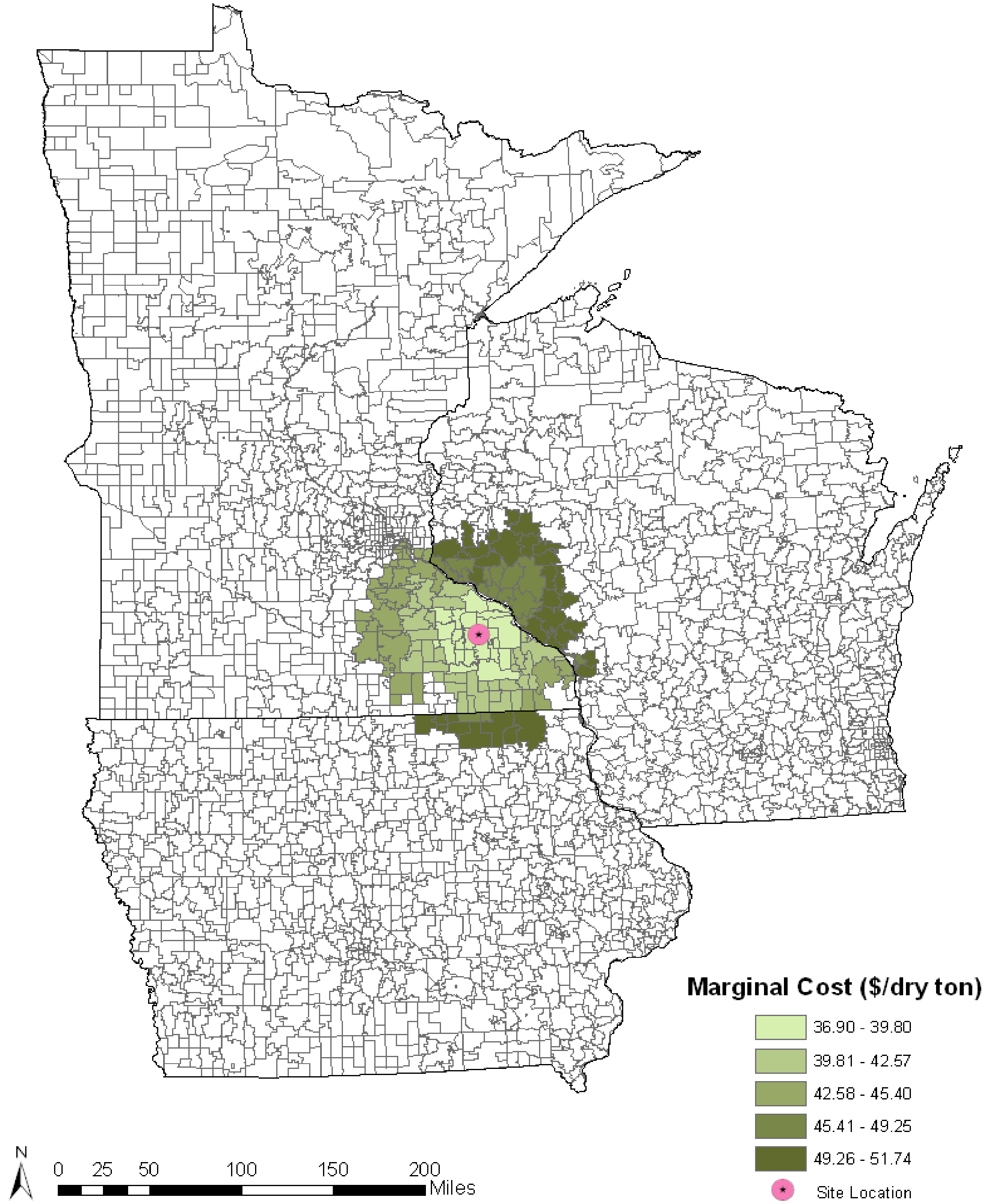

Figure 66. Marginal cost by ZCTA for upland hardwood pulpwood in MN (Elgin, MN 55932 zip code).

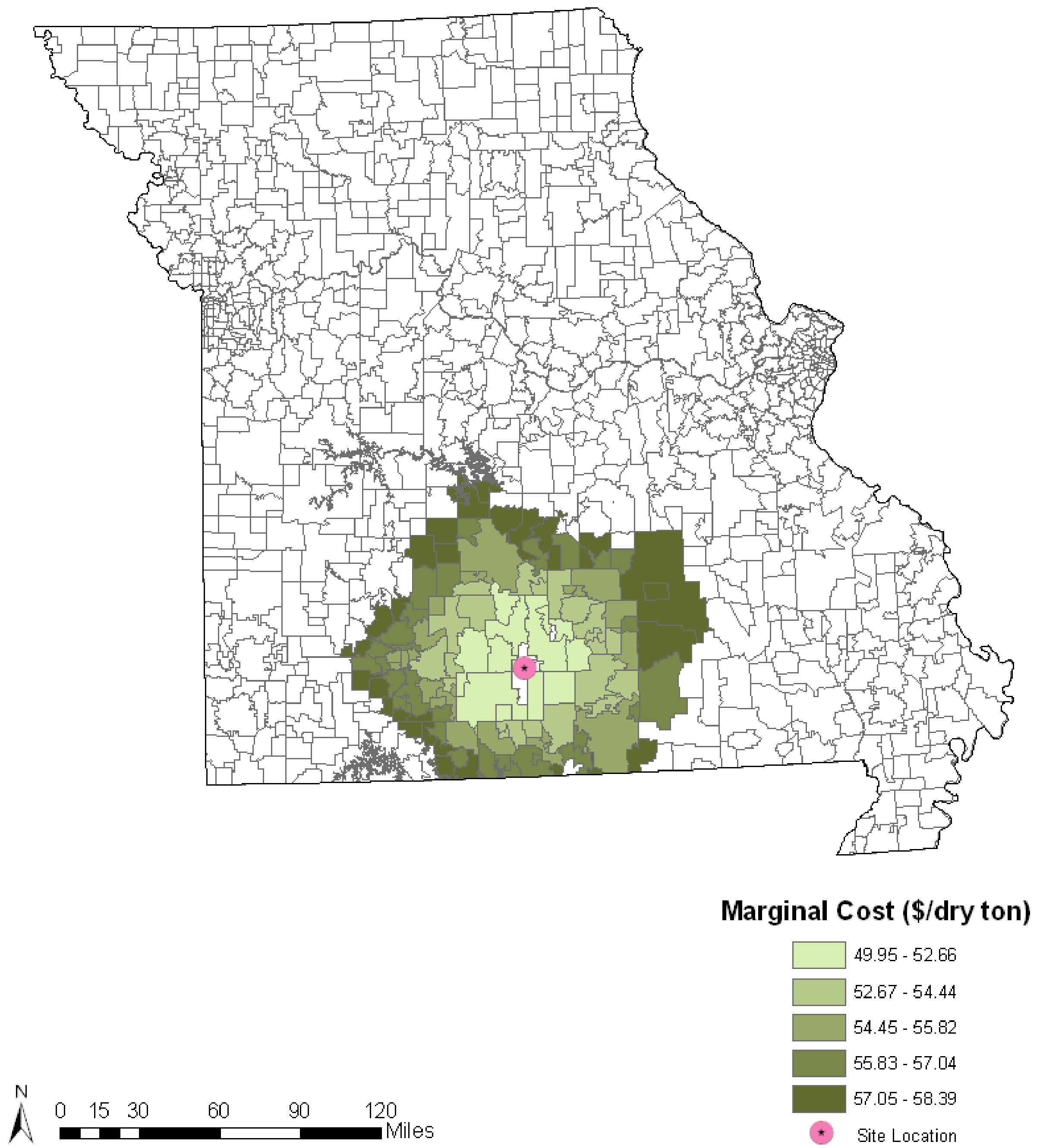

Figure 67. Marginal cost by ZCTA for upland hardwood pulpwood in MO (Norwood, MO, 65717 zip code).

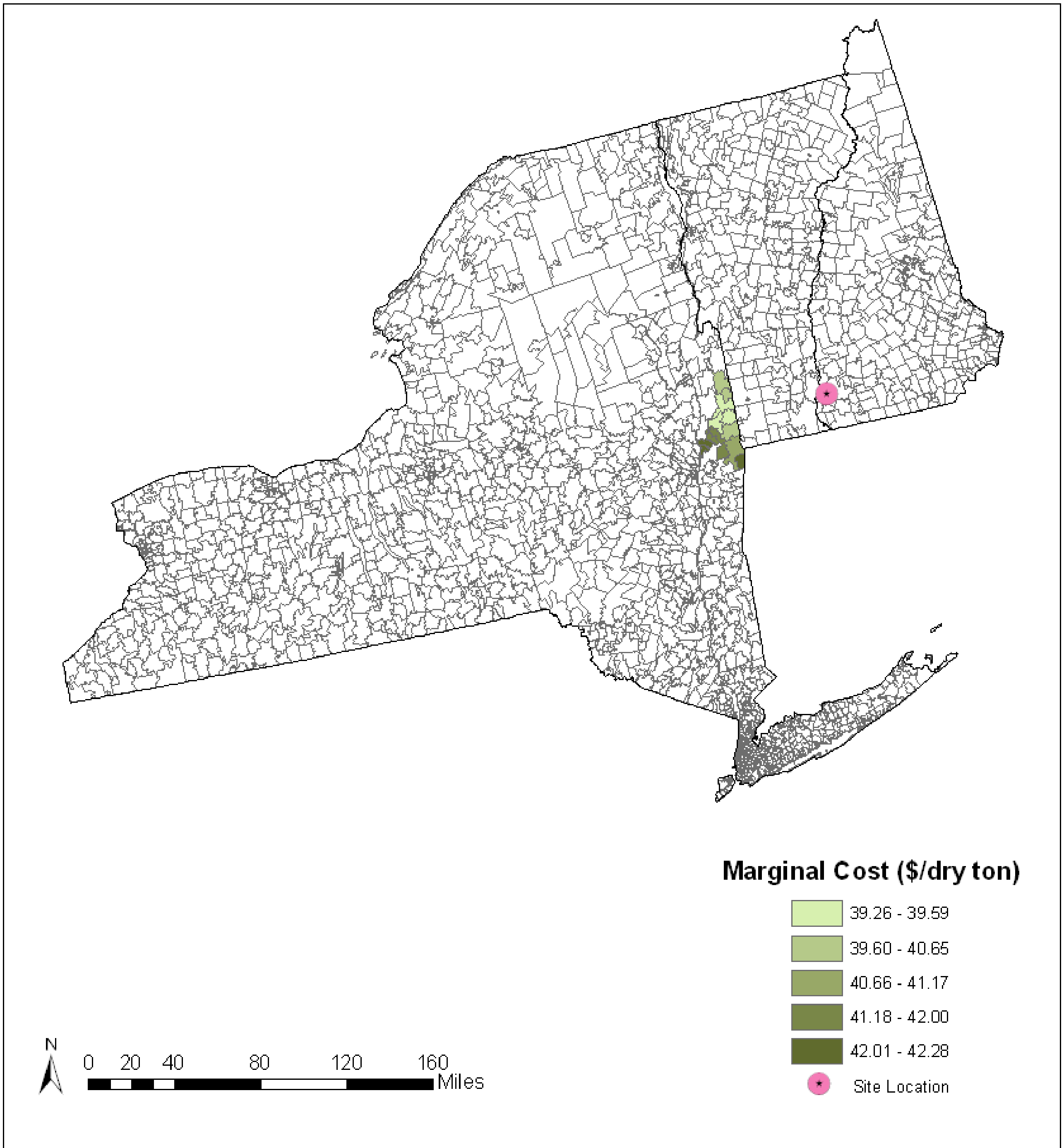

Figure 68. Marginal cost by ZCTA for upland hardwood pulpwood in NH (Westmoreland, NH, for the 03467 zip code).

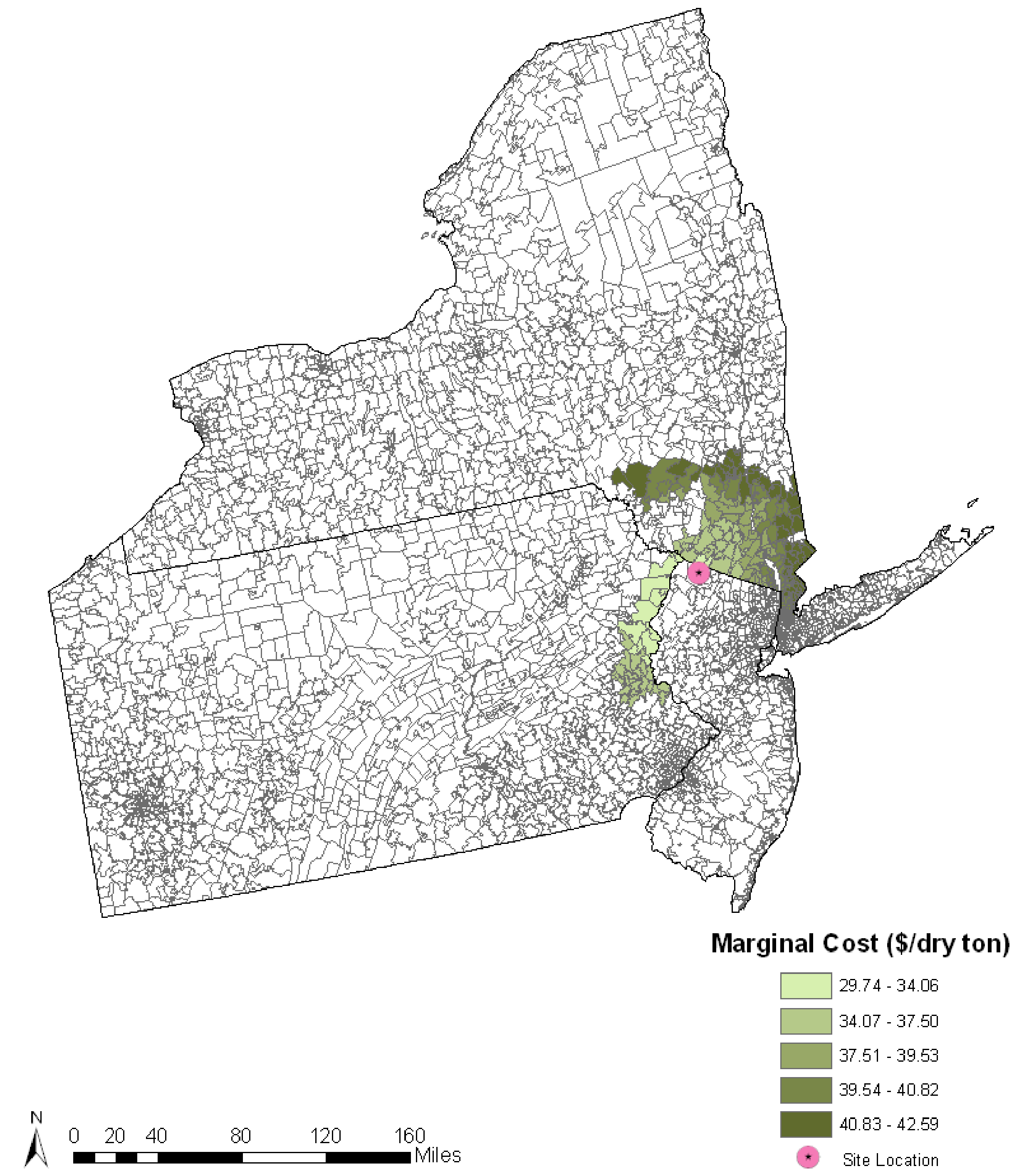

Figure 69. Marginal cost by ZCTA for upland hardwood pulpwood in NJ (Sussex, NJ, 07461 zip code).

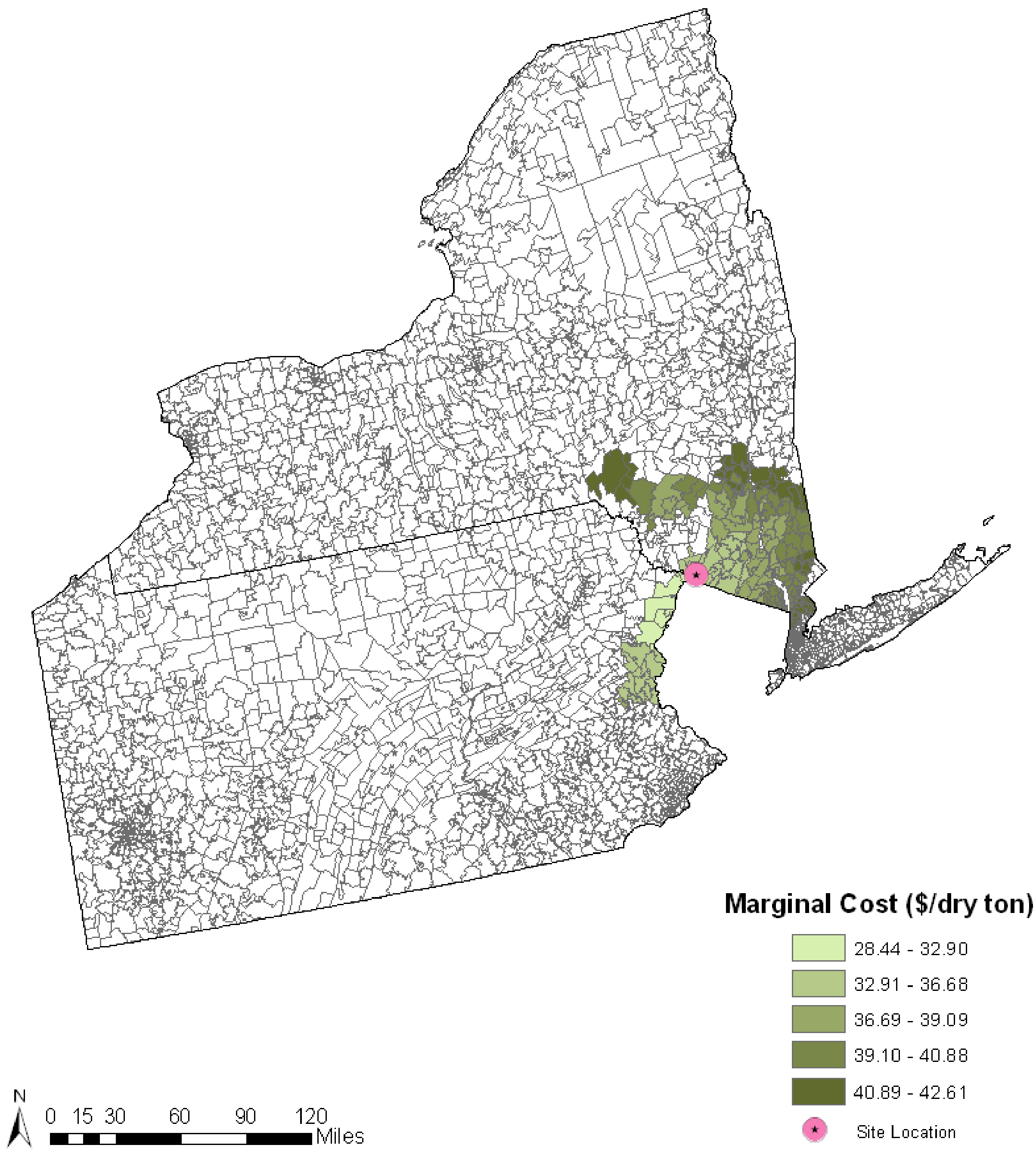

Figure 70. Marginal cost by ZCTA for upland hardwood pulpwood in NY (Port Jervis, NY, 12771 zip code).

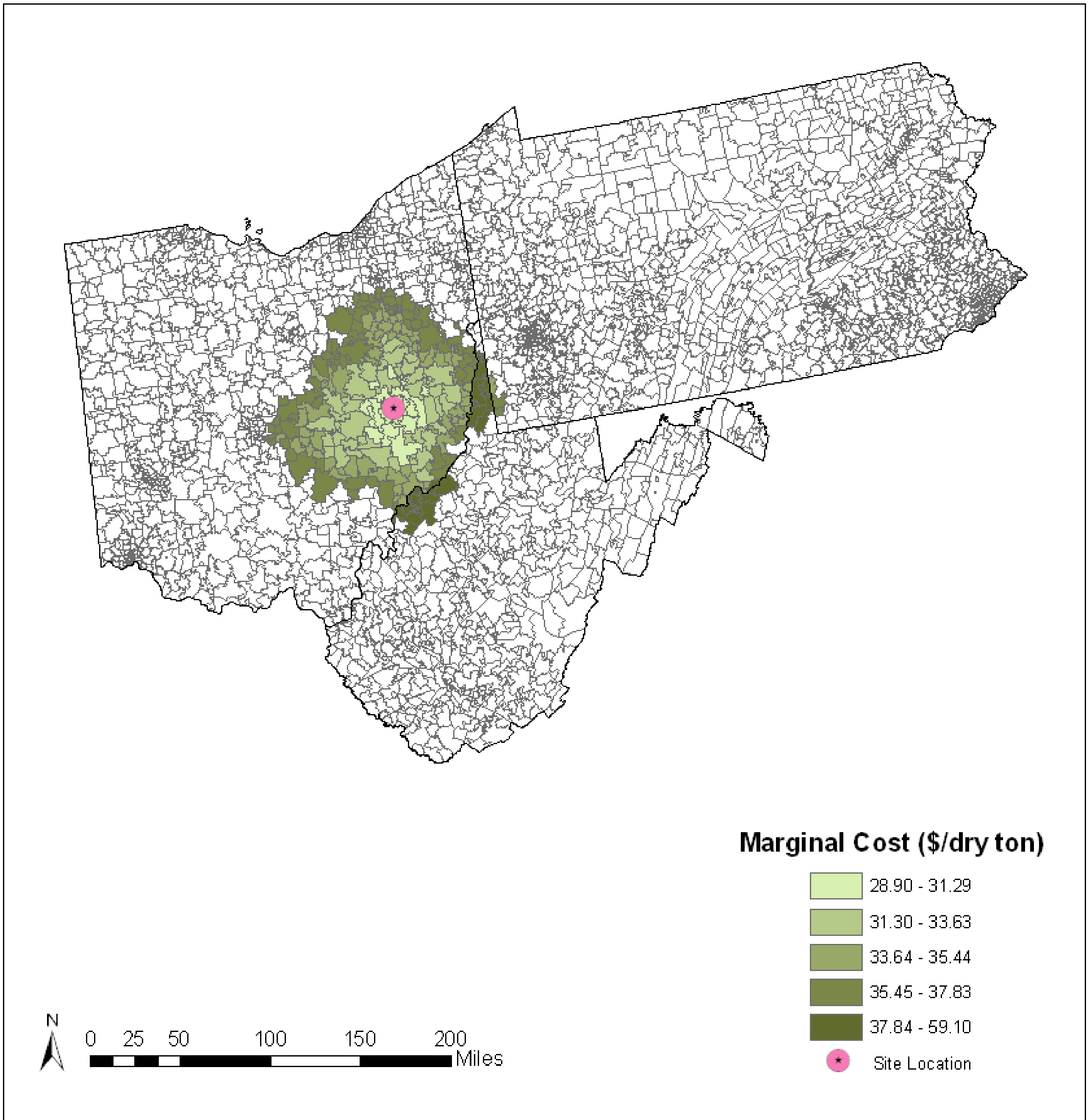

Figure 71. Marginal cost by ZCTA for upland hardwood pulpwood in OH (Cambridge, OH, 43725 zip code).

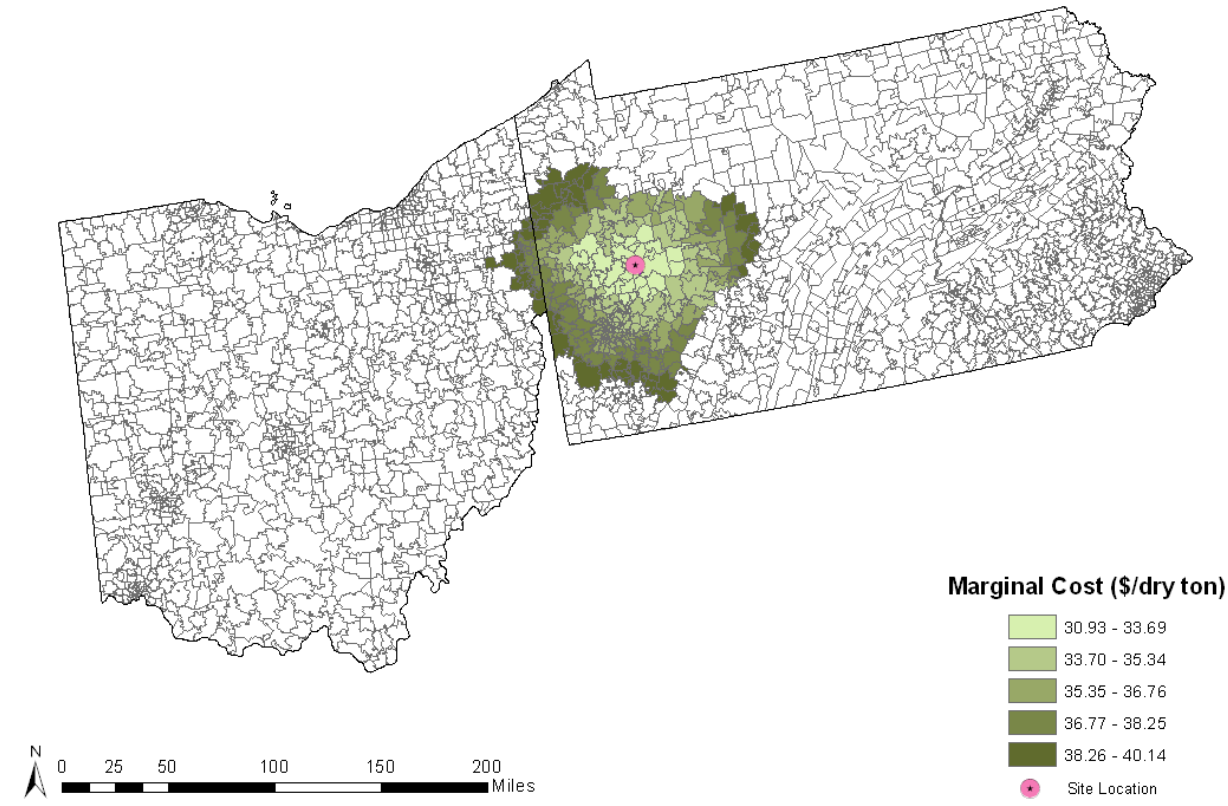

Figure 72. Marginal cost by ZCTA for upland hardwood pulpwood in PA (Worthington, PA, 16262 zip code).

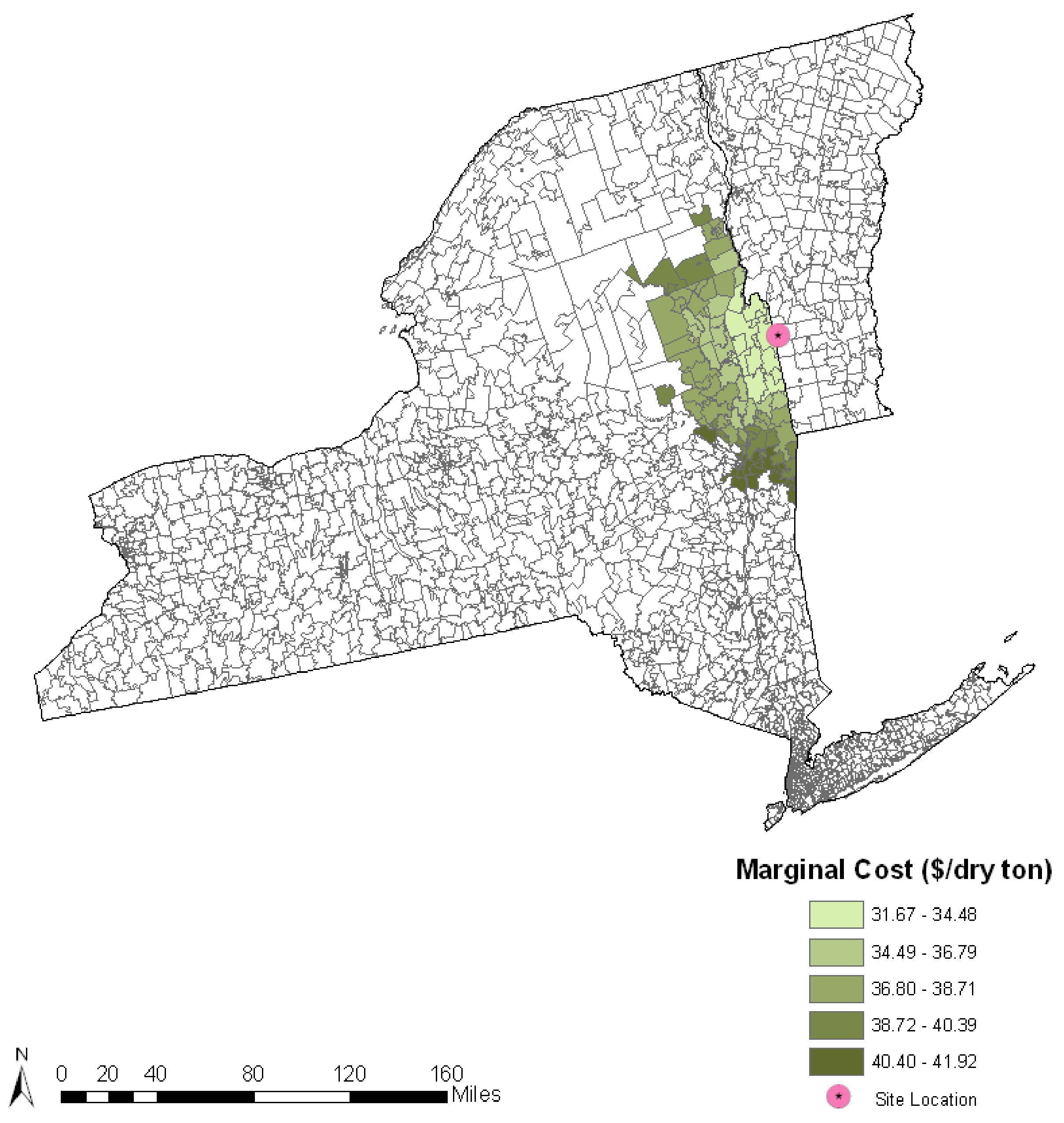

Figure 73. Marginal cost by ZCTA for upland hardwood pulpwood in VT (West Pawlett, VT, 05775 zip code).

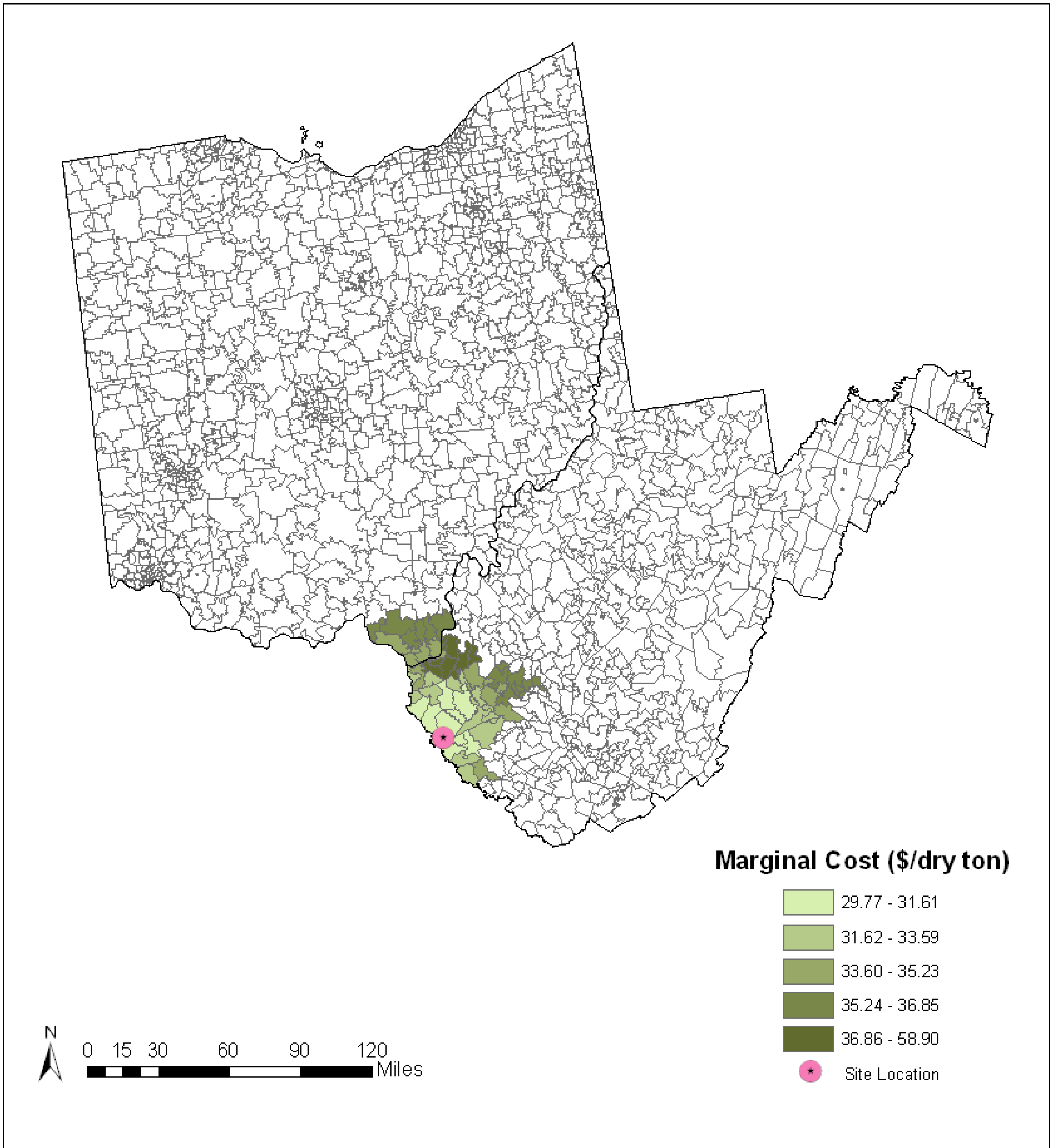

Figure 74. Marginal cost by ZCTA for upland hardwood pulpwood in WV (Wislondale, WV, 25699 zip code).

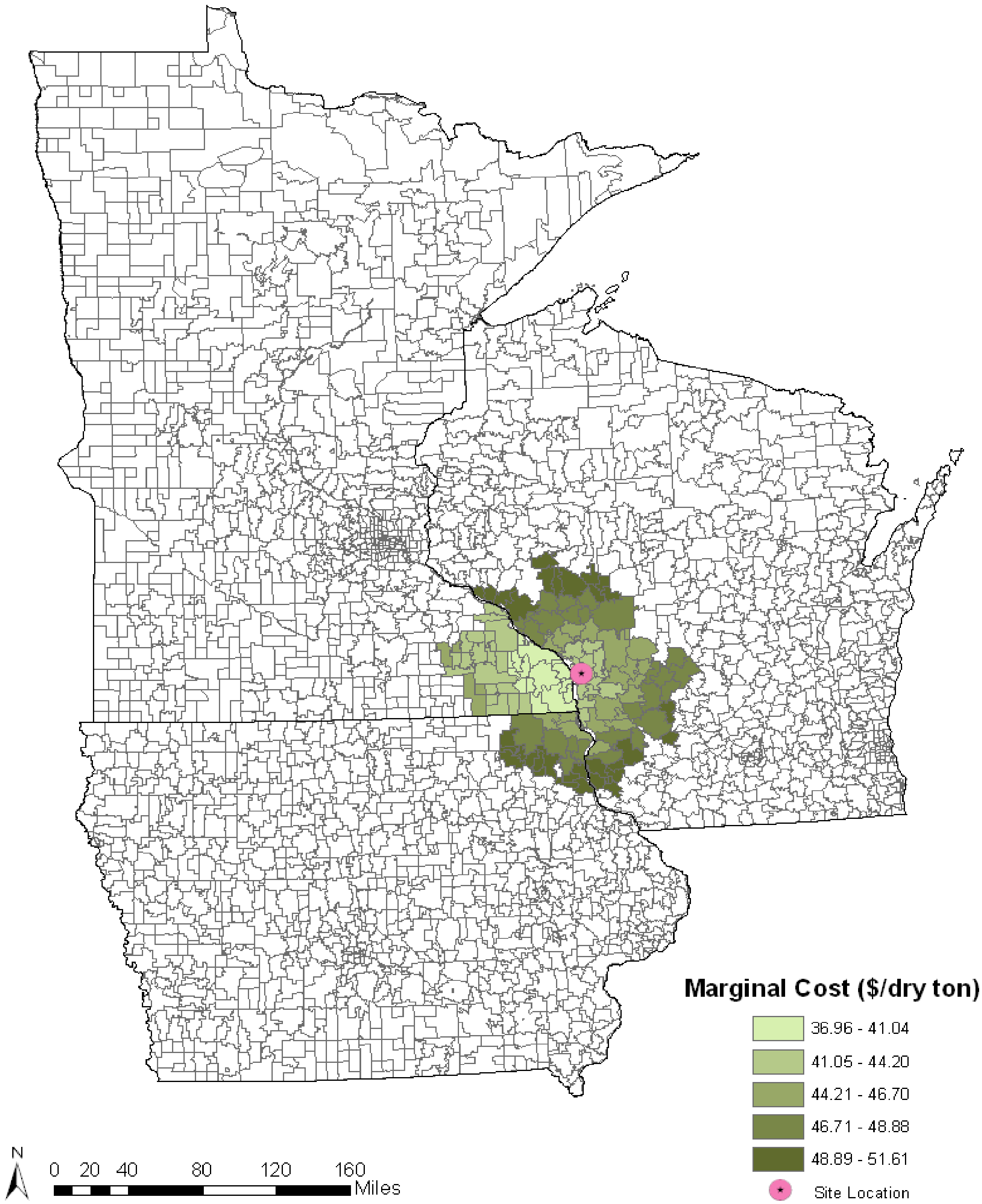

Figure 75. Marginal cost by ZCTA for upland hardwood pulpwood in WI (La Crosse, WI, 54602 zip code).

4. Concluding Remarks

The rationale for this research was driven by the United States continued dependence on imported oil for energy which is projected to increase by 40% by 2020. Enhancing the use of alternative energy sources will reduce economic and national security vulnerability from imported petroleum-based products. The goal of the study was to advance the science of modeling the supply chain of cellulosic feedstocks in a geo-spatial context. The significant contribution of this research was improved modeling of the cellulosic feedstock supply chain and estimation of resources costs, harvesting costs, and transportation costs for 84 different types of cellulosic feedstocks. Another significant contribution was estimating the producers' supply curves (marginal cost curves) and improving the imagery intelligence of bio-basins associated with these supply curves. Estimating the costs for procuring cellulosic feedstocks from bio-basins at the 5-digit zip code tabulation area (ZCTA) resolution for 33 eastern states provides invaluable insight for policy makers, business planners, and investors.

Significant outcomes of the study were identifying low cost bio-basins in the eastern United States. Least cost bio-basins for softwood mill residues were identified in south-central and southeast GA, southern MS, southern Arkansas, central Louisiana, southern Maine, and southeastern New Hampshire. Average total costs (ATC) ranged from $43.19 to $81.21/dry ton. Least cost bio-basins hardwood mill residues were identified in central Mississippi, southwestern Alabama, western Alabama, northwestern Louisiana, eastern Mississippi, and West Virginia. ATC ranged from $30.74 to $53.67/dry ton. Least cost bio-basins for this region for softwood or hardwood logging residues produced from chipping tops and limbs at the log-deck landing were located in southern Arkansas, northeastern North Carolina, northern Louisiana, eastern Mississippi, and southern West Virginia. ATC ranged from $29.85 to $40.58/dry ton.

Least cost bio-basins for natural softwood pulpwood occurred in North Carolina, South Carolina, and Virginia. ATC ranged from $43.77 to $50.77/dry ton. Higher cost bio-basins with the largest concentrations of natural softwood pulpwood were in Alabama, Florida, and southeast Oklahoma. Least cost bio-basins for upland hardwood pulpwood occurred in Delaware, Indiana, Ohio, and Pennsylvania. ATC ranged from $23.93 to $53.95/dry ton. Higher costs bio-basins with the largest concentrations of upland hardwood pulpwood were in Maryland, Missouri, and

Wisconsin. Missouri had large concentrations of upland hardwood pulpwood but had the highest ATC consistently exceeding $53.95/dry ton.

Least cost bio-basins for corn stover were located in northwest Texas, southern Minnesota, western Indiana, northern Illinois, and northeastern Iowa. ATC for corn stover ranged $14.03 to $26.13/dry ton. Least cost bio-basins for wheat straw were located in northwestern Mississippi, eastern Arkansas, and southwestern Kentucky, southern Missouri, northwestern Indiana, southern Ohio, and Lower Michigan. ATC for wheat straw ranged from $27.27 to $42.61/dry ton. Least cost bio-basins for sorghum straw were located in southeast Texas. ATC for sorghum straw ranged from $30.25 to $31.04/dry ton.

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Appendix A

USDA Forest Service ecoregion and forest type descriptions

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ECOREGIONS

Appalachian Mountains Ecoregion (M221 Central Appalachian Broadleaf Forest--Coniferous Forest--Meadow Province)

Land-surface form.--This province is composed of subdued low mountains of crystalline rocks and open low mountains with valleys underlain by folded strong and weak strata. Some dissected plateaus with mountainous topography are also present. The relief is high (up to 3,000 ft [900 m]). Elevations range from 300 to 6,000 ft (90 to 1,800 m), and are higher to the south, reaching 6,684 ft (2,037 m) at Mount Mitchell, North Carolina.

Climate.--The climate is temperate, with distinct summer and winter, and all areas are subject to frost. Average annual temperatures range from below 50F (10C) in the north to about 64F (18C) at the south end of the highlands. The average length of the frost-free period is about 100 days in the northern mountains, and about 220 days in the low southern parts of the Appalachian Highlands. Average annual precipitation varies from 35 in (890 mm) in the valleys to up to 80 in (2,040 mm) on the highest peaks--the highest in the Eastern United States. Precipitation is fairly well distributed throughout the year (see Appendix 2, climate diagram for Boone, North Carolina). Snowfall is more than 24 in (610 mm) in Pennsylvania, increasing southward along the mountains to about 30 in (770 mm) in the Great Smoky Mountains. Southeast- and southfacing slopes are notably warmer and drier than northwest- and northfacing slopes, because they face the sun and are on the lee side of the ridges. One result is that forest fires are more frequent on southfacing slopes.

Vegetation.--Vertical zonation prevails, with the lower limits of each forest belt rising in elevation toward the south. The valleys of the southern Appalachian Mountains support a mixed oak-pine forest that resembles its counterpart on the coastal plains (described below for the Southeastern Mixed Forest Province). Above this zone lies the Appalachian oak forest, dominated by a dozen species each in the white oak and black oak groups. Chestnut was once abundant, but a blight has eliminated it as a canopy tree. Above this zone lies the northeastern hardwood forest, composed of birch, beech, maple, elm, red oak, and basswood, with an admixture of hemlock and white pine. Spruce-fir forest and meadows are found on the highest peaks of the Allegheny and Great Smoky Mountains. Mixed mesophytic forest extends into narrow valleys (coves) of the southern Appalachians, where oak vegetation predominates.

The pattern of vegetation is complicated by topography and substrate. For example, the forests of the Great Smoky Mountains range from open oak and southern pine stands on drier, warmer slopes at low elevations to northern coniferous forests of spruce and fir on cold, moist slopes higher up. But southern pine stands reach up along exposed ridges, and hemlock forest extends down into protected ravines where moisture and local temperature conditions resemble those found at higher elevations.

Soils.--Ultisols are found on ridge crests, in areas of gentle topography, and in intermountain basins. Soils on steeper landforms are Inceptisols.

Fauna.--The southern limit of distribution of many northern forest mammals coincides with the boundaries of this province. Species distribution maps show fingers of distribution for many species running southward along the crest of the Appalachians. But many species are being confined to scattered areas at higher elevations as forests are cleared or lost due to spruce-fir die-off. The black bear, widely distributed in other parts of North America, occurs quite commonly in the Appalachians and surrounding areas. The eastern cougar, once an important predator, is now thought to be extinct. Whitetail deer are very common.

At upper elevations in extensions of boreal forest, red-breasted nuthatches, black-throated green warblers, golden-crowned warblers, golden-crowned kinglets, and northern juncos forage in red spruce and Fraser fir trees. In the hardwood forests, there are crow-sized pileated woodpeckers, downy, hairy, and red-bellied woodpeckers, common flickers, and wild turkeys. The understory, especially in areas with rhododendrons and azaleas, hosts worm-eating warblers, and the brilliant hooded warbler is found in lush undergrowth. Louisiana waterthrush patrol the streamsides. The mixed mesophytic forest in coves supports a large variety of nesting birds, including the wood thrush, ovenbird, summer tanager, rose-breasted grosbeak, and all the other species already named. The passenger pigeon, once abundant, is now extinct.

Unique to the region is its great variety of salamanders: 27 species inhabit the southern Appalachians--more than any other part of North America.

Delta Ecoregion (234 Lower Mississippi Riverine Forest Province)

Land-surface form.--The province consists of flat to gently sloping broad floodplain and low terraces made up of alluvium and loess. From near sea level in the south, altitude increases gradually to about 660 ft (200 m) in the north. Most of the area is flat, with an average southward slope of less than 8 in/mi (127 mm/km). The only noticeable slopes are sharp terrace scarps and natural levees that rise sharply to several meters above adjacent bottom lands or stream channels. This is the land of oxbow lakes--the cutoff meanders. Swamps are significant in the extreme southern part of Louisiana.

Climate.--The climate is similar to that found in adjoining parts of the Subtropical Division. Winters are warm, with temperatures ranging from 50 to 60F (10 to 16C), and summers are hot, with temperatures ranging from 70 to 80F (21 to 27C). Rain falls throughout the year, with a minimum in autumn. Temperature and precipitation decrease as one moves northward. At Natches, Mississippi, average temperatures for January and August are about 50F (10C) and 75F (24C), respectively. Average annual precipitation is 55 in (1,400 mm). Snowfall is negligible. Farther north, at Cairo, Illinois, average temperatures for January and August are about 41F (5C) and 77F (25C), respectively. Average annual precipitation is 43 in (1,100 mm).

Vegetation.--Before cultivation, this area was covered by bottom-land deciduous forest with an abundance of green and Carolina ash, elm, cottonwood, sugarberry, sweetgum, and water tupelo, as well as oak and baldcypress. Pecan is also present, associated with eastern sycamore, American elm, and roughleaf dogwood. Vines are prolific along water courses.

Soils.--The soils are a mosaic of Inceptisols (in alluvial bottom land), Alfisols (in areas of loess), and Mollisols (in areas with swampy vegetation).

Fauna.--Among the numerous bird species found here are the prothonotary warbler, white-eyed vireo, wood duck, yellow-billed cuckoo, Louisiana waterthrush, and all the species found in the Southeastern Mixed Forest.

Eastern Broadleaf Ecoregion (222 Eastern Broadleaf Forest (Continental) Province)

Land-surface form.--Most of the area is rolling, but some parts are nearly flat and in the Ozark Highlands the relief is moderate (up to 1,000 ft [300 m]). Low rolling hills, dissected plateaus, and basins are found in Tennessee and Kentucky. The northern parts of the province have been glaciated, but not the southern. Elevations range from 80 to 1,650 ft (24 to 500 m).

Climate.--The climate has many characteristics in common with the oceanic broadleaf forest to the east, but precipitation decreases in quantity and effectiveness as one moves inland. Average annual temperatures range from 40F (4C) in the north to 65F (18C) in the south. Summers are hot, with frequent tornadoes. Precipitation varies from 20 in (510 mm) near the 95th meridian to 40 in (1,020 mm) in Ohio, and to 50 in (1,280 mm) in Tennessee. Most precipitation takes place during the growing season.

Vegetation.--Like its counterpart to the east, this province is dominated by broadleaf deciduous forest, but the smaller amounts of precipitation found here favor the drought-resistant oak-hickory association. Although other forests have oak and hickory, only this particular forest association has both species in abundance.

The oak-hickory forest is medium-tall to tall, becoming savannalike in its northern reaches from eastern Oklahoma to Minnesota, where it gradually turns into prairie (described below for the Prairie Parkland [Temperate] Province). From eastern Kansas to Indiana, it forms a mosaic pattern with prairie. Widespread dominants are white oak, red oak, black oak, bitternut hickory, and shagbark hickory. The understory is usually well developed, often with flowering dogwood. Other understory species include sassafras and hophornbeam. The shrub layer is distinct, with some evergreens. Many wildflower species occur. Wetter sites typically feature an abundance of American elm, tuliptree, and sweet gum.

Northern reaches of the oak-hickory forest contain increasing numbers of maple, beech, and basswood. The maple-basswood forest, dominated by sugar maple and American basswood, occurs from central Minnesota south through Wisconsin and northeastern Iowa. Glaciated areas of Ohio and Indiana feature a beech-maple forest defined by American beech and sugar maple. In these latter associations, oak and hickory occur on poor sites.

Soils.--As in the oceanic broadleaf forest, the soils change from Alfisols in the north to Ultisols in southerly latitudes. Toward the continental interior, calcification sets in as forest soils give way to the darker soils of the grasslands (Mollisols).

Fauna.--In the oak-hickory forest, acorns and hickory nuts provide abundant food for the ubiquitous gray squirrel. Fox squirrels are often found, as are eastern chipmunks.

Roving flocks of blue jays also feed on forest nuts. In summer, scarlet and/or summer tanagers, rose-breasted grosbeaks, and ovenbirds are common. The wild turkey is also found here. The cerulean warbler is common in the beech-maple forest, and occurs elsewhere as well.

Gulf Coastal Plain Ecoregion (232 Outer Coastal Plain Mixed Province)

Land-surface form.--This province comprises the flat and irregular Atlantic and Gulf Coastal Plains down to the sea. Well over 50 percent of the area is gently sloping. Local relief is less than 300 ft (90 m), although some areas are gently rolling. Most of the region's numerous streams are sluggish; marshes, swamps, and lakes are numerous.

Climate.--The climate regime is equable, with a small to moderate annual temperature range. Average annual temperature is 60 to 70F (16 to 21C). Rainfall is abundant and well distributed throughout the year; precipitation ranges from 40 to 60 in (1,020 to 1,530 mm) per year.

Vegetation.--Temperate rainforest, also called temperate evergreen forest or laurel forest, is typical in this province. Temperate rainforest has fewer species of trees than its equatorial or tropical counterparts, and hence larger populations of individual species. Trees are not as tall here as in low-latitude rainforests; leaves are usually smaller and more leathery, and the leaf canopy less dense. Common species include evergreen oaks and members of the laurel and magnolia families. There is usually a well-developed lower stratum of vegetation that may variously include tree ferns, small palms, shrubs, and herbaceous plants. Lianas and epiphytes are abundant. At higher elevations, where fog and clouds persist, the trunks and branches of trees are often sheathed in moss. A striking example of epiphyte accumulation at lower elevations is the Spanish "moss" that festoons the Evangeline oak, baldcypress, and other trees of the eastern Gulf coast.

Along the Atlantic coast, the extensive coastal marshes and interior swamps are dominated by gum and cypress. Most upland areas are covered by subclimax pine forest, which has an understory of grasses and sedges called savannas. Undrained shallow depressions in savannas form upland bogs or pocosins, in which evergreen shrubs predominate.

A word about the vegetation of the coastal Southeastern United States may prevent some misunderstanding. On forest maps of the United States and on numerous maps of world vegetation, this coastal zone is shown as having needleleaf evergreen or coniferous forest. It is true that sandy uplands have forests of loblolly and slash pine, and that baldcypress is a dominant tree in swamps; but such vegetation represents either xerophytic and hydrophytic forms in excessively dry or wet habitats, or second-growth forest following fire and deforestation. The climax vegetation of mesophytic habitats is the evergreen-oak and magnolia forest.

Soils.--Soils are mainly Ultisols, Spodosols, and Entisols. Temperate rainforest grows on a wide variety of upland soils, but most tend to be wet, acidic, and low in major plant nutrients. The soils are derived mainly from coastal plain sediments ranging from heavy clay to gravel, with sandy materials predominant. Silty soils occur mainly on level expanses. Sands are prevalent in hilly areas, but they also cover broad flats in central Florida.

Fauna.--This region provides habitat for a wide variety of animals. Except for a few isolated areas where black bear or the endangered Florida panther are found in small numbers, the whitetail deer is the only large indigenous mammal. Common small mammals include raccoons, opossums, flying squirrels, rabbits, and numerous species of ground-dwelling rodents.

Bobwhite and wild turkey are the principal game birds. Migratory nongame bird species are numerous, as are migratory waterfowl. Winter birds are are diverse and numerous. The red-cockaded woodpecker is an endangered species.

Of the numerous species of reptiles found in this province, the American alligator is the largest.

Lake States Ecoregion (212 Laurentian Mixed Forest Province)

Land-surface form.--Most of this province has low relief, but rolling hills occur in many places. Lakes, poorly drained depressions, morainic hills, drumlins, eskers, outwash plains, and other glacial features are typical of the area, which was entirely covered by glaciers during parts of the Pleistocene. Elevations range from sea level to 2,400 ft (730 m).

Climate.--Winters are moderately long and somewhat severe, but more than 120 days have temperatures above 50F (10C). Average annual temperatures range from 35 to 50F (2 to 10C). A short growing season imposes severe restrictions on agriculture; the frost-free season lasts from 100 to 140 days. Snow usually stays on the ground all winter. During winter, the province lies north of the main cyclonic belt; but during summer it lies within this belt, and the weather is changeable. Average annual precipitation is moderate, ranging from 24 to 45 in (610 to 1,150 mm); maximum precipitation comes in summer.

Vegetation.--This province lies between the boreal forest and the broadleaf deciduous forest zones and is therefore transitional. Part of it consists of mixed stands of a few coniferous species (mainly pine) and a few deciduous species (mainly yellow birch, sugar maple, and American beech); the rest is a macromosaic of pure deciduous forest in favorable habitats with good soils and pure coniferous forest in less favorable habitats with poor soils. Mixed stands have several species of conifer, mainly northern white pine in the Great Lakes region, with an admixture of eastern hemlock. Eastern redcedar is found in the southeast. Pine trees are often the pioneer woody species that flourish in burned-over areas or on abandoned arable land. Because they grow more rapidly than deciduous species where soils are poor, they quickly form a forest canopy; but where deciduous undergrowth is dense, they have trouble regenerating, and remain successful only where fire recurs. Fires started by lightning are common in this province, particularly where soils are sandy and there is a layer of dry litter in summer.

Soils.--The greatly varying soils include peat, muck, marl, clay, silt, sand, gravel, and boulders, in various combinations. Spodosols are dominant in New England and along the Great Lakes coast; Inceptisols and Alfisols dominate farther inland. The Alfisols are medium to high in bases and have gray to brown surface horizons and subsurface horizons of clay accumulation.

Fauna.--In winter, the shorttail weasel (ermine) and snowshoe hare turn white, as they do in polar provinces. The black bear, striped skunk, marmot, chipmunk, and two genera of jumping mice all pass the winter in hibernation. So do badger and the striped ground squirrel that live in the western parts of the province. Beaver and muskrat remain active all winter, working beneath the ice that covers the lakes and streams.

Ptarmigan also turn white in winter. Many other birds, especially insectivorous species, migrate south. Common summer resident birds include the white-throated sparrow, northern junco, and yellow-bellied sapsucker.

Northeast Ecoregion (M212 Adirondack-New England Mixed Forest--Coniferous Forest--Alpine Meadow Province)

Land-surface form.--This province is composed of subdued glaciated mountains and maturely dissected plateaus of mountainous topography. The mountains and plateaus are underlain by granite and metamorphic rocks and thinly mantled by glacial till. Many glacially broadened valleys have glacial outwash deposits and contain numerous swamps and lakes. The relief is between 1,000 and 3,000 ft (300 and 900 m). Elevations range from 500 to 4,000 ft (150 to 1,220 m); a few isolated peaks are higher than 5,000 ft (1,500 m).

Climate.--The climate, a continental forest type, is characterized by warm summers. Because maritime air masses have year-round access to the eastern seaboard, precipitation is evenly distributed throughout the year, distinguishing this climate from that of the Laurentian Mixed Forest Province. To the west and north, well-defined summer maximum and winter minimum temperatures reflect the predominance of tropical air masses in summer and continental-polar air masses in winter. Winter can be severely cold, as in Wisconsin, but is less so closer to the ocean. Average annual temperatures range from 37 to 52F (3 to 11C). The average length of the frost-free period is about 100 days. Precipitation in Albany, New York, averages 35 in (890 mm) per year. Average annual snowfall is more than 100 in (2,550 mm).

Vegetation.--This mountainous region is in the transition zone between the boreal spruce-fir forest to the north and the deciduous forest to the south. Growth form and species are very similar to those found to the north, but red spruce tends to replace white spruce. Vertical vegetational zonation is present. Valleys contain a hardwood forest where the principal trees are sugar maple, yellow birch, and beech, with an admixture of hemlock. Low mountain slopes support a mixed forest of spruce, fir, maple, beech, and birch. The compensating effect of latitude is apparent in the altitudinal limits of zonation, which rise in elevation as one moves south: the approximate lower limit of spruce and fir on Mt. Katahdin is 500 ft (150 m); in the White Mountains, about 2,500 ft (800 m); in the Adirondack Mountains, 3,000 ft (900 m); and in the Catskills, 3,500 ft (1,100 m). Above the mixed-forest zone lie pure stands of balsam fir and red spruce, which devolve into krummholz at higher elevations. Above timberline on Mount Washington, there is tundralike growth called alpine meadow.

Soils.--Most soils are Spodosols that are stony, cool, and moist.

Fauna.--This community shares some species with both the Laurentian Mixed Forest and boreal forest, but some species are unique to its alpine tundra, such as longtail shrew, boreal (southern) redback vole, gray-cheeked thrush, spruce grouse, and gray jay.

FOREST TYPES

Upland hardwood

Stands that have at least 10 percent stocking and classed as an oak-hickory or maple-beech-birch forest type.

Lowland hardwood

Stands that have at least 10 percent stocking with a forest type of oak-gum-cypress or elm-ash-cottonwood.

Natural Softwood (a.k.a. Natural Pine)

Stands that (a) have not been artificially regenerated, (b) are classed as a pine or other softwood forest type, and (c) have at least 10 percent stocking.

Mixed Natural Softwood and Hardwood

Stands in which hardwoods constitute a plurality of the stocking but in which pines account for 25 to 50 percent of the stocking.

Pine Plantation

Stands that (a) have been artificially regenerated by planting or direct seeding, (b) are classed as a pine or other softwood forest type, and (c) have at least 10 percent stocking.

CITATIONS

Ecoregions:

Bailey, R.G. 1995. Description of the ecoregions of the United States. Miscel. Pub. 1391. Washington, DC: U.S. Department of Agriculture, Forest Service. 108 p.

Forest Types:

Various forest resource bulletins published by the U.S. Forest Service, Forest Inventory and Analysis unit of the Southern Research Station, Asheville, NC

Appendix B

Bio-basin ZCTA maps for the top ten sites for total mill residues, hardwood mill residues, and softwood mill residues for southern region with MCs.

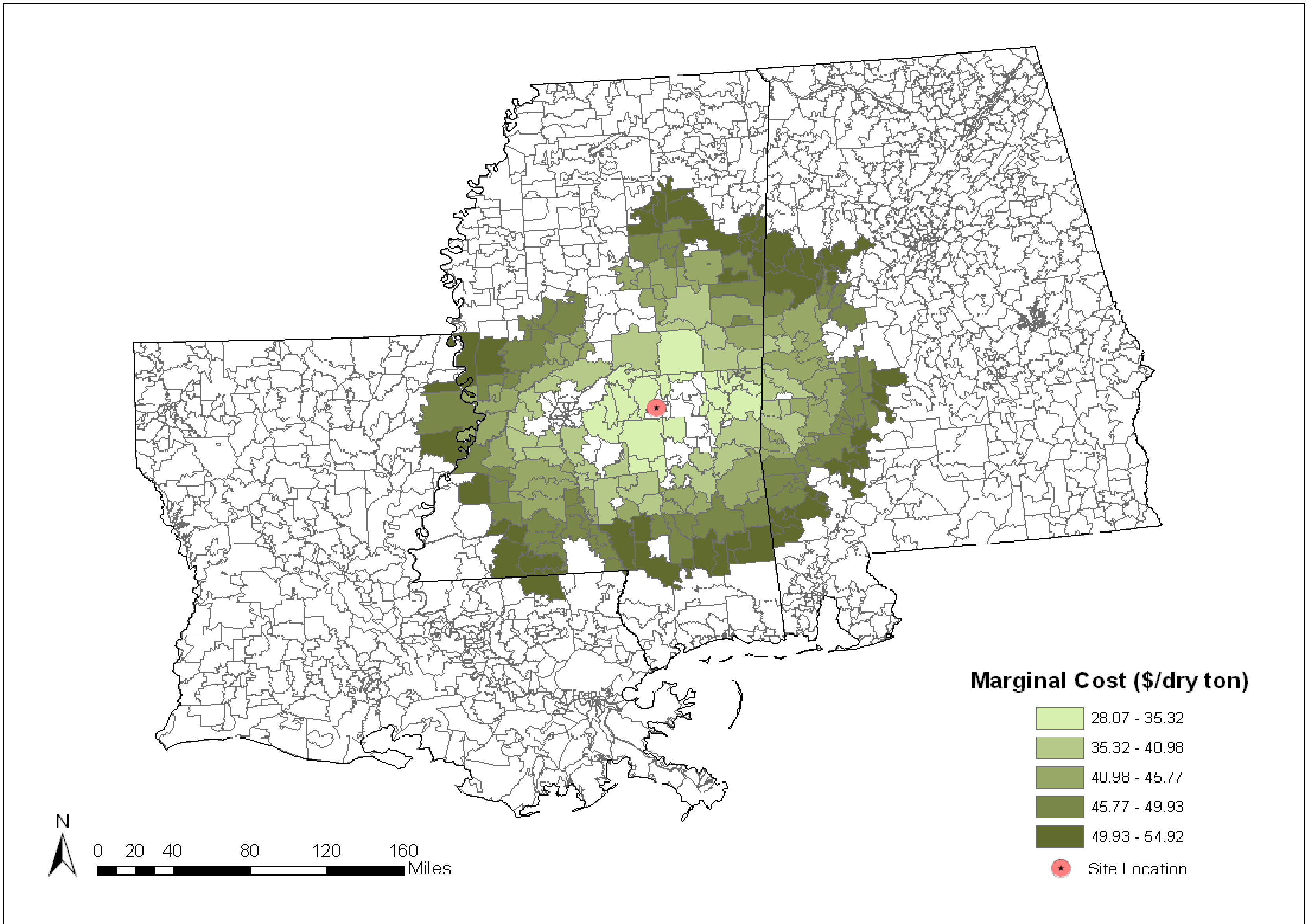

Figure B1. MC by ZCTA of total mill residues for the 39092 zip code bio-basin.

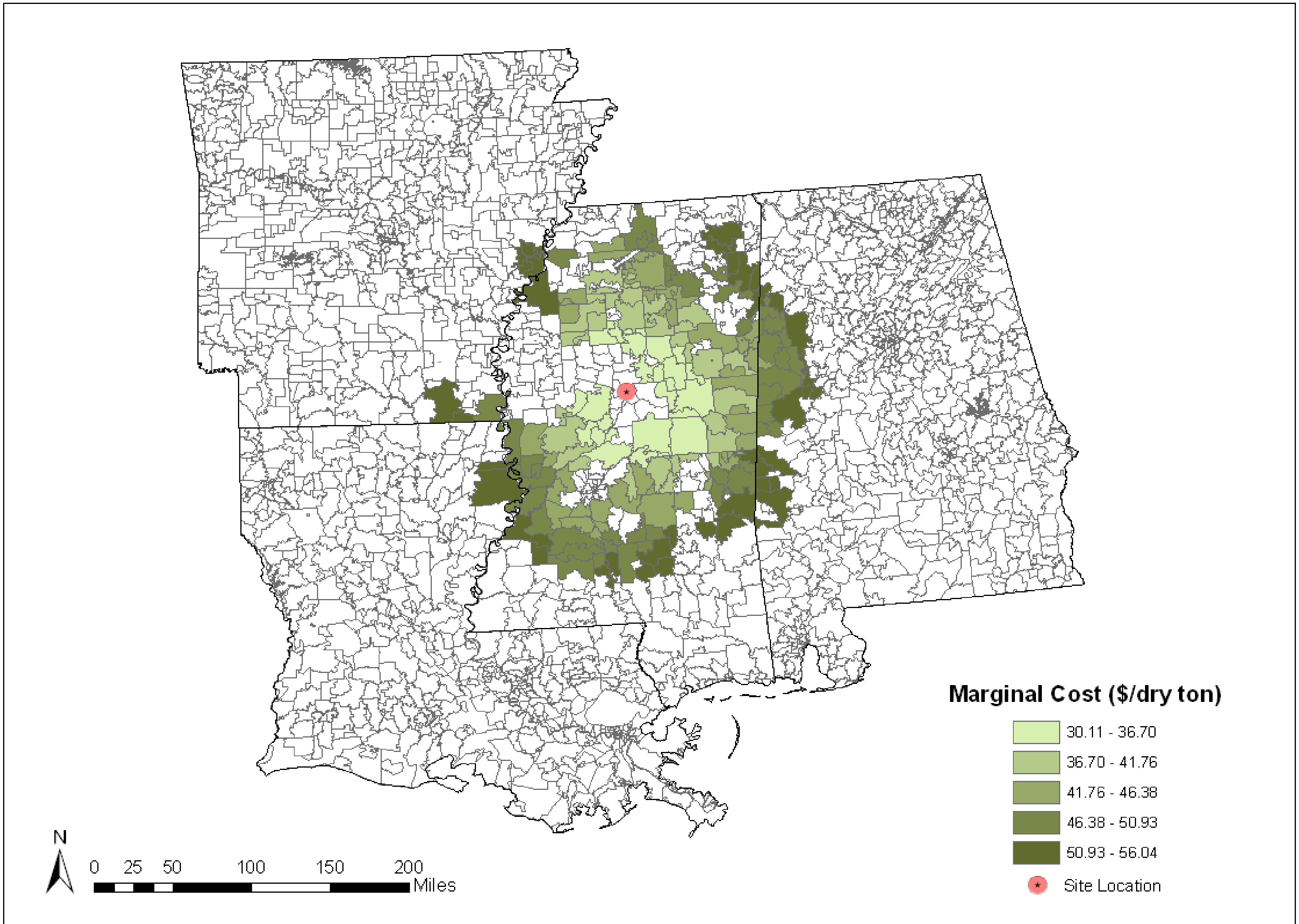

Figure B2. MC by ZCTA of total mill residues for the 39192 zip code bio-basin.

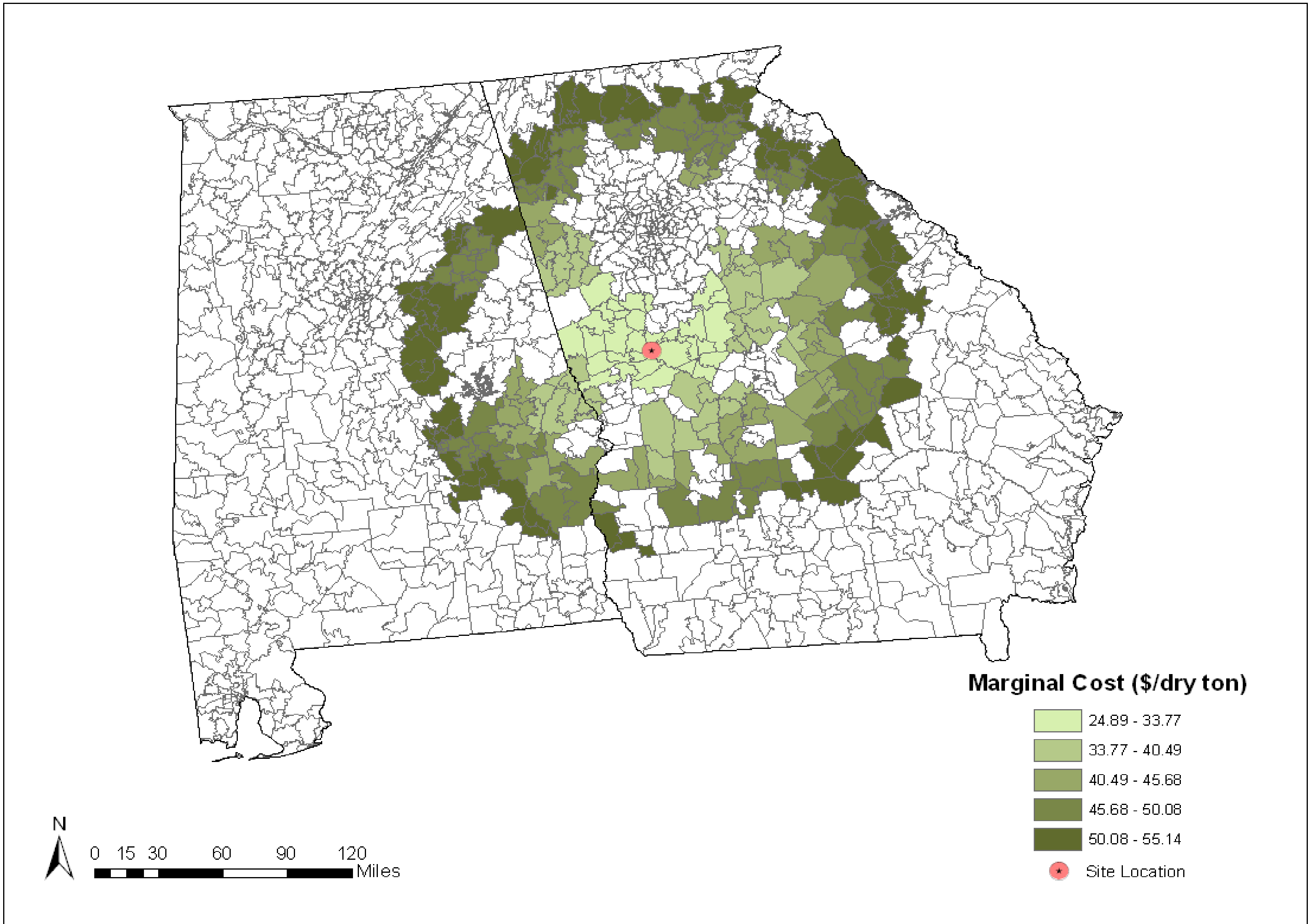

Figure B3. MC by ZCTA of total mill residues for the 30206 zip code bio-basin.

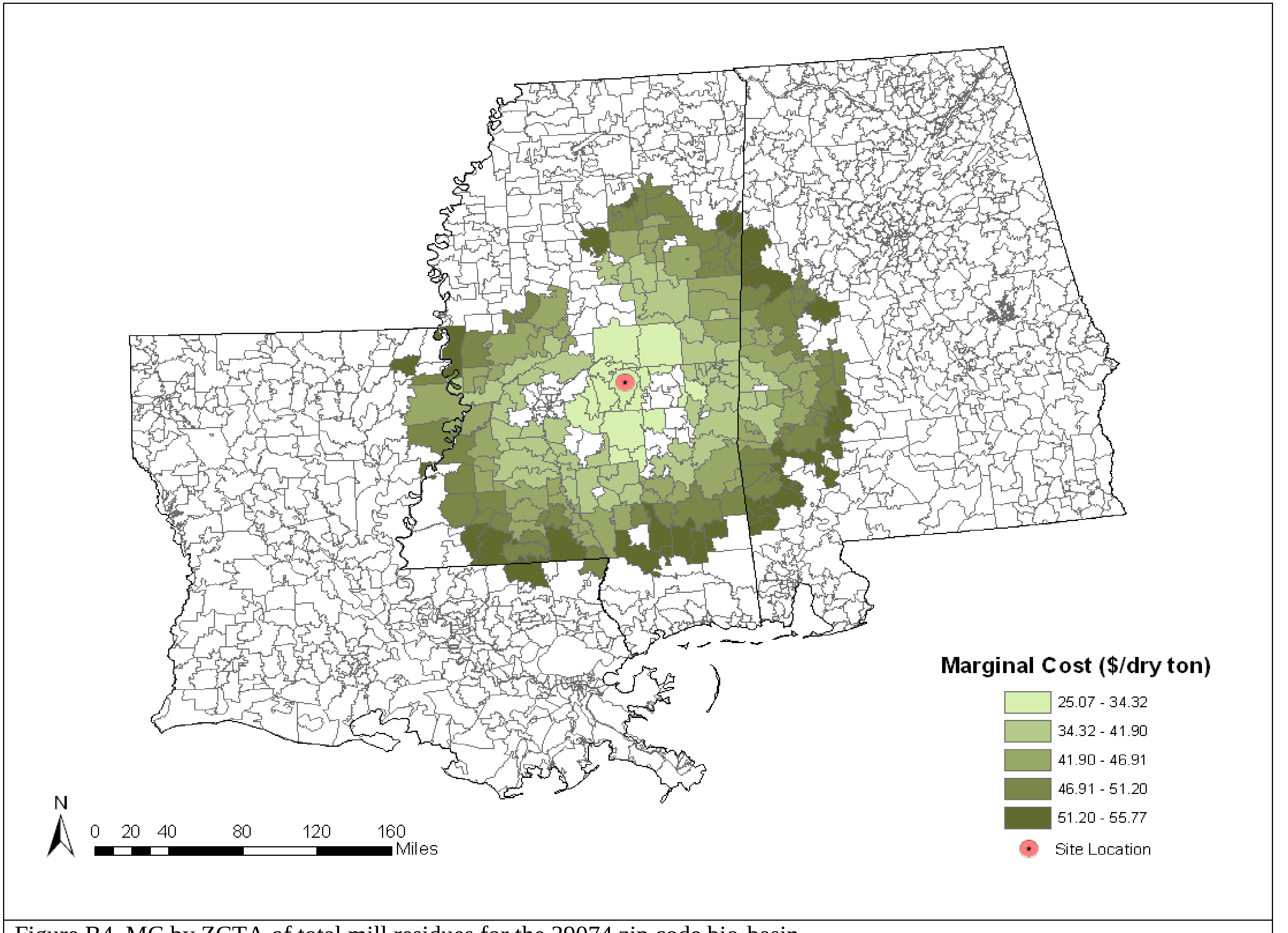

Figure B4. MC by ZCTA of total mill residues for the 39074 zip code bio-basin.

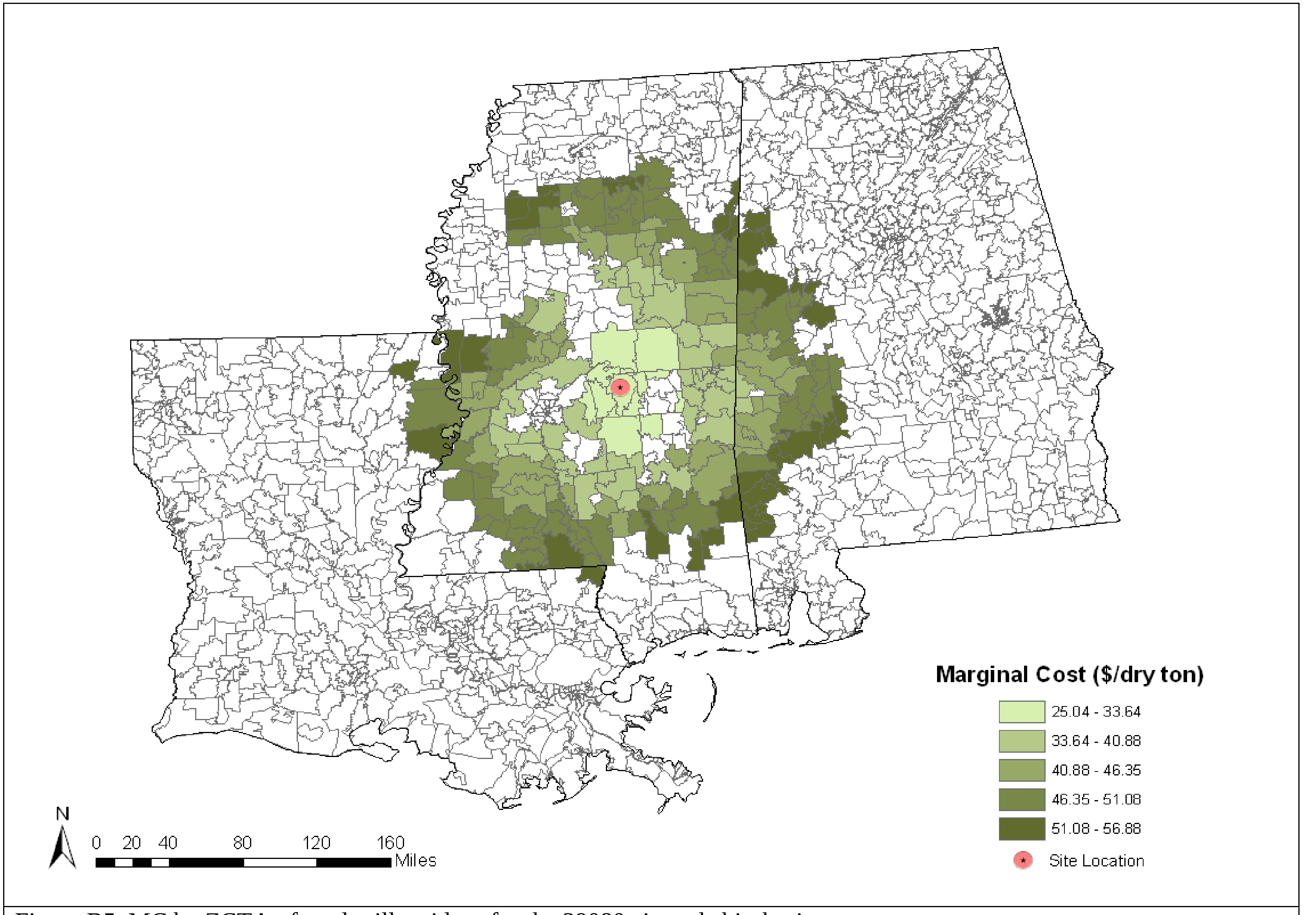

Figure B5. MC by ZCTA of total mill residues for the 39080 zip code bio-basin.

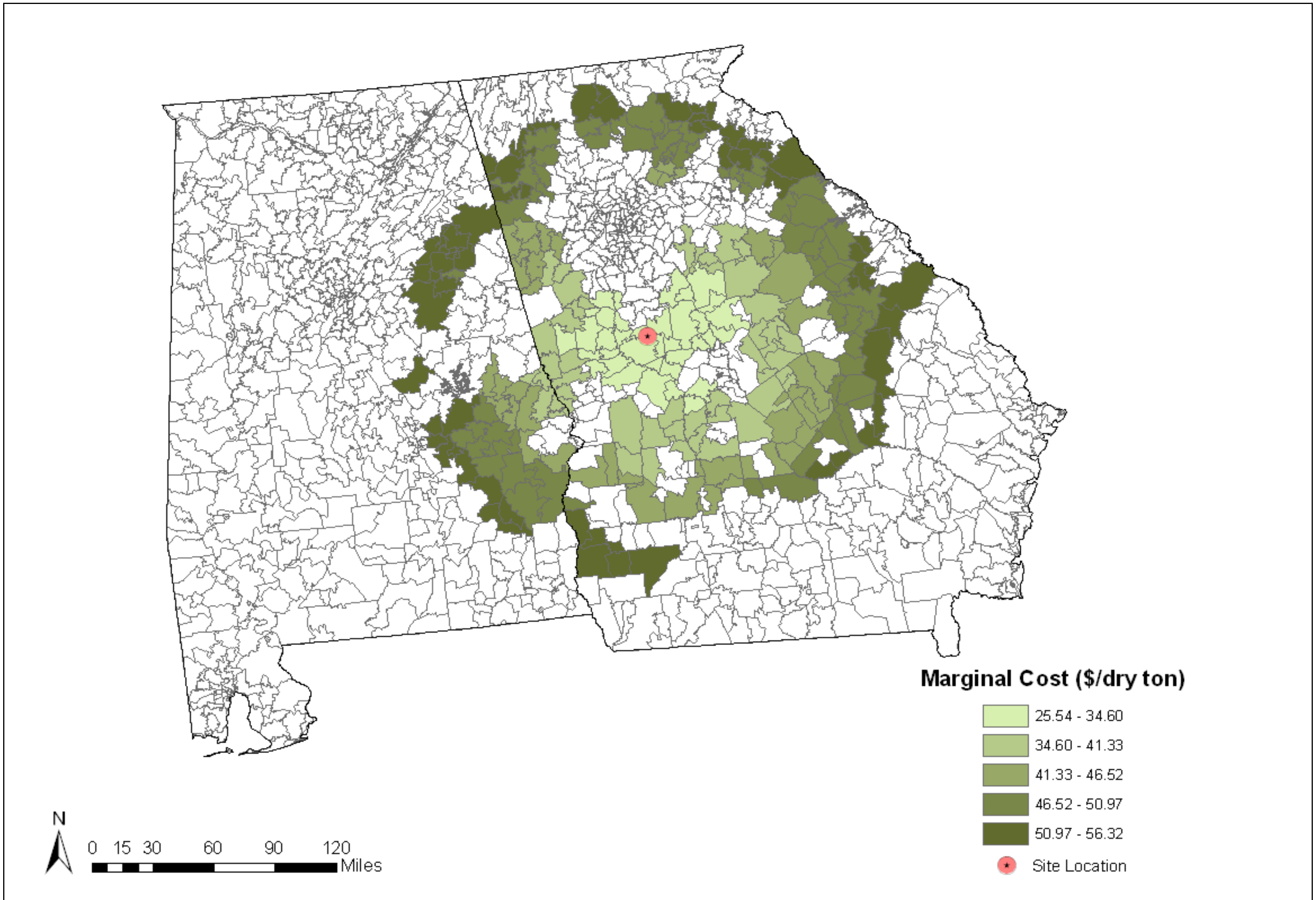

Figure B6. MC by ZCTA of total mill residues for the 30285 zip code bio-basin.

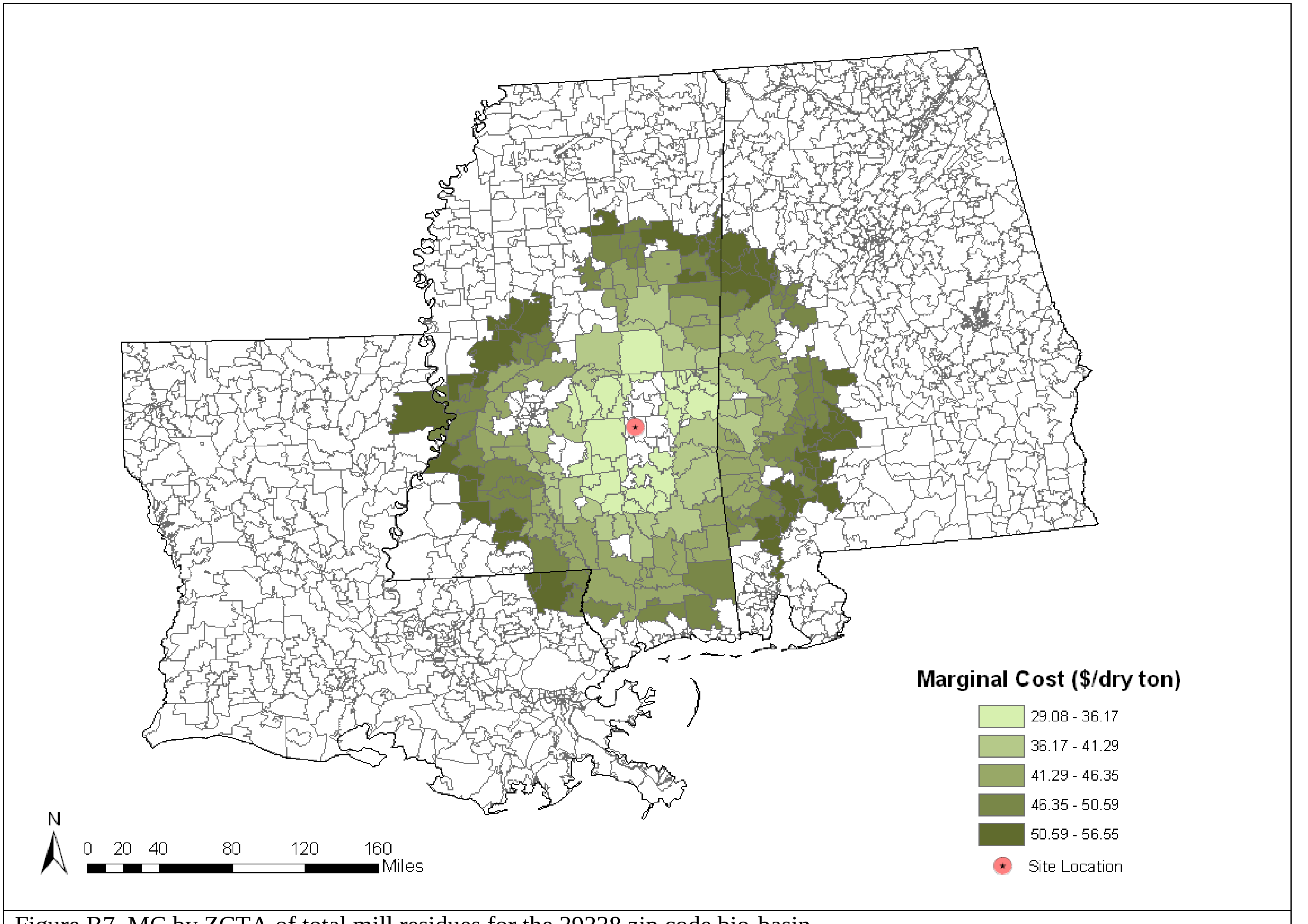

Figure B7. MC by ZCTA of total mill residues for the 39338 zip code bio-basin.

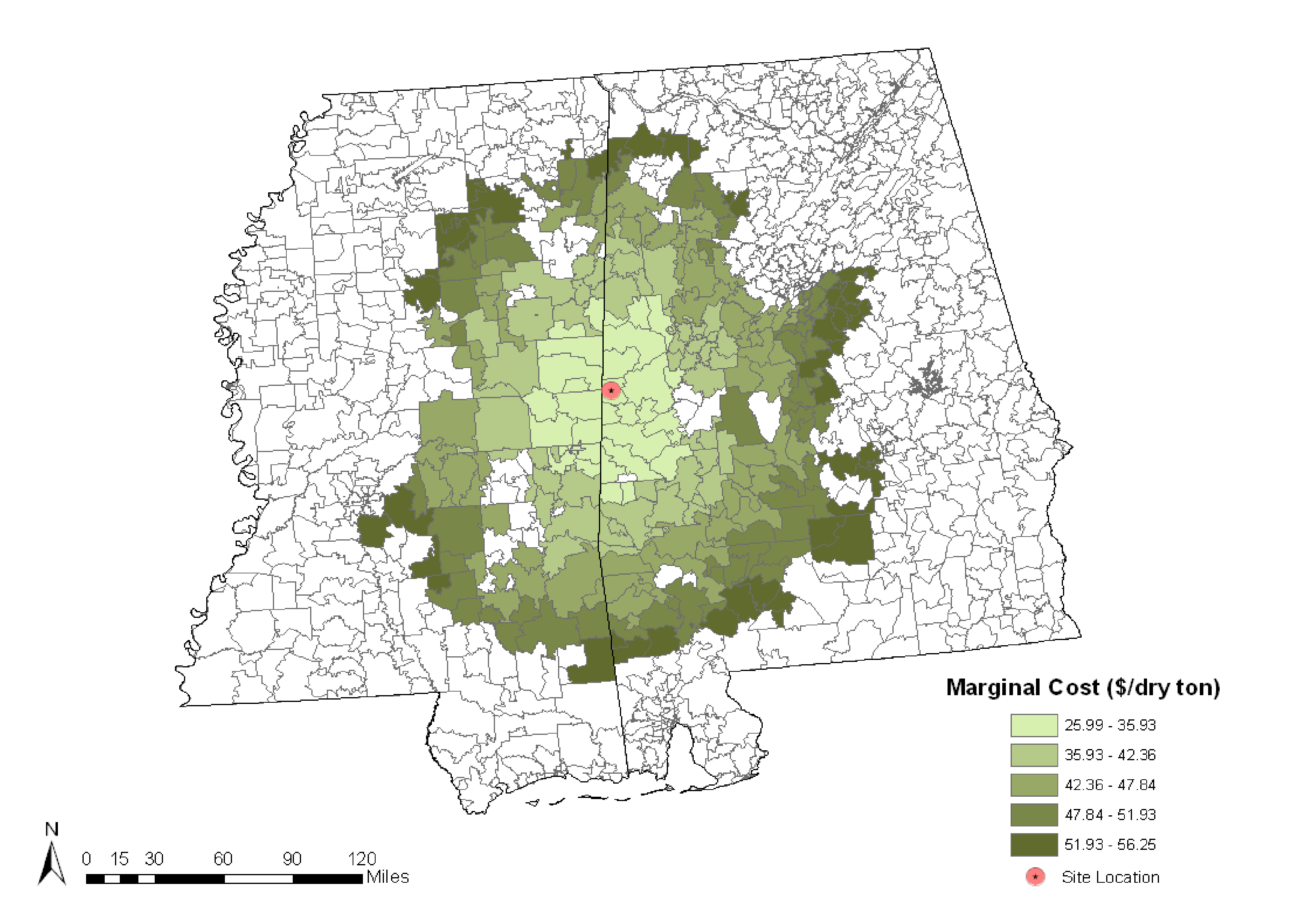

Figure B8. MC by ZCTA of total mill residues for the 35464 zip code bio-basin.

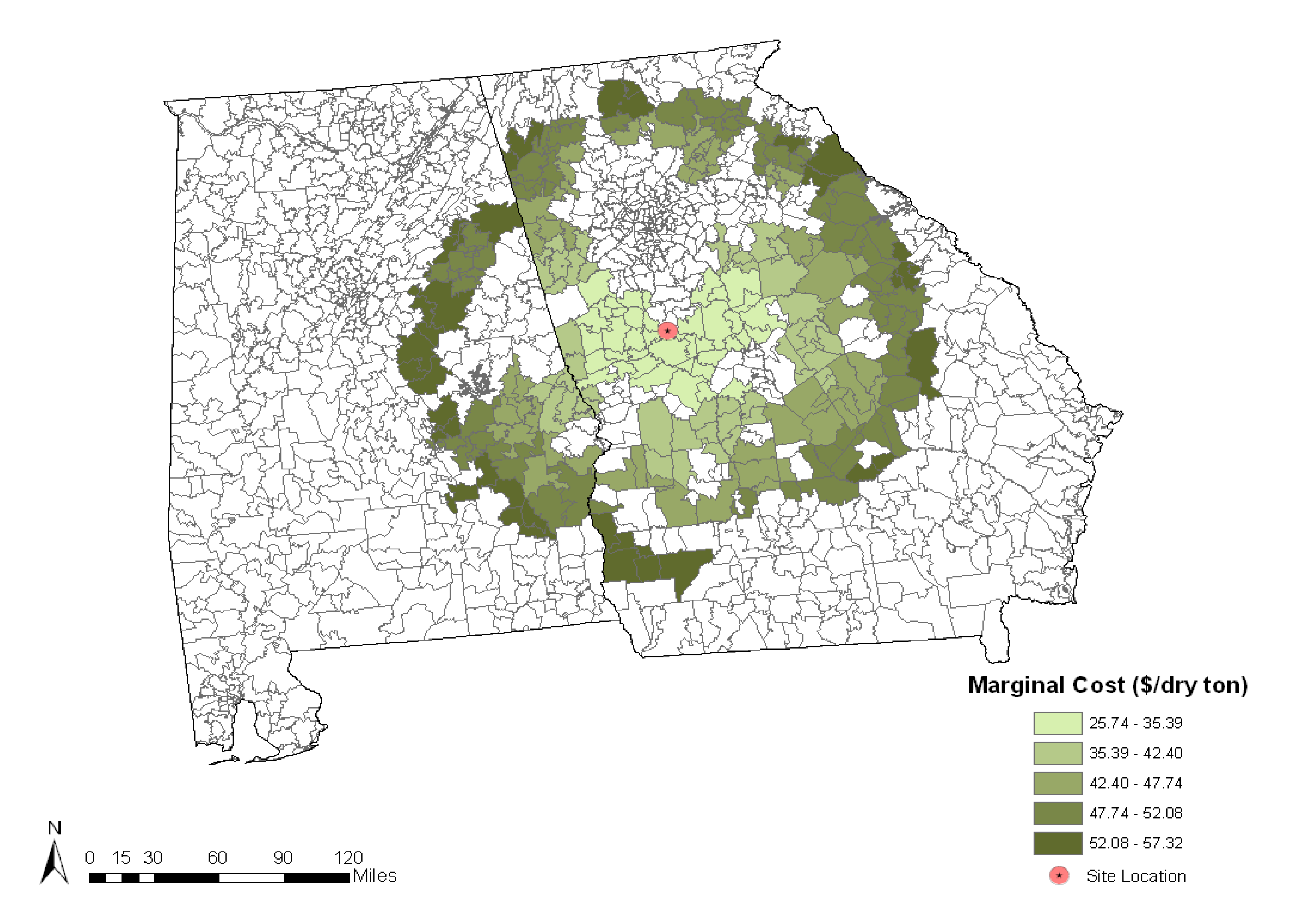

Figure B9. MC by ZCTA of total mill residues for the 30256 zip code bio-basin.

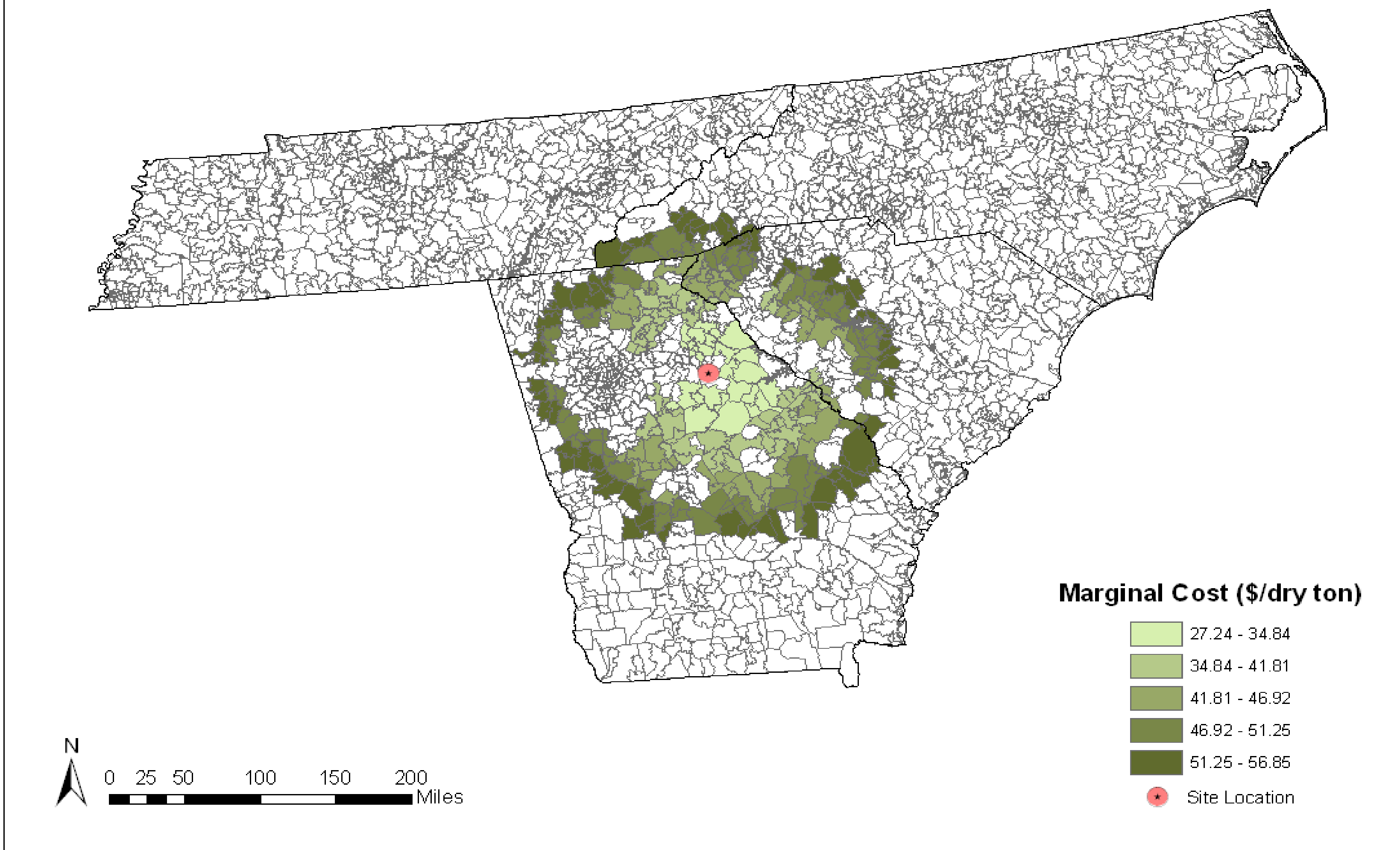

Figure B10. MC by ZCTA of total mill residues for the 30671 zip code bio-basin.

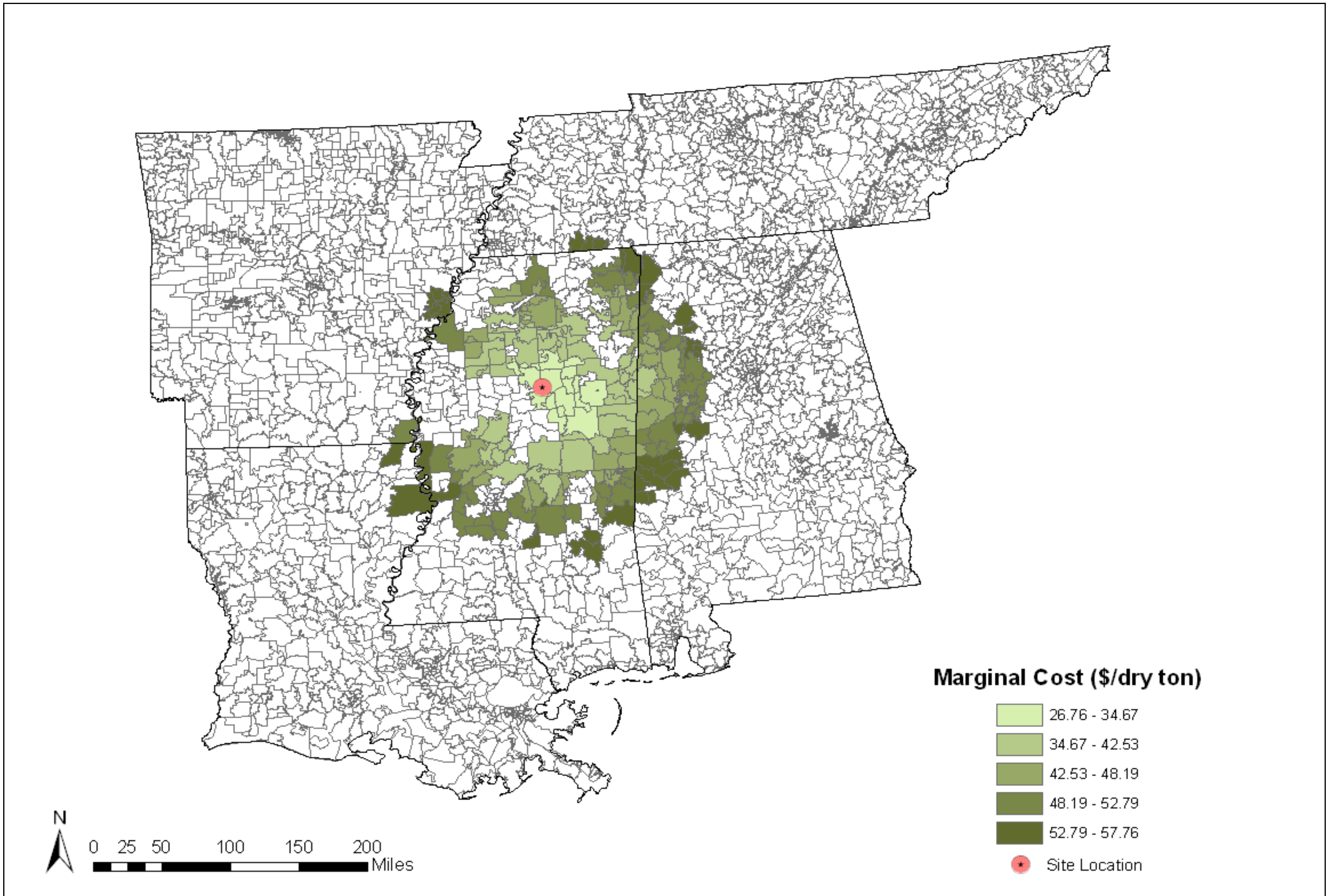

Figure B11. MC by ZCTA of hardwood mill residues for the 39767 zip code bio-basin.

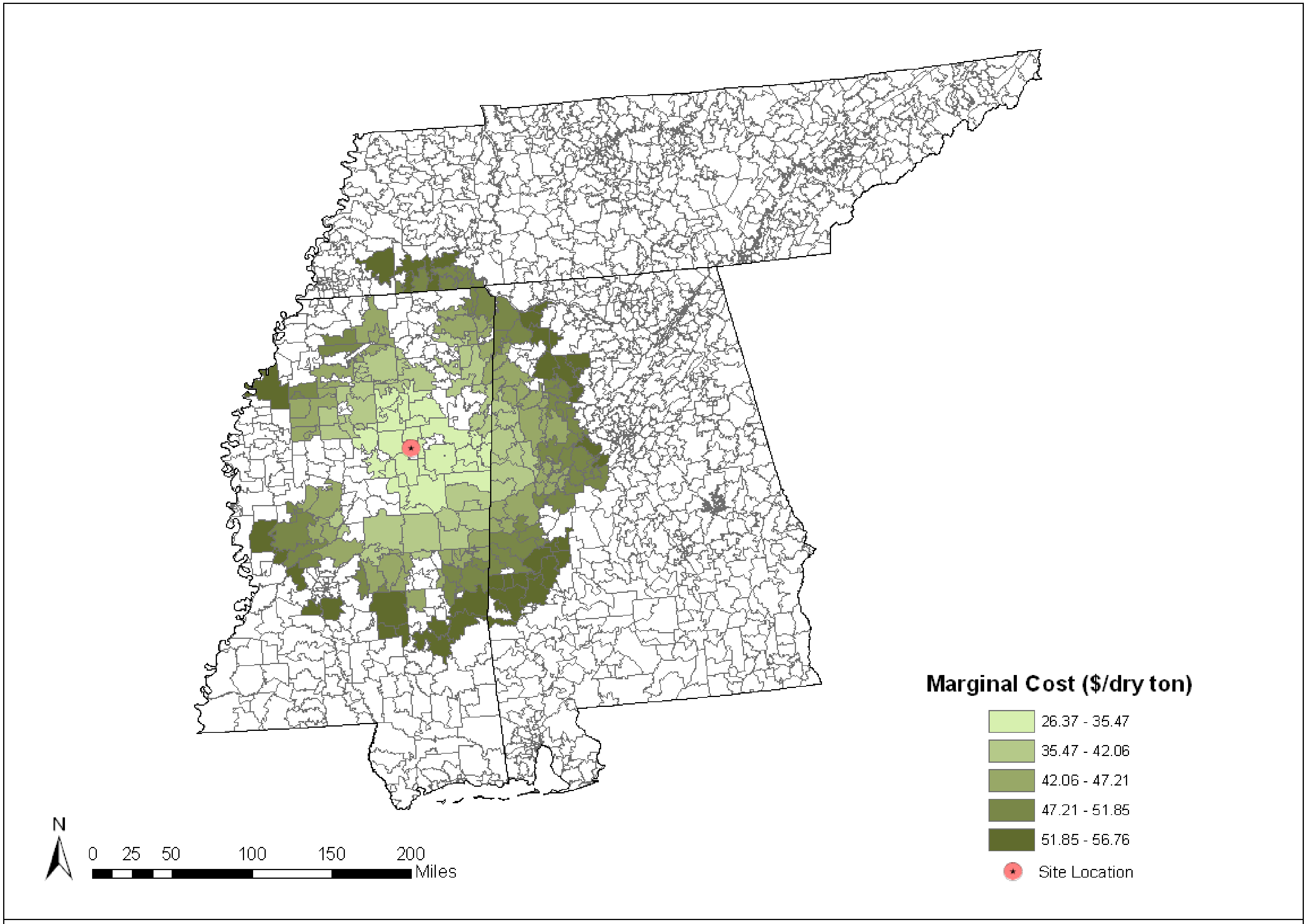

Figure B12. MC by ZCTA of hardwood mill residues for the 39752 zip code bio-basin.

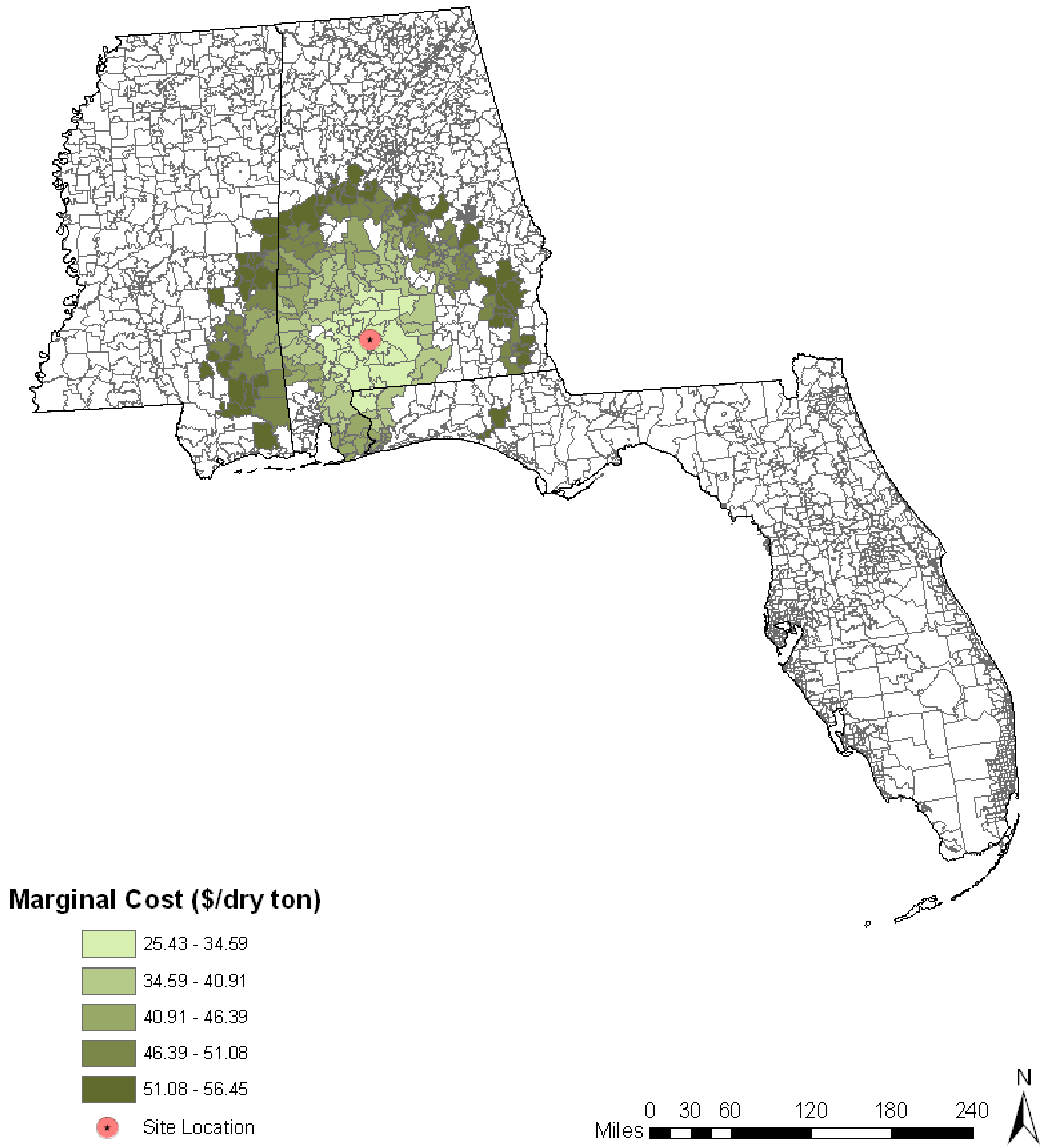

Figure B13. MC by ZCTA of hardwood mill residues for the 36470 zip code bio-basin.

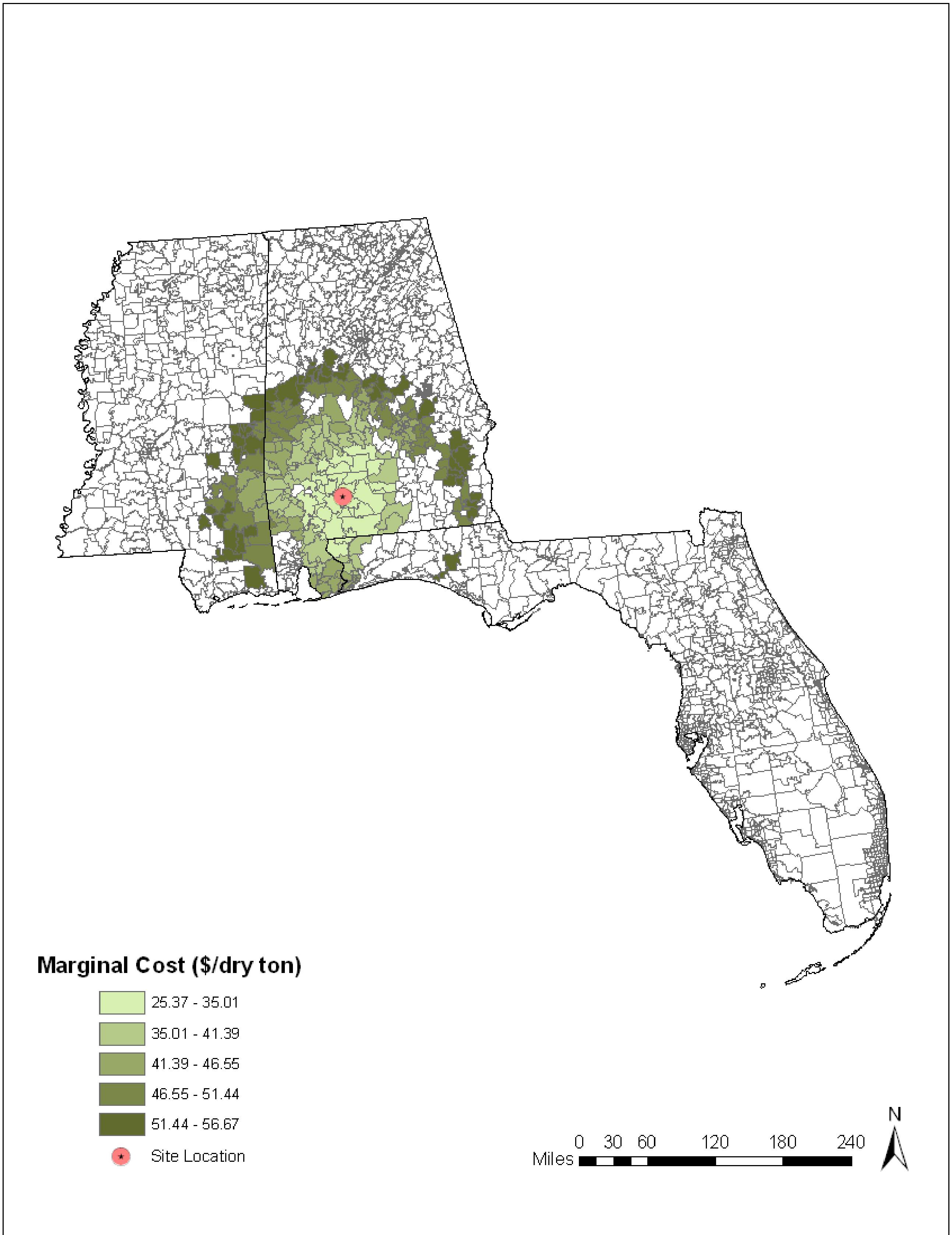

Figure B14. MC by ZCTA of hardwood mill residues for the 36462 zip code bio-basin.

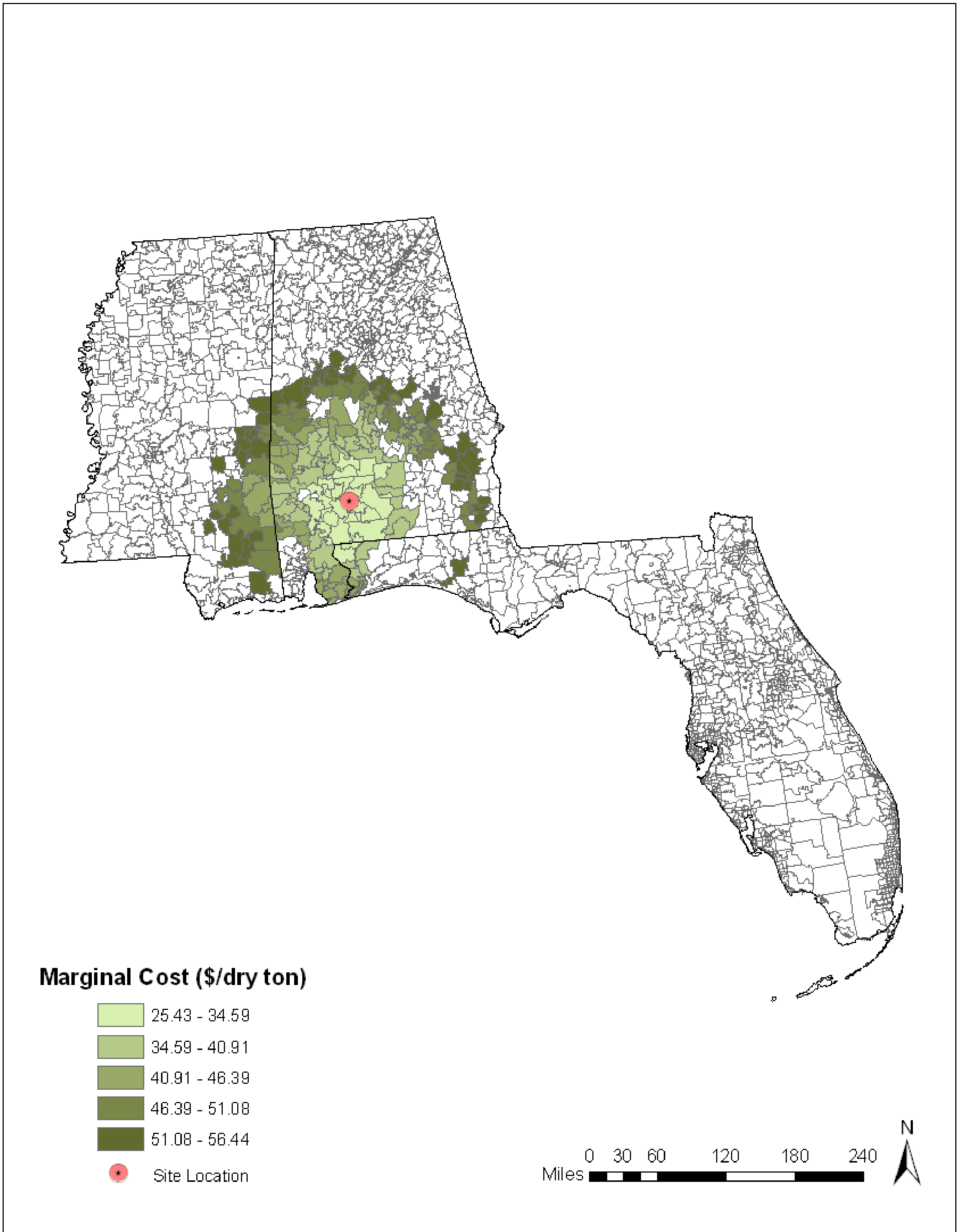

Figure B15. MC by ZCTA of hardwood mill residues for the 36461 zip code bio-basin.

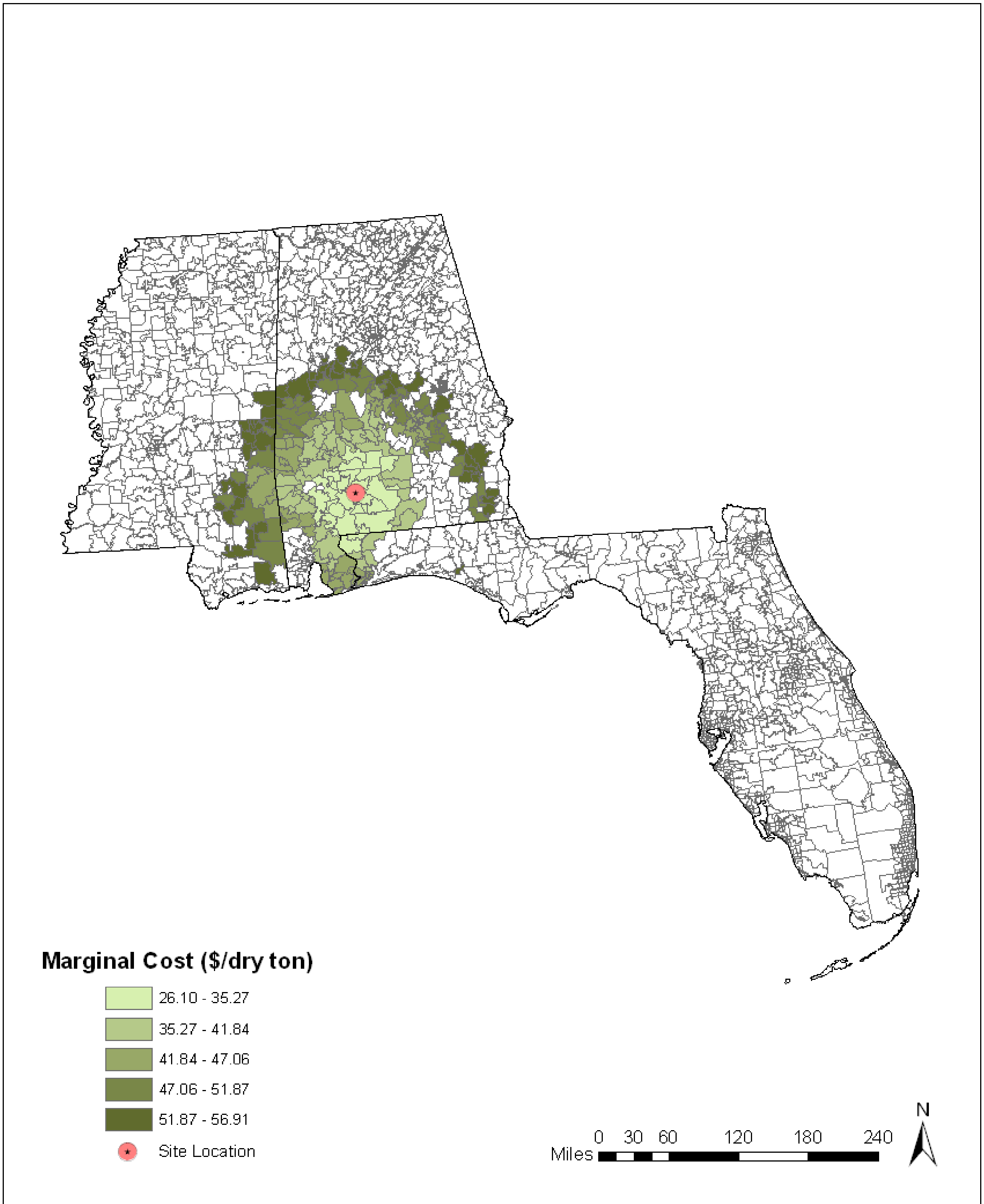

Figure B16. MC by ZCTA of hardwood mill residues for the 36460 zip code bio-basin.

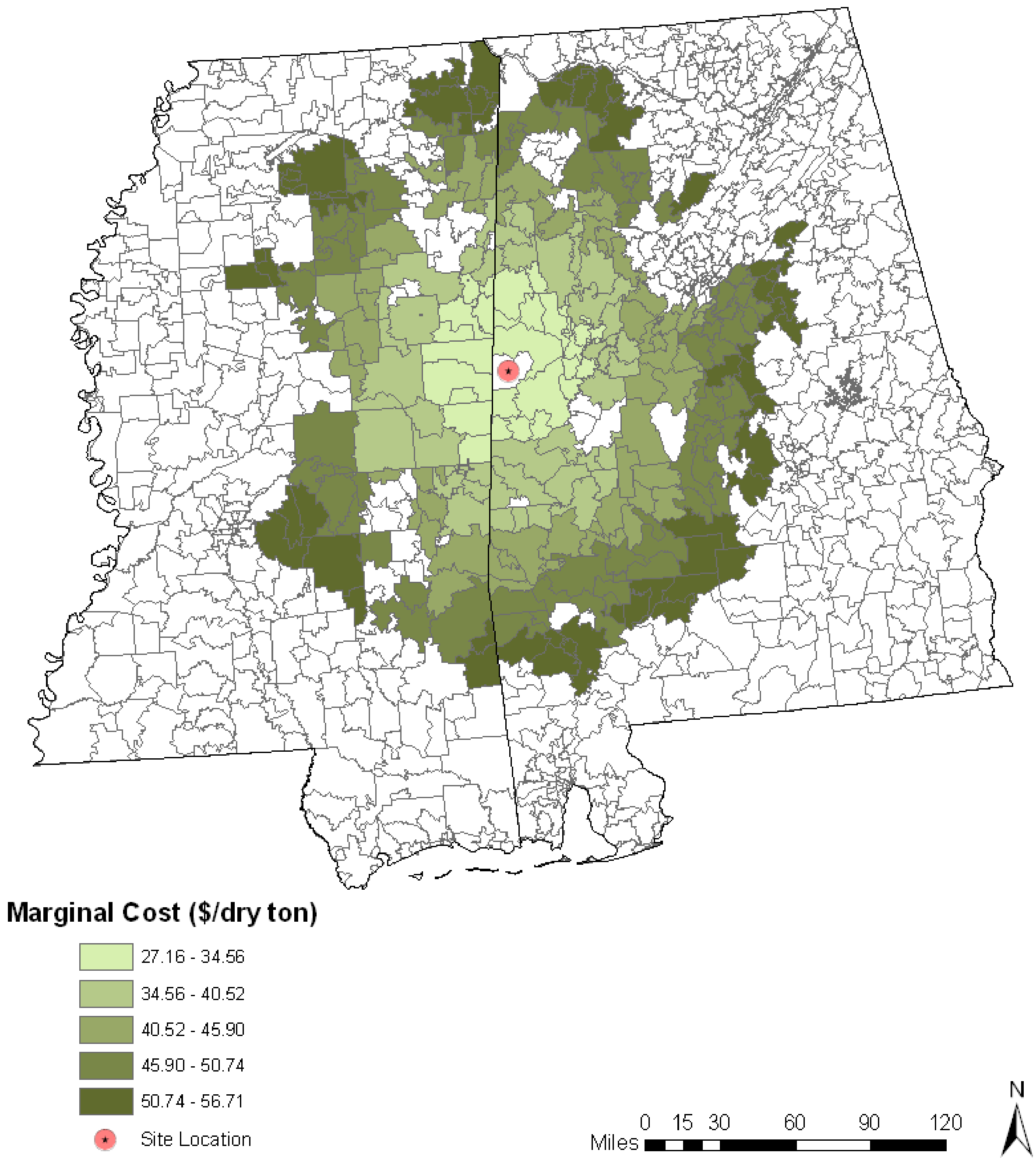

Figure B17. MC by ZCTA of hardwood mill residues for the 35442 zip code bio-basin.

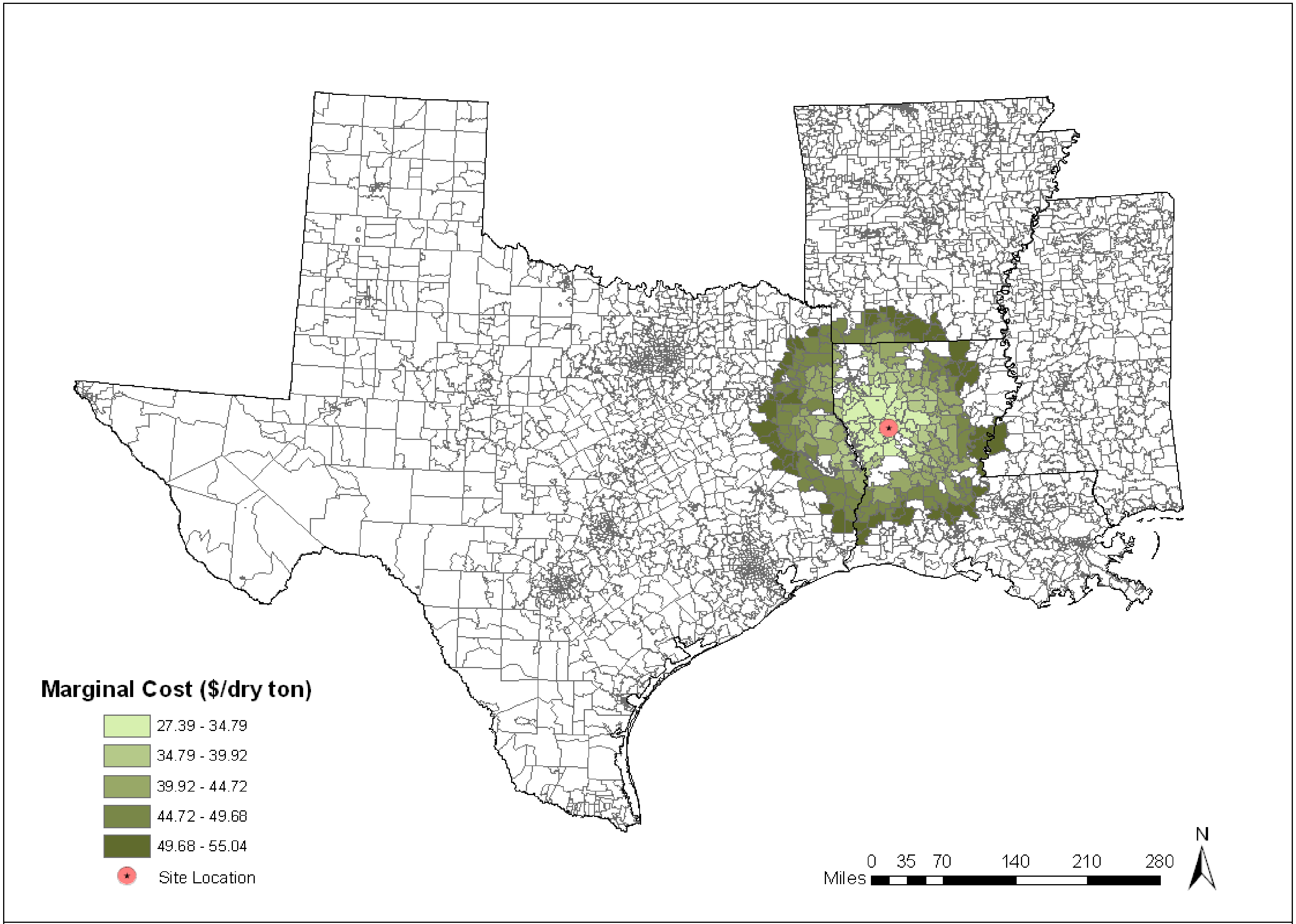

Figure B18. MC by ZCTA of hardwood mill residues for the 71066 zip code bio-basin.

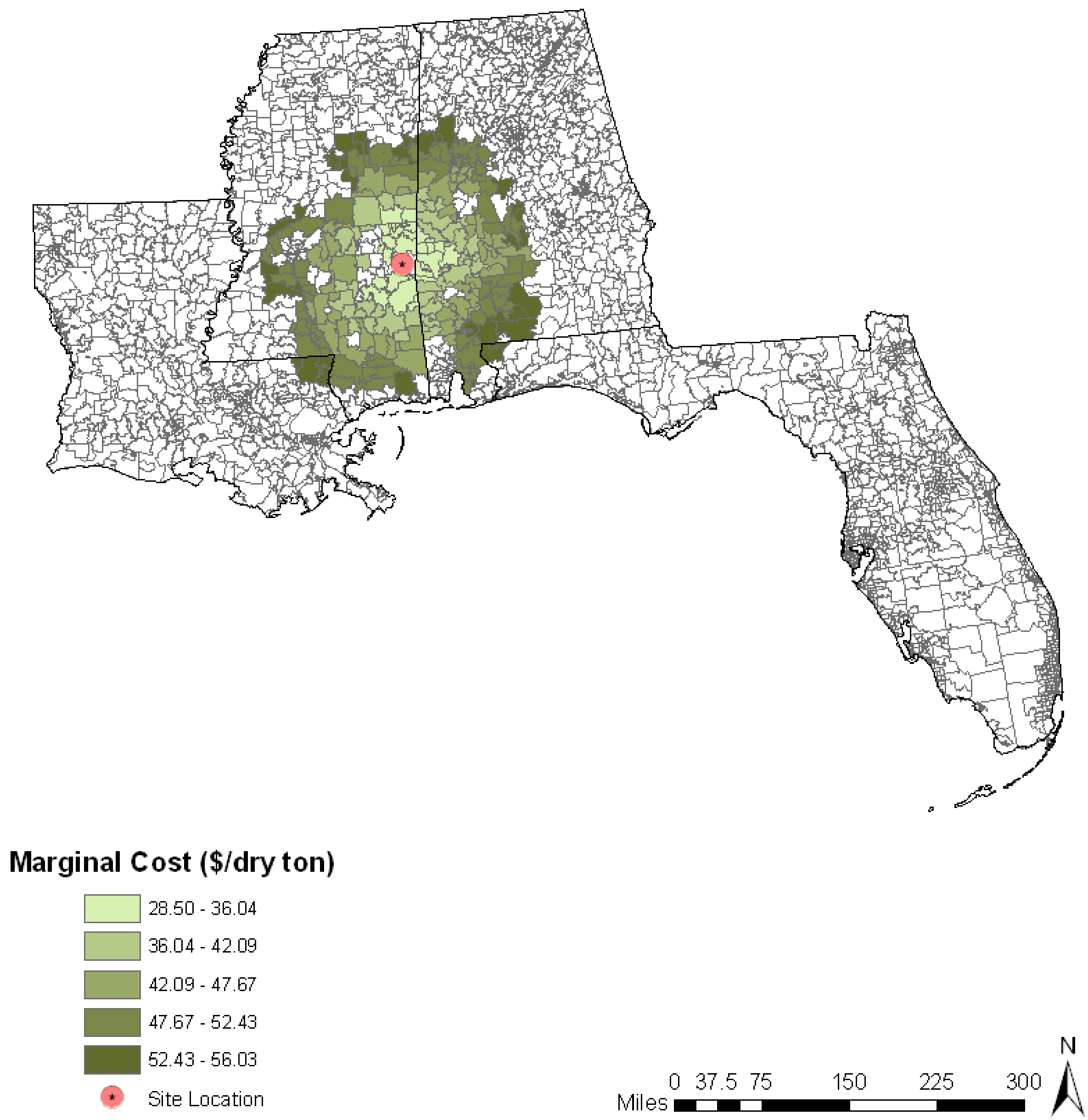

Figure B19. MC by ZCTA of hardwood mill residues for the 39355 zip code bio-basin.

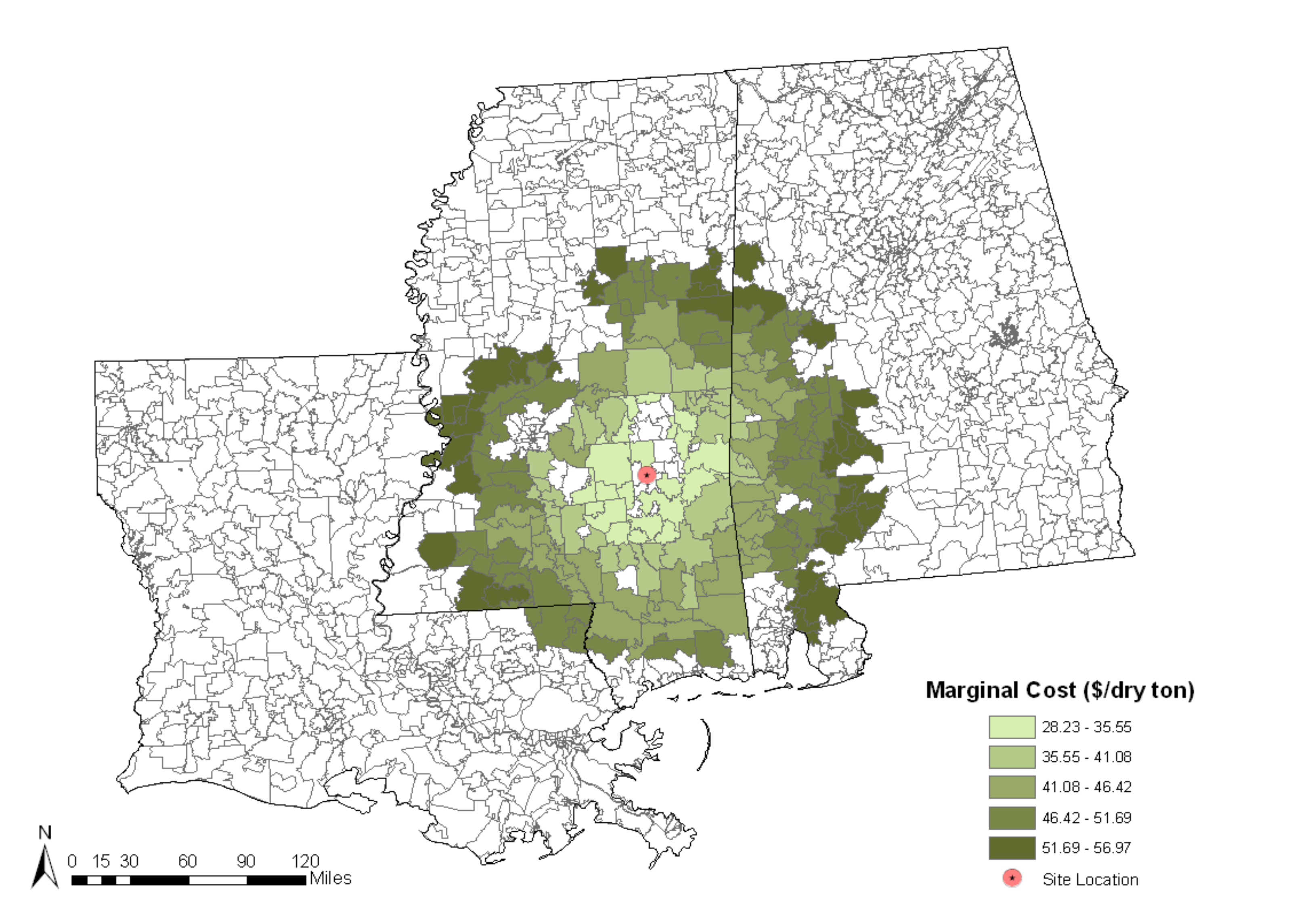

Figure B20. MC by ZCTA of hardwood mill residues for the 39422 zip code bio-basin.

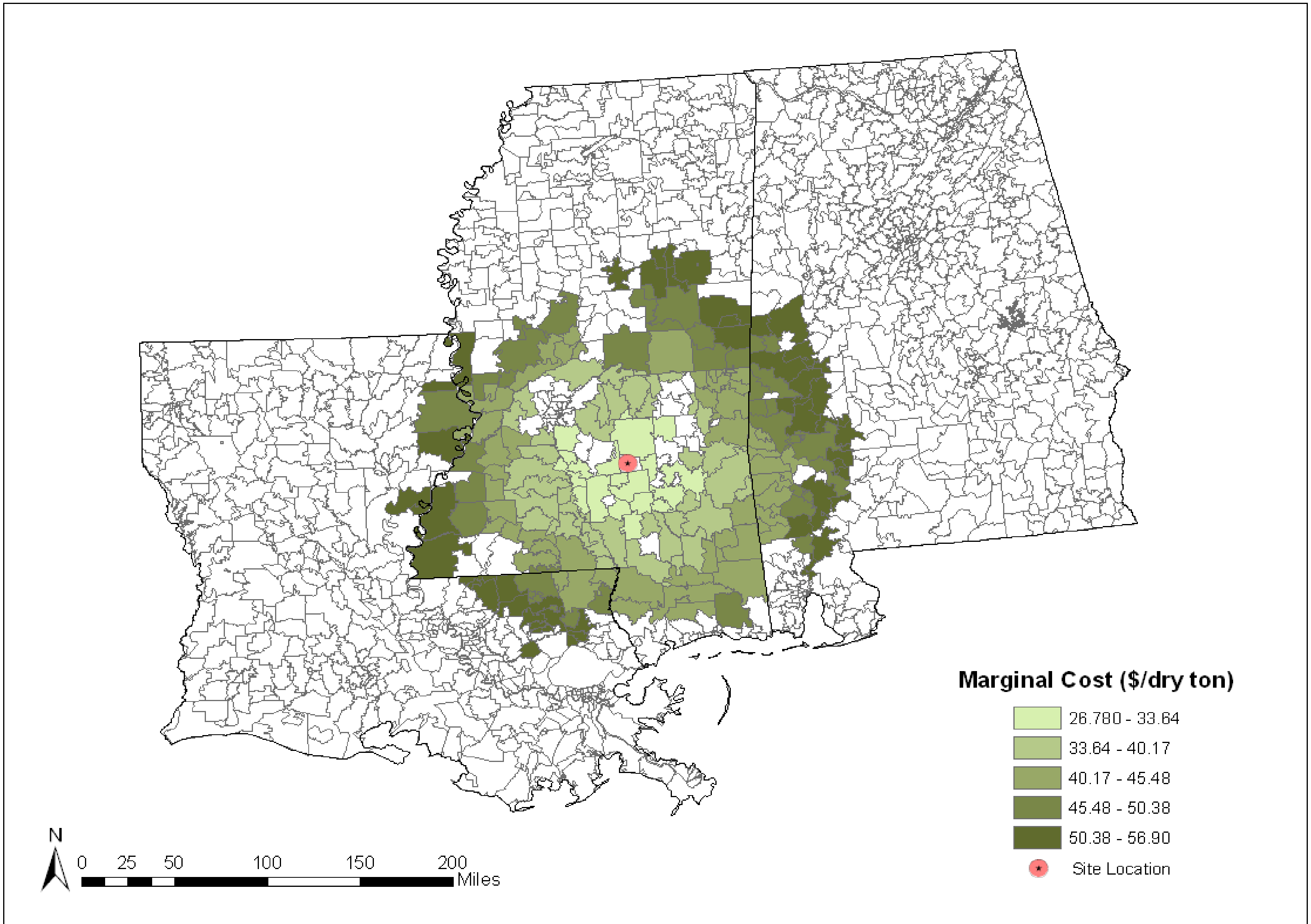

Figure B21. MC by ZCTA of softwood mill residues for the 39116 zip code bio-basin.

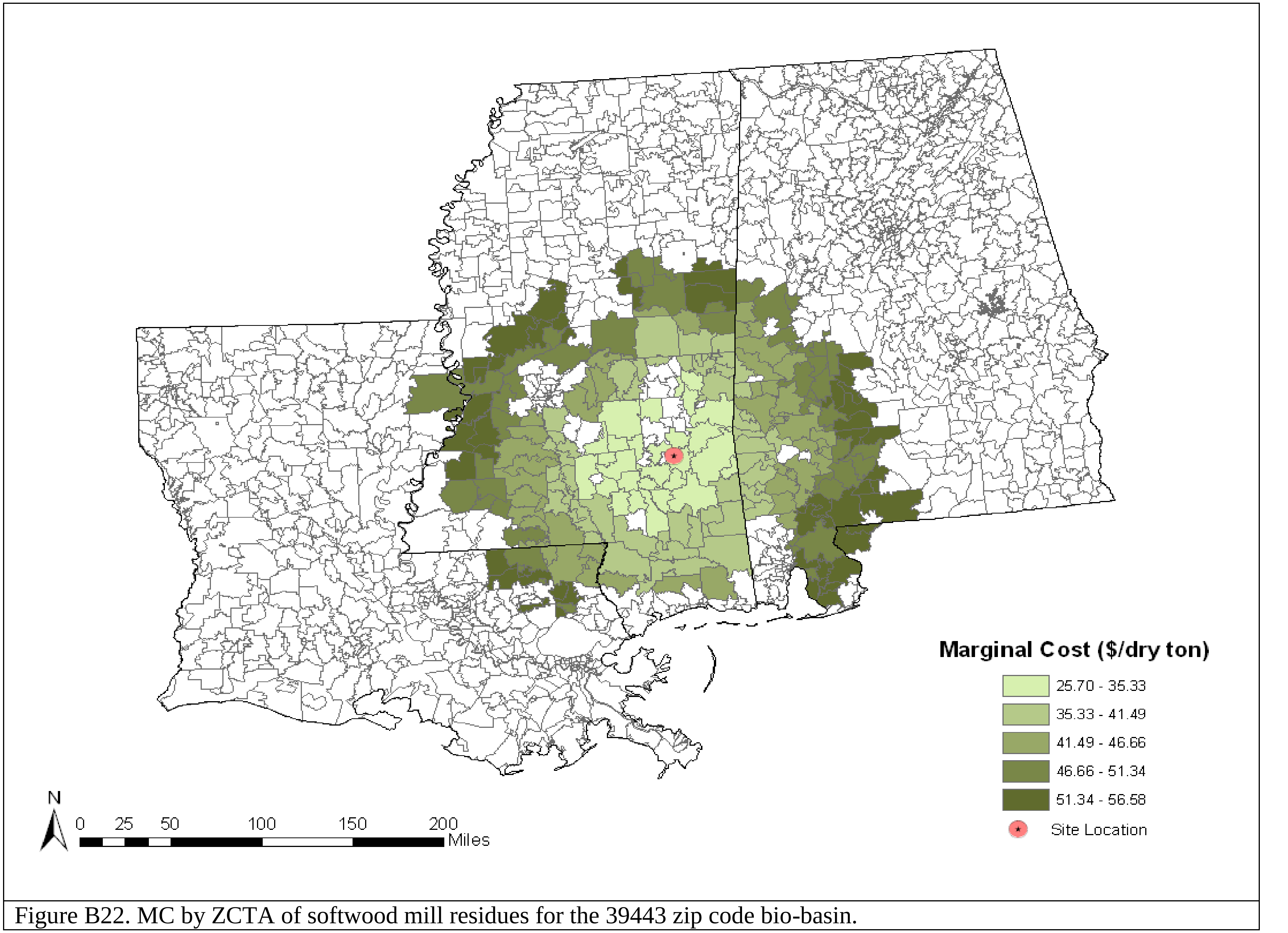

Figure B22. MC by ZCTA of softwood mill residues for the 39443 zip code bio-basin.

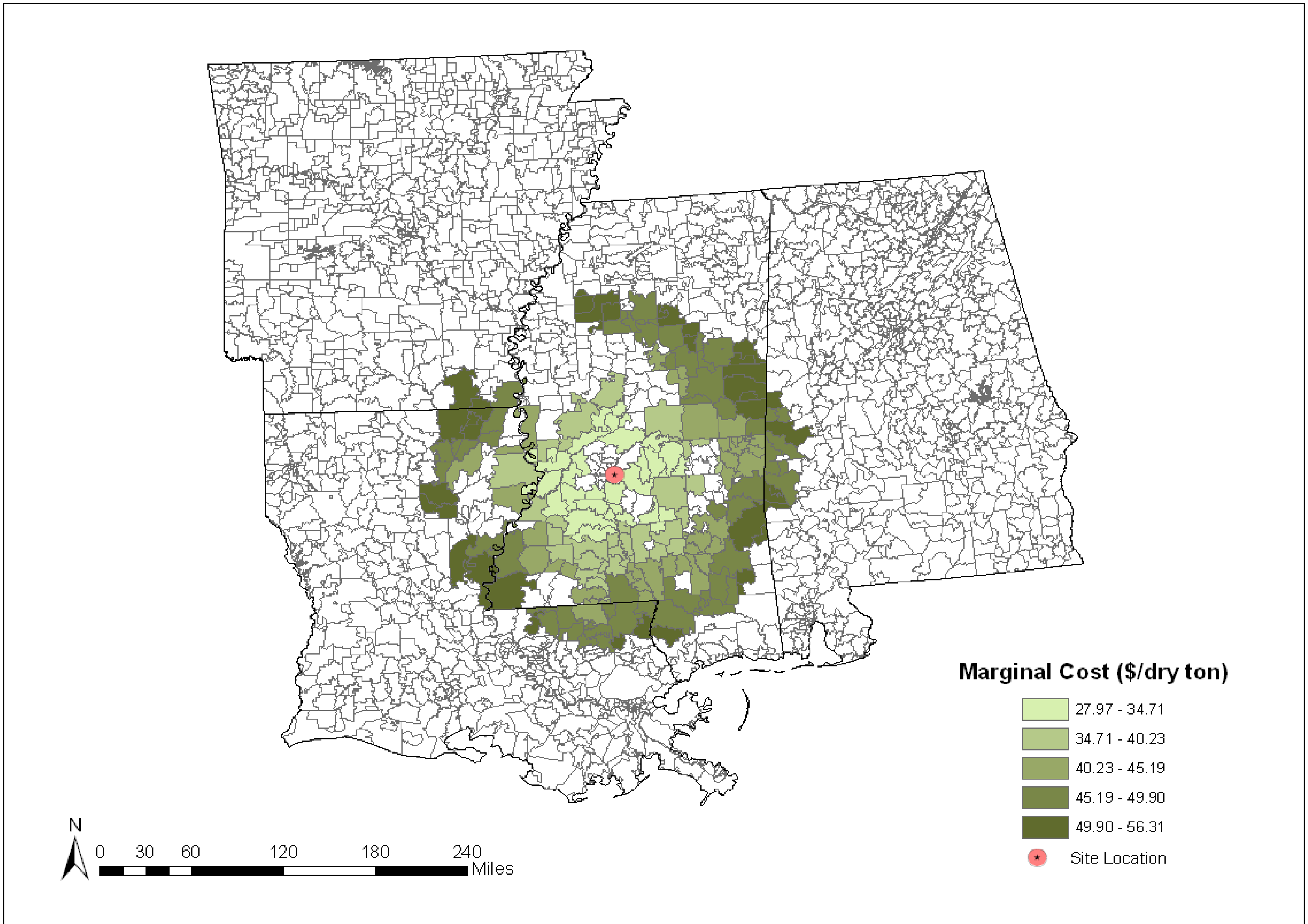

Figure B23. MC by ZCTA of softwood mill residues for the 39288 zip code bio-basin.

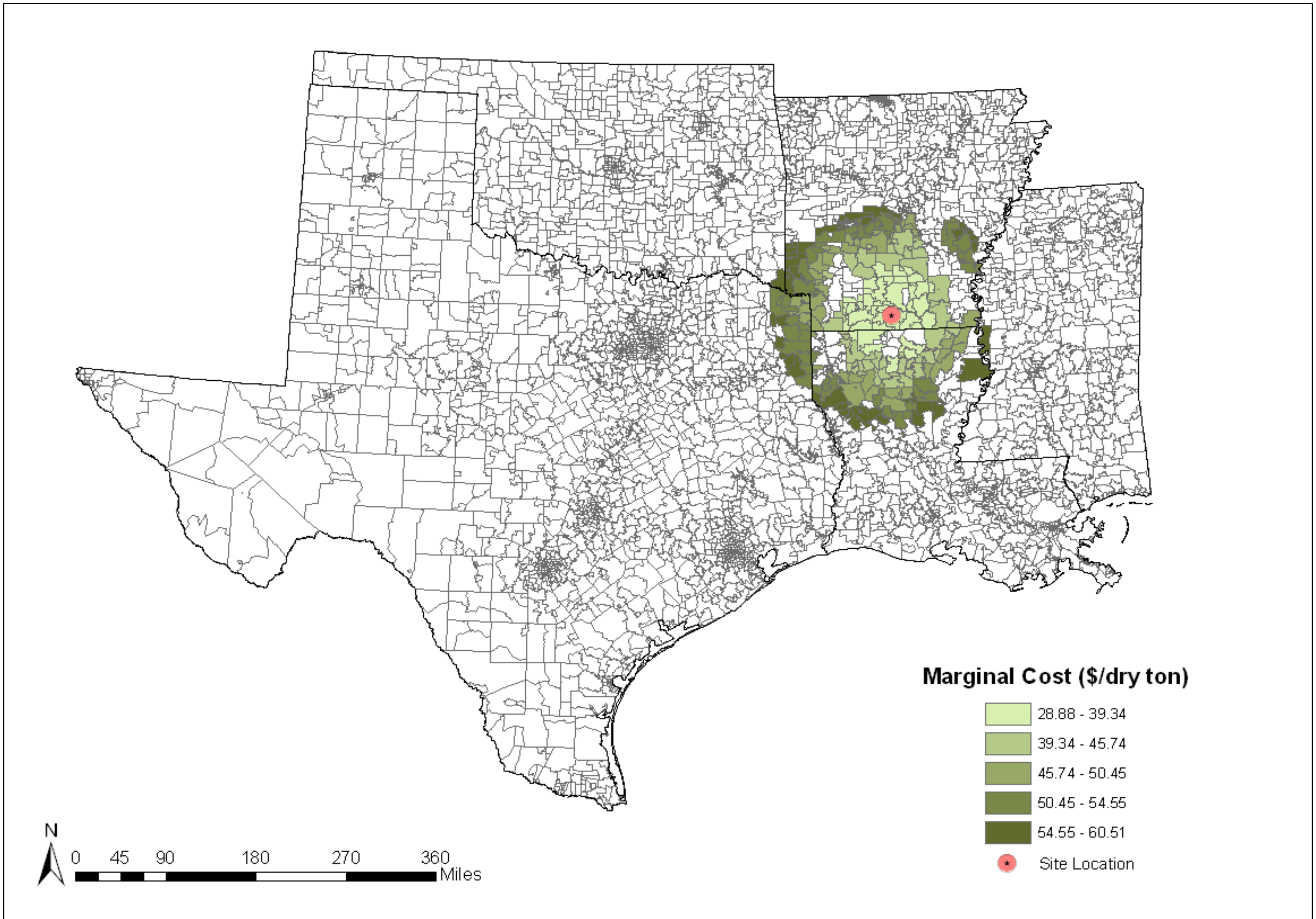

Figure B24. MC by ZCTA of softwood mill residues for the 71759 zip code bio-basin.

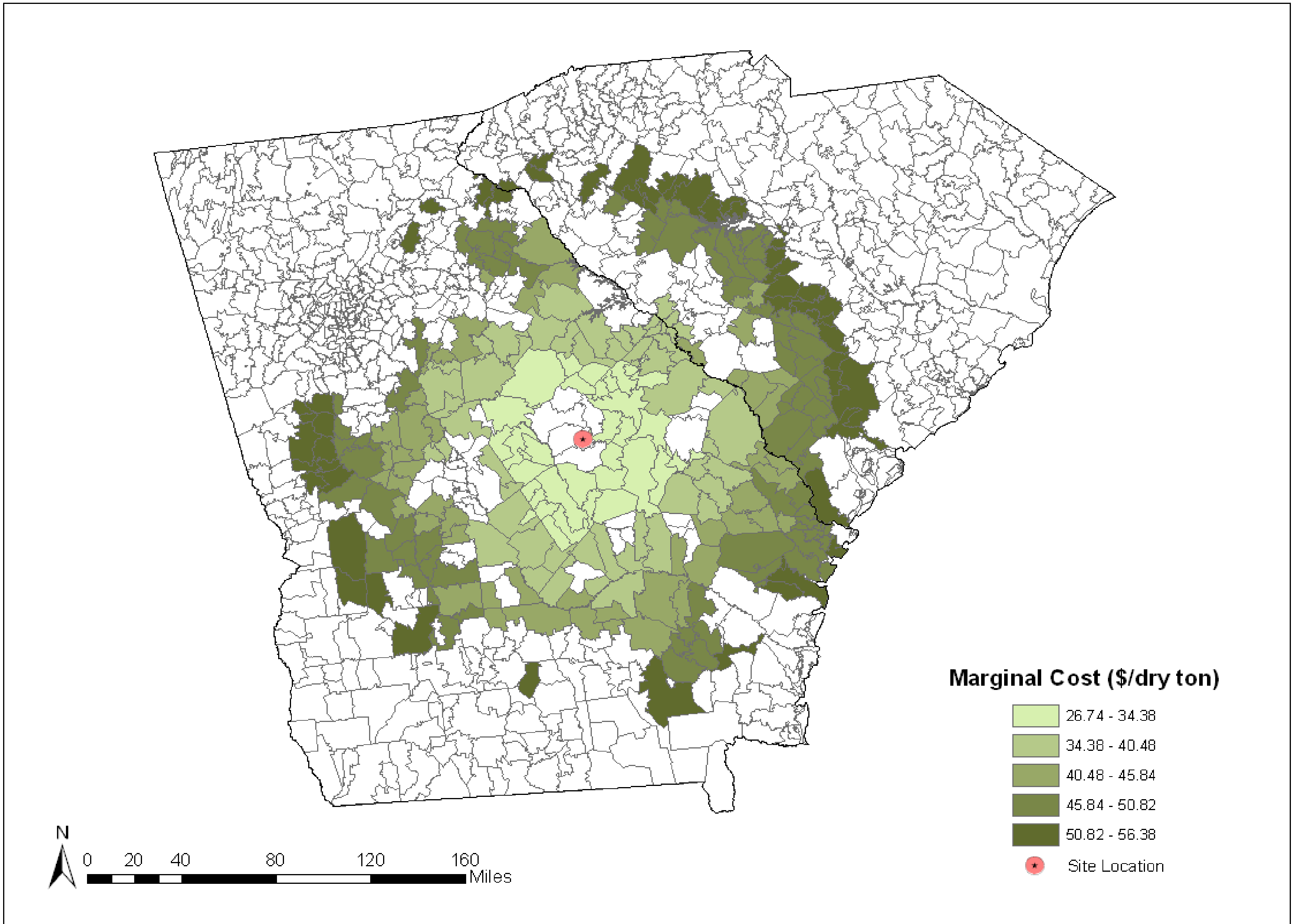

Figure B25. MC by ZCTA of softwood mill residues for the 31035 zip code bio-basin.

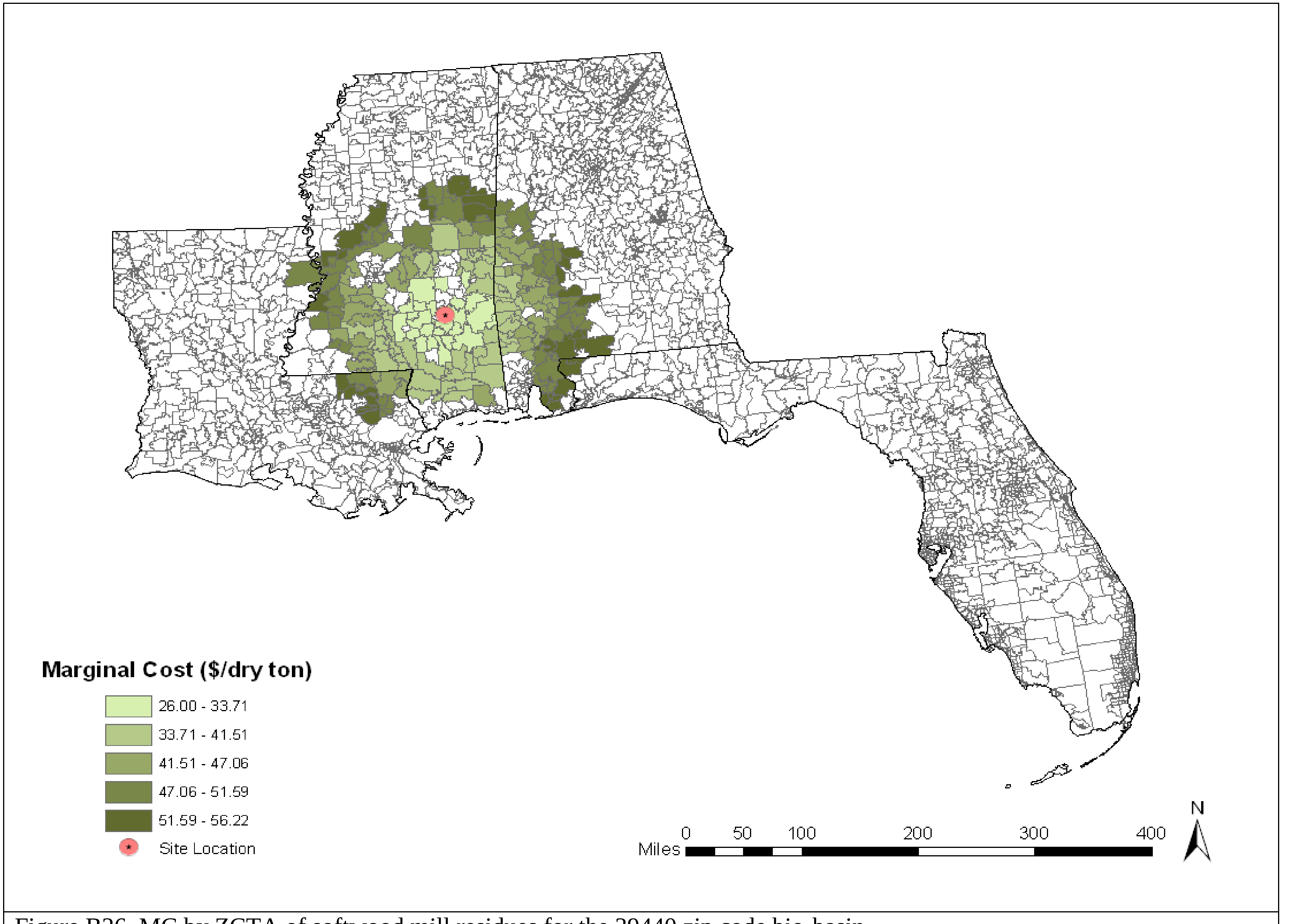

Figure B26. MC by ZCTA of softwood mill residues for the 39440 zip code bio-basin.

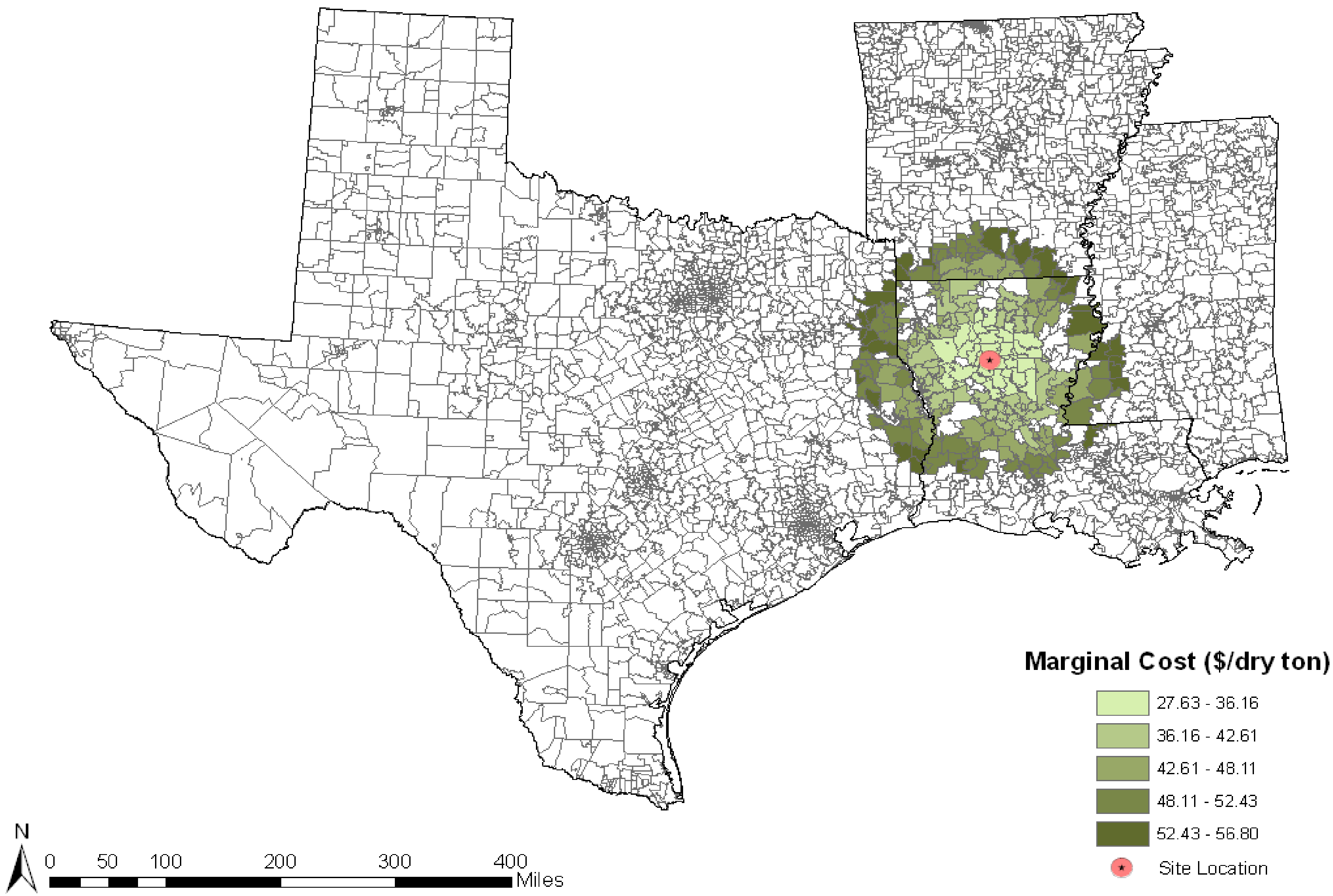

Figure B27. MC by ZCTA of softwood mill residues for the 71483 zip code bio-basin.

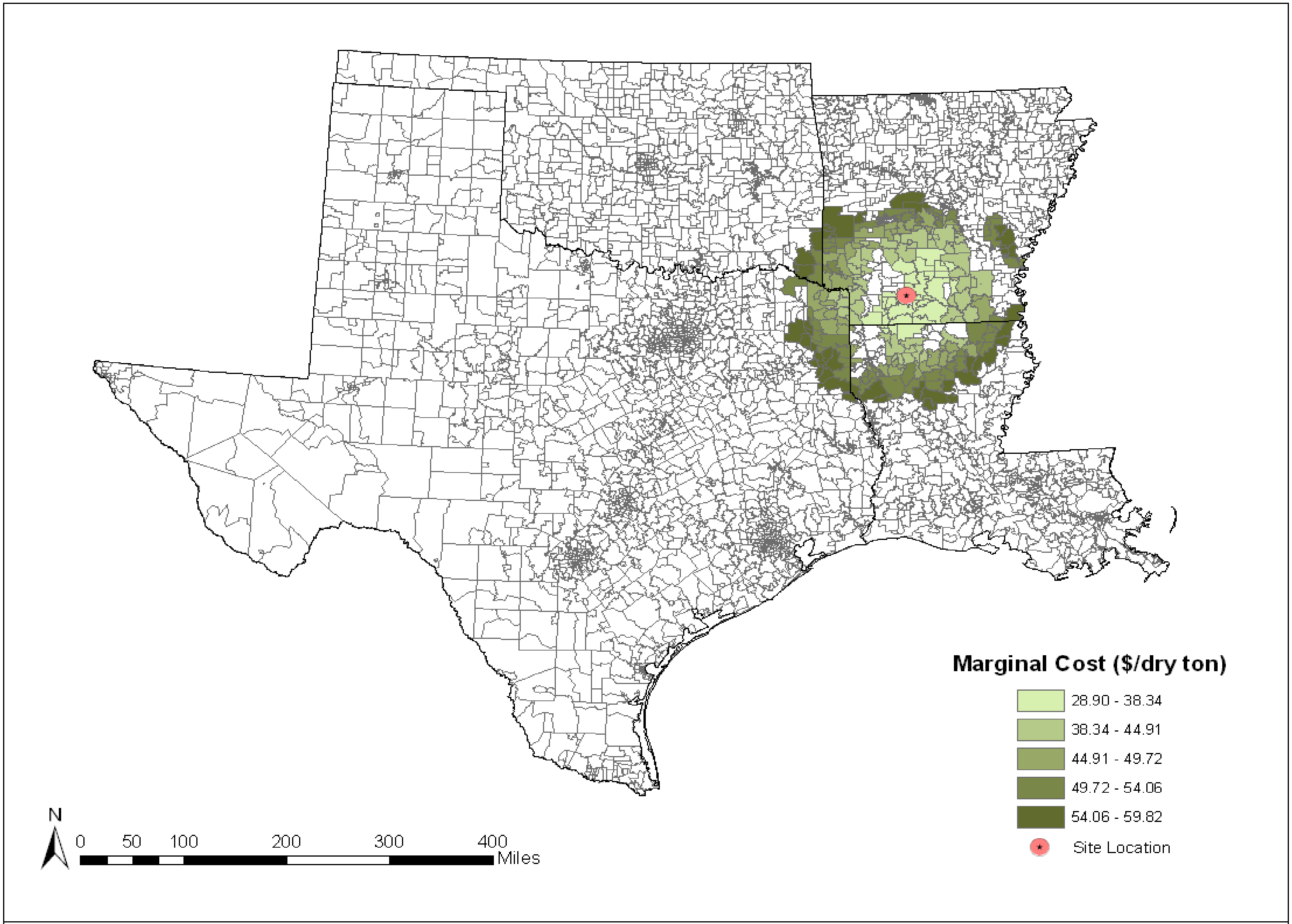

Figure B28. MC by ZCTA of softwood mill residues for the 71764 zip code bio-basin.

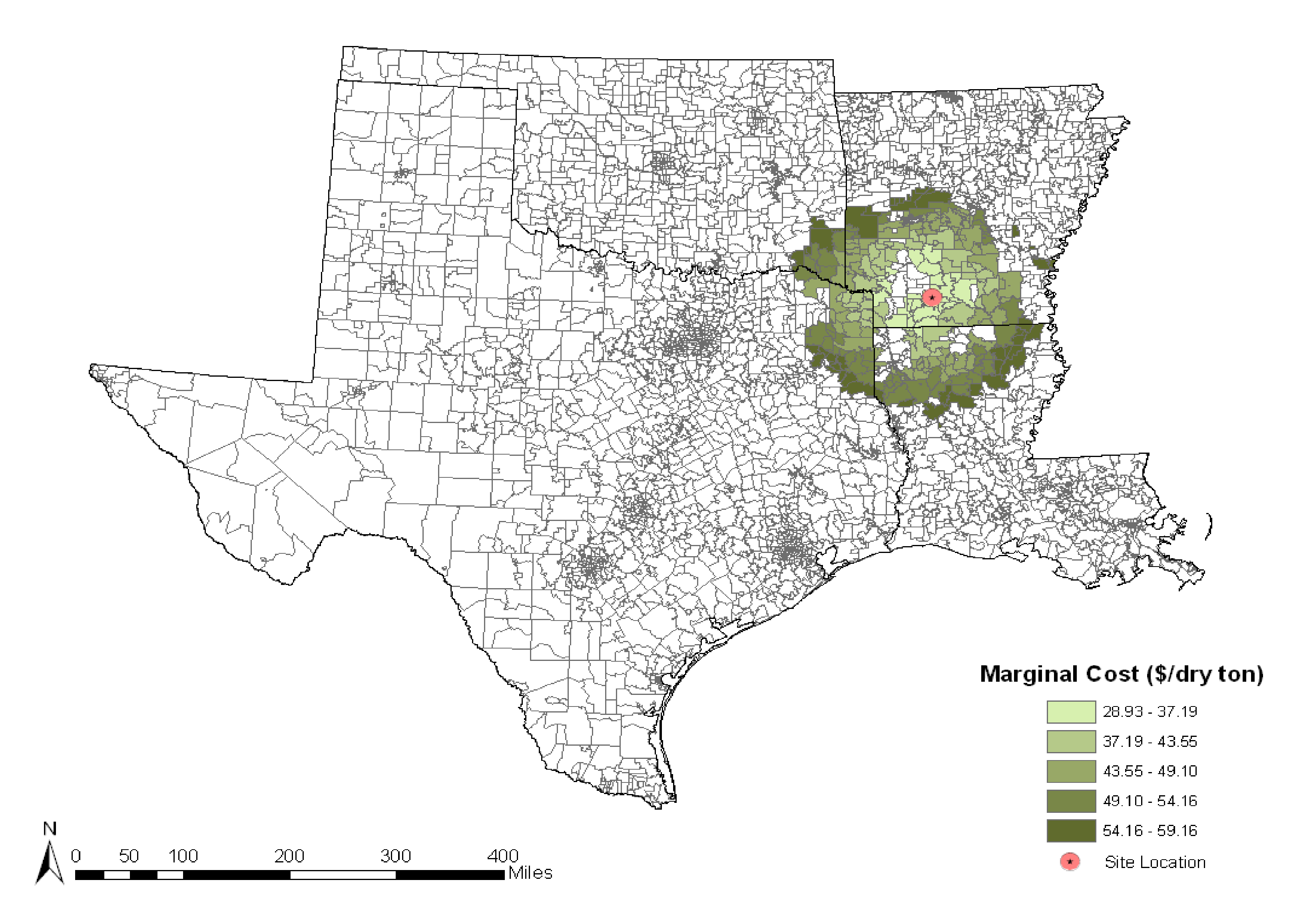

Figure B29. MC by ZCTA of softwood mill residues for the 71858 zip code bio-basin.

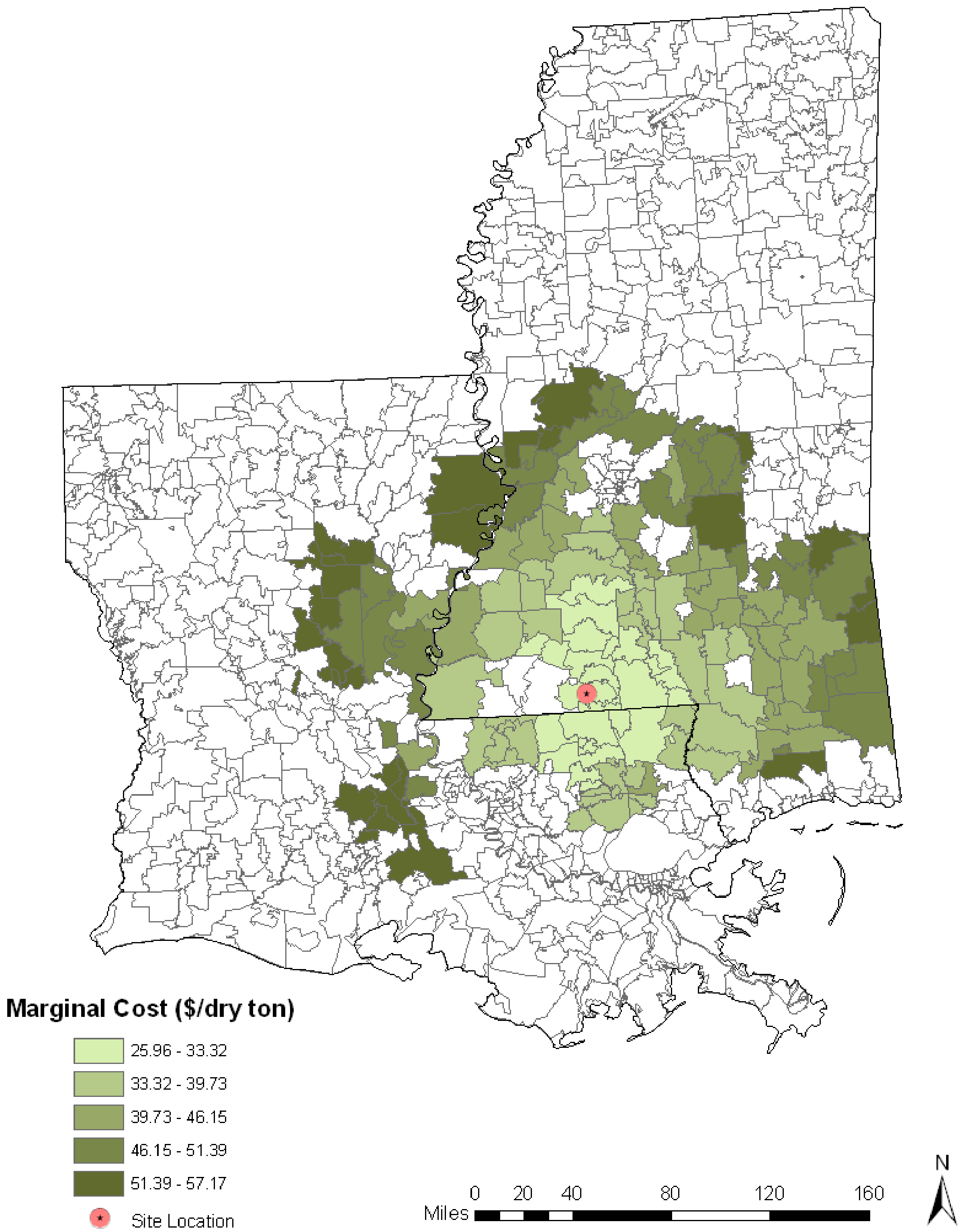

Figure B30. MC by ZCTA of softwood mill residues for the 39652 zip code bio-basin.

Appendix C

Bio-basin ZCTA maps for the top ten sites for logging residues for southern region with MCs.

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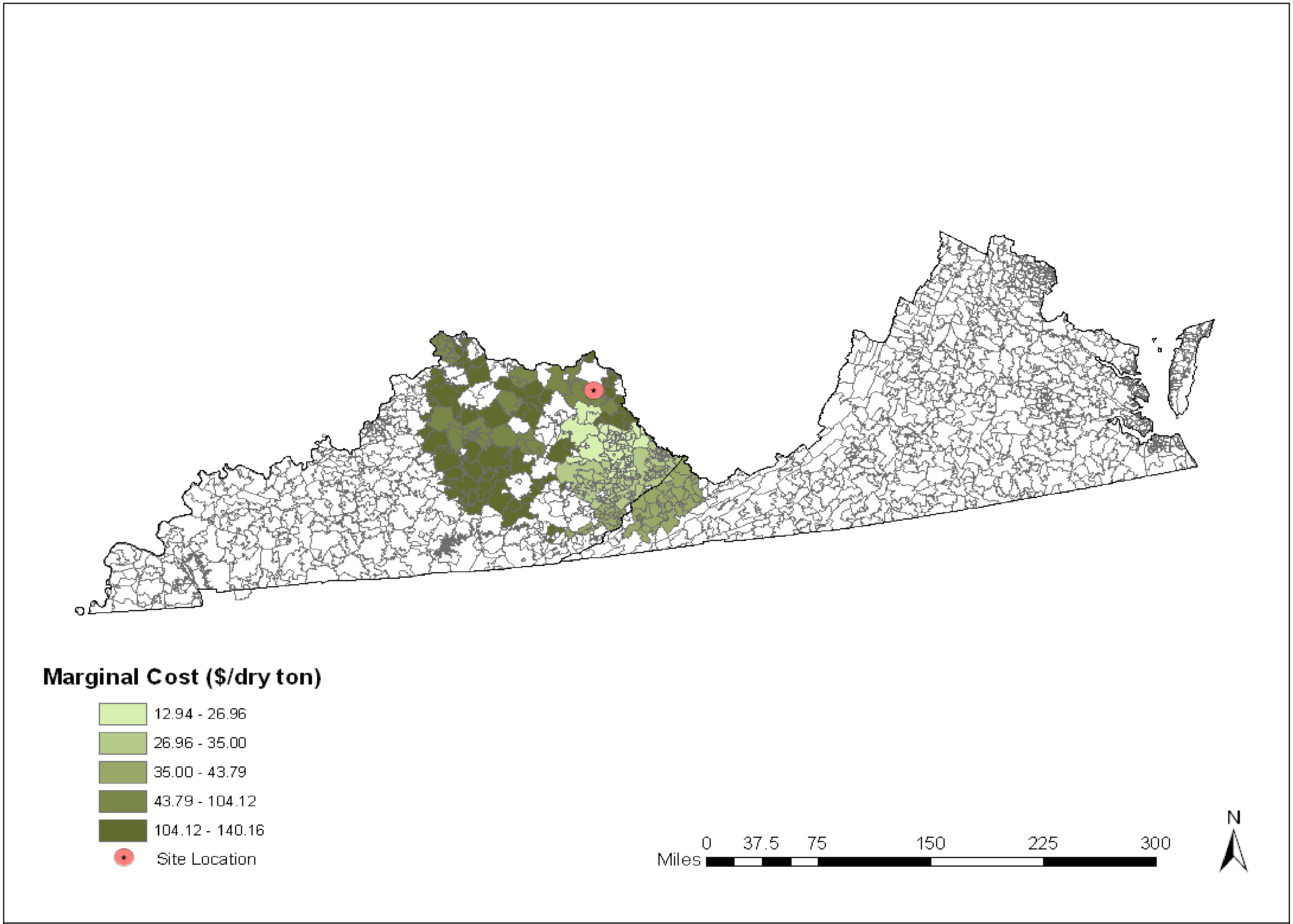

Figure C1. MC by ZCTA of total logging residues for the 41143 zip code bio-basin.

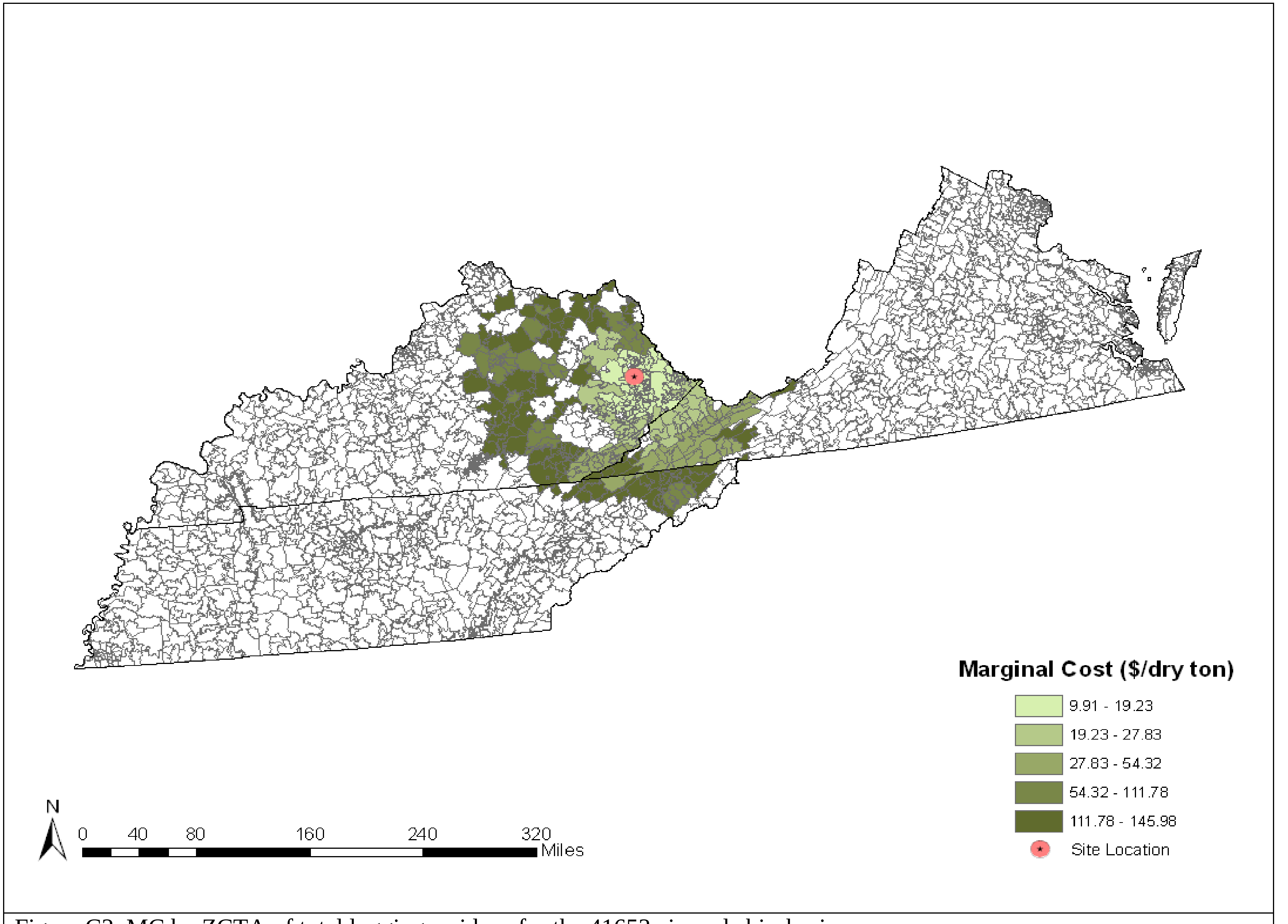

Figure C2. MC by ZCTA of total logging residues for the 41653 zip code bio-basin.

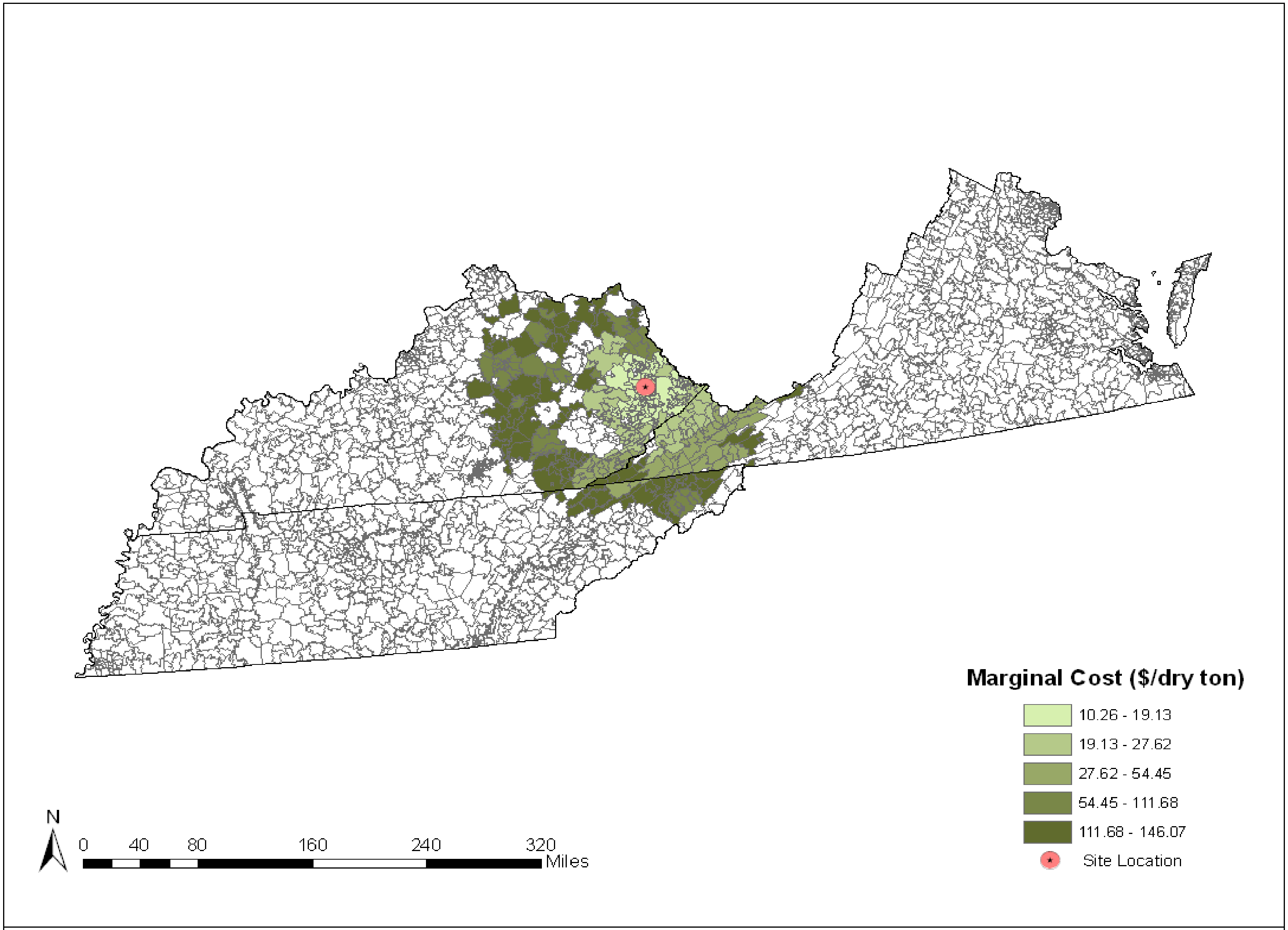

Figure C3. MC by ZCTA of total logging residues for the 41601 zip code bio-basin.

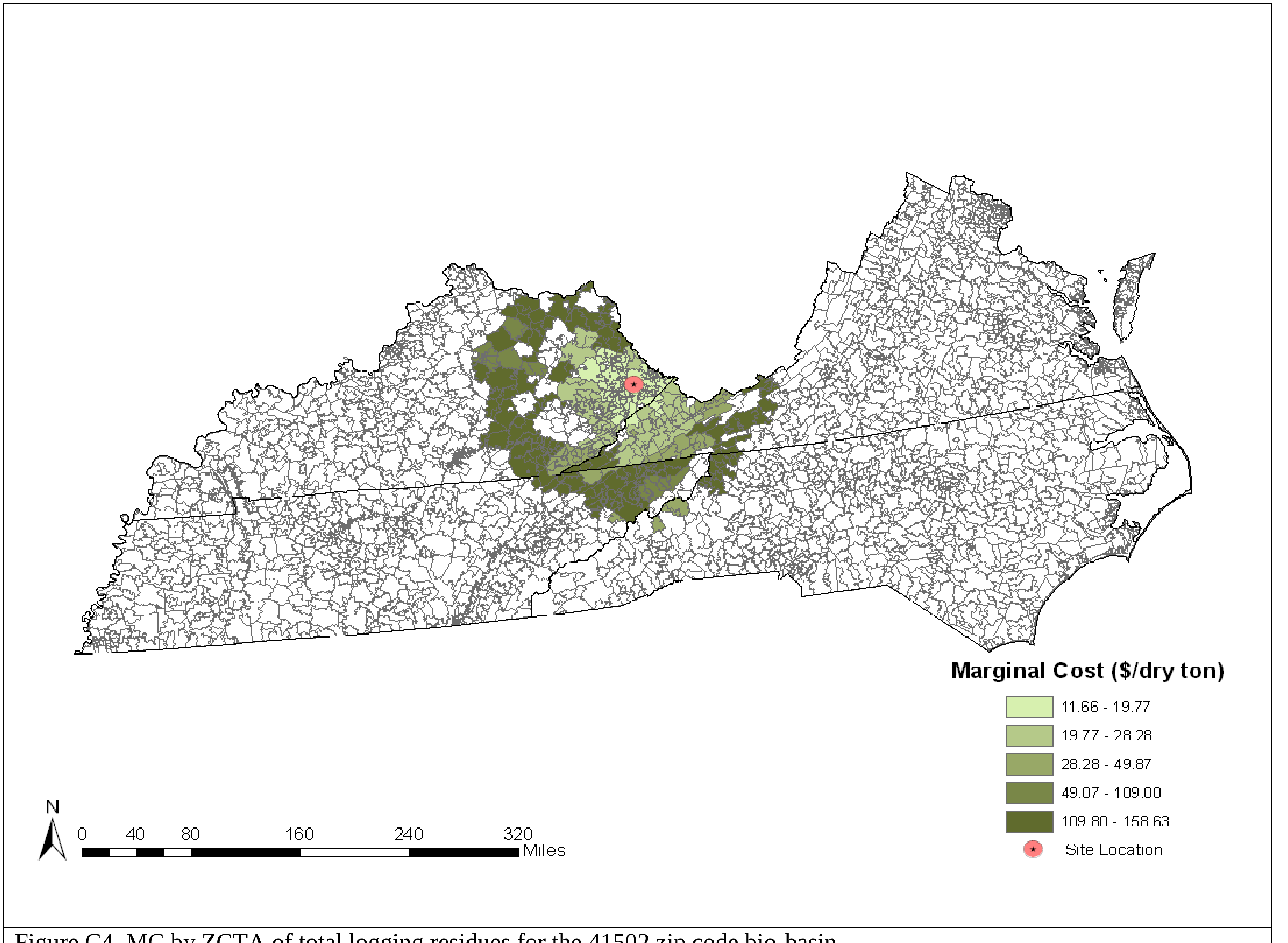

Figure C4. MC by ZCTA of total logging residues for the 41502 zip code bio-basin.

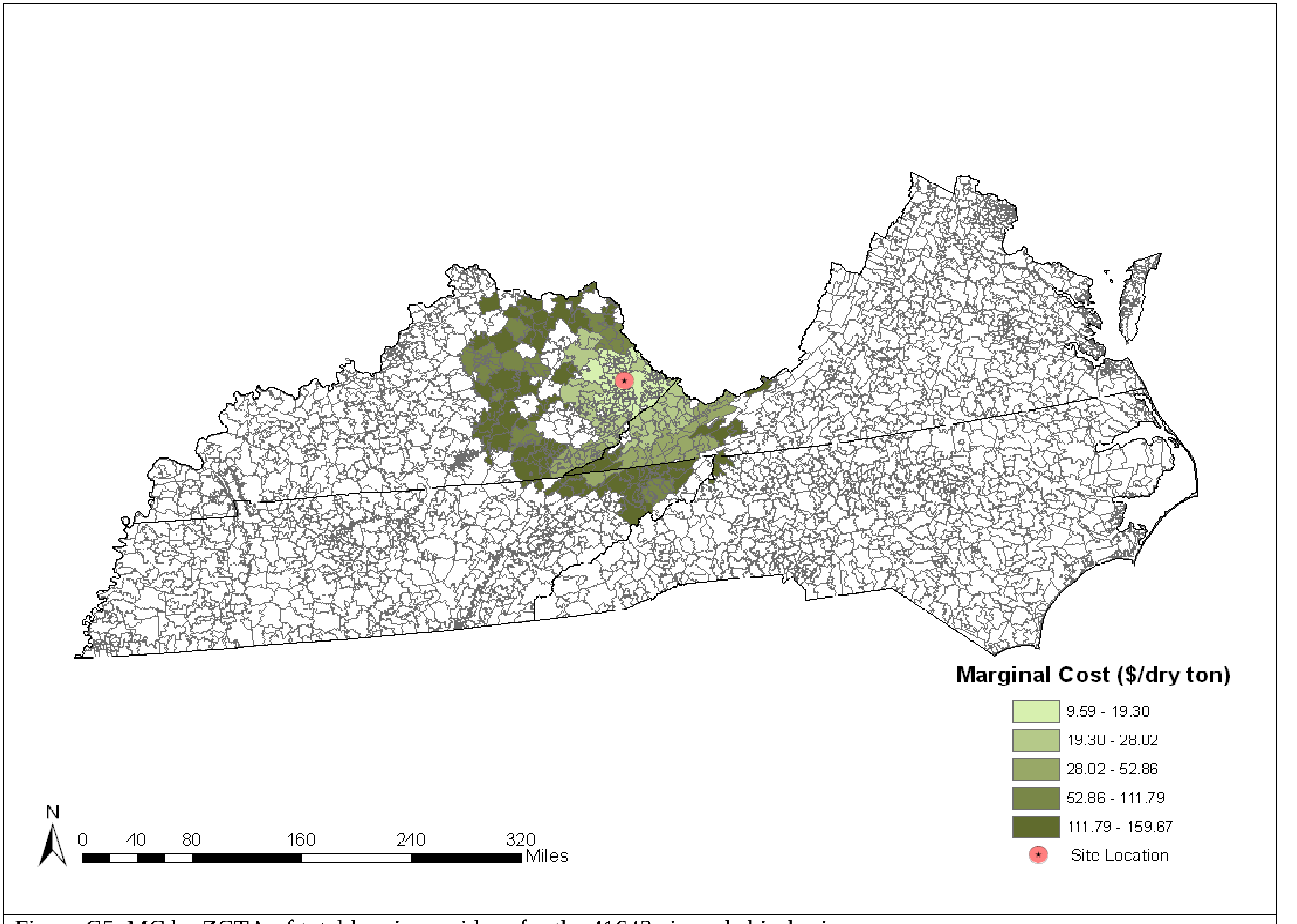

Figure C5. MC by ZCTA of total logging residues for the 41642 zip code bio-basin.

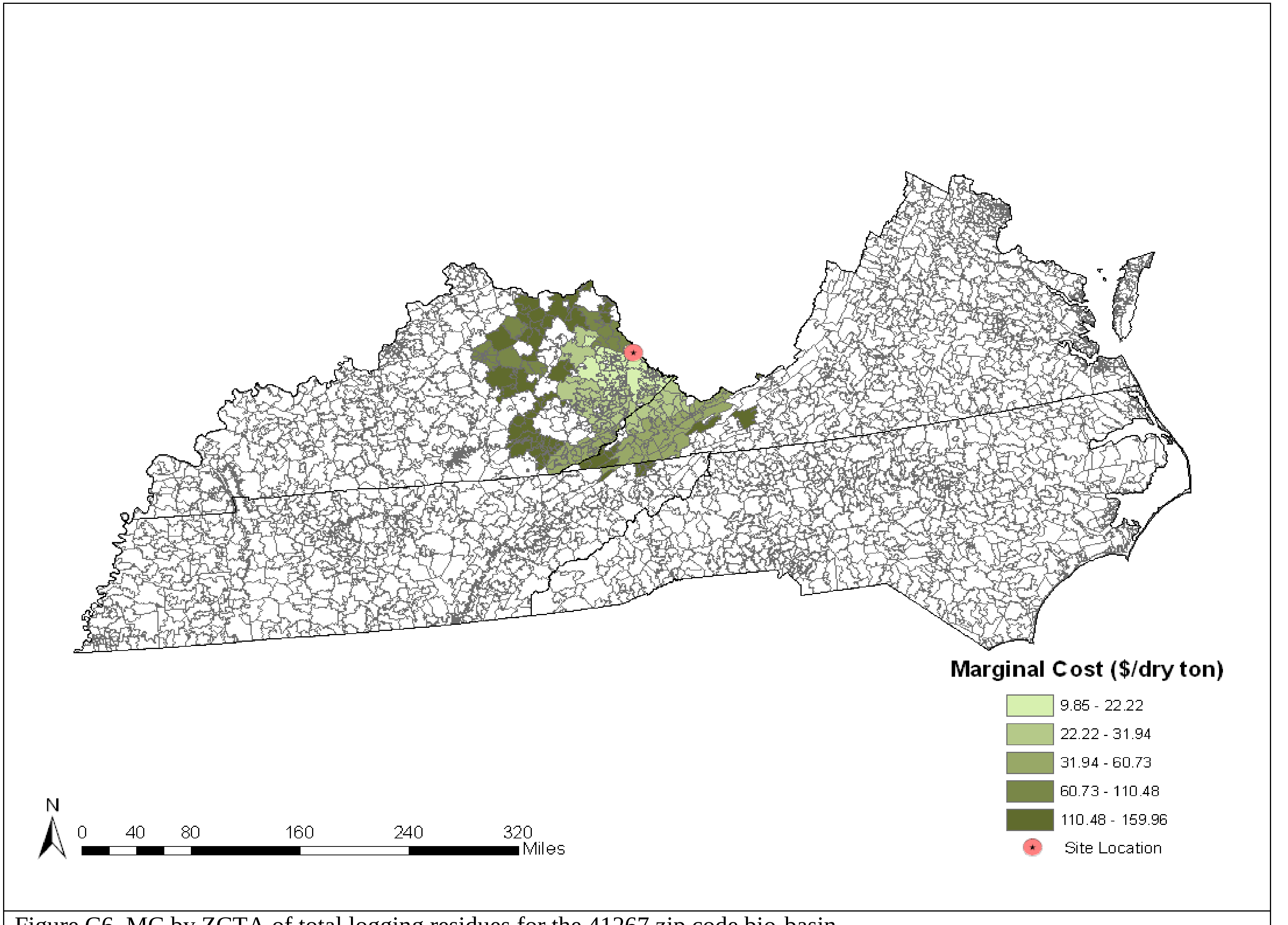

Figure C6. MC by ZCTA of total logging residues for the 41267 zip code bio-basin.

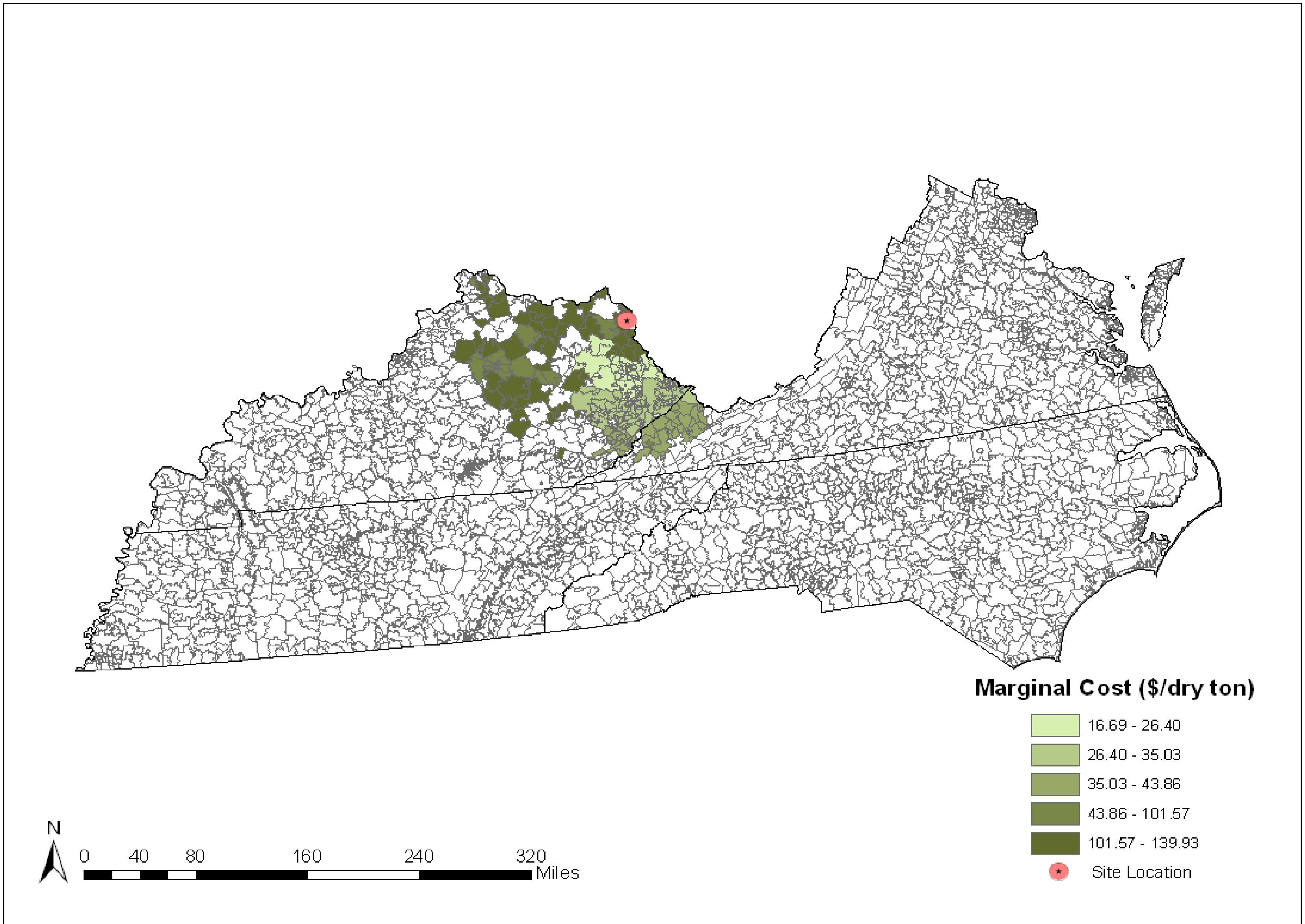

Figure C7. MC by ZCTA of total logging residues for the 41129 zip code bio-basin.

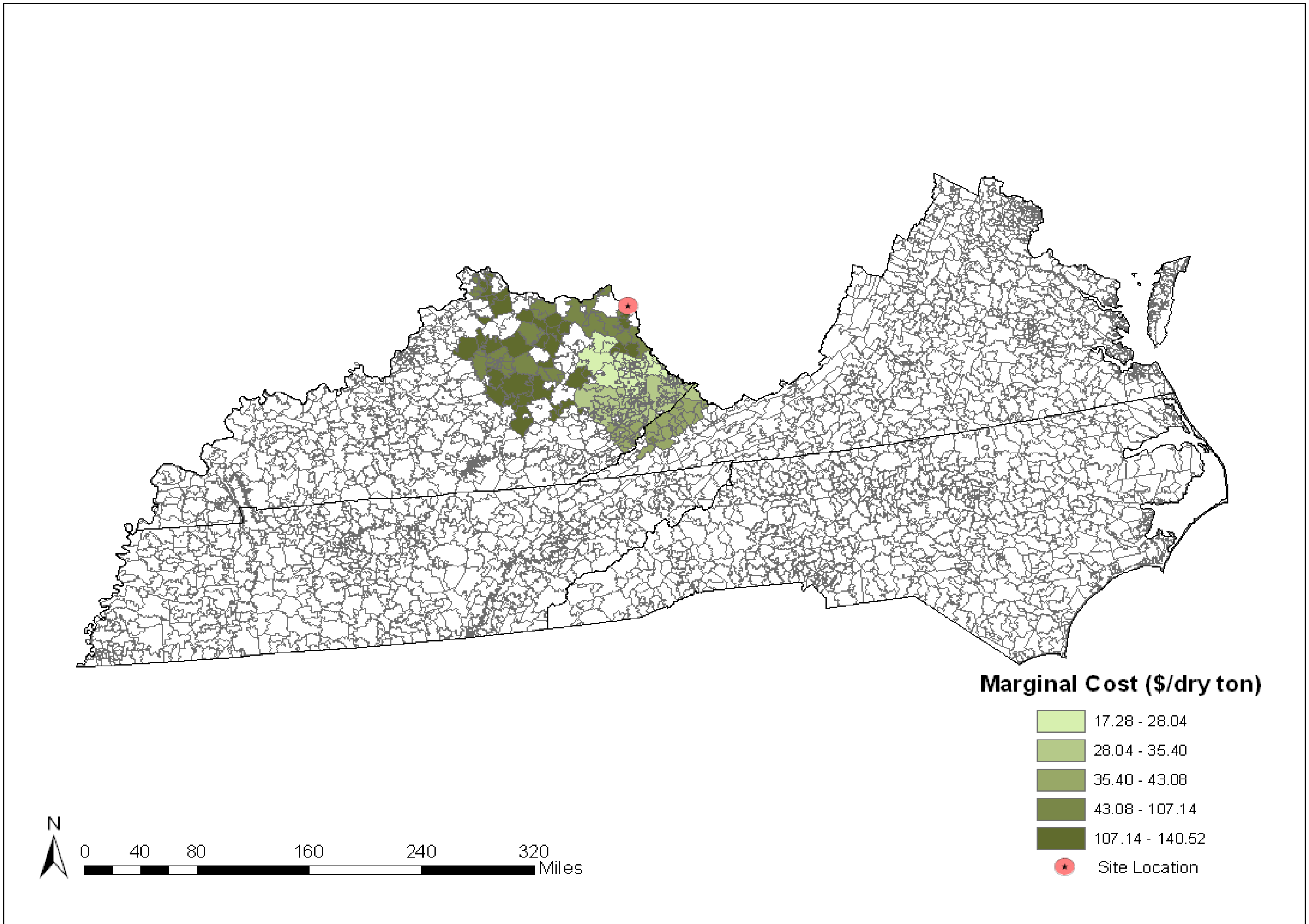

Figure C8. MC by ZCTA of total logging residues for the 41168 zip code bio-basin.

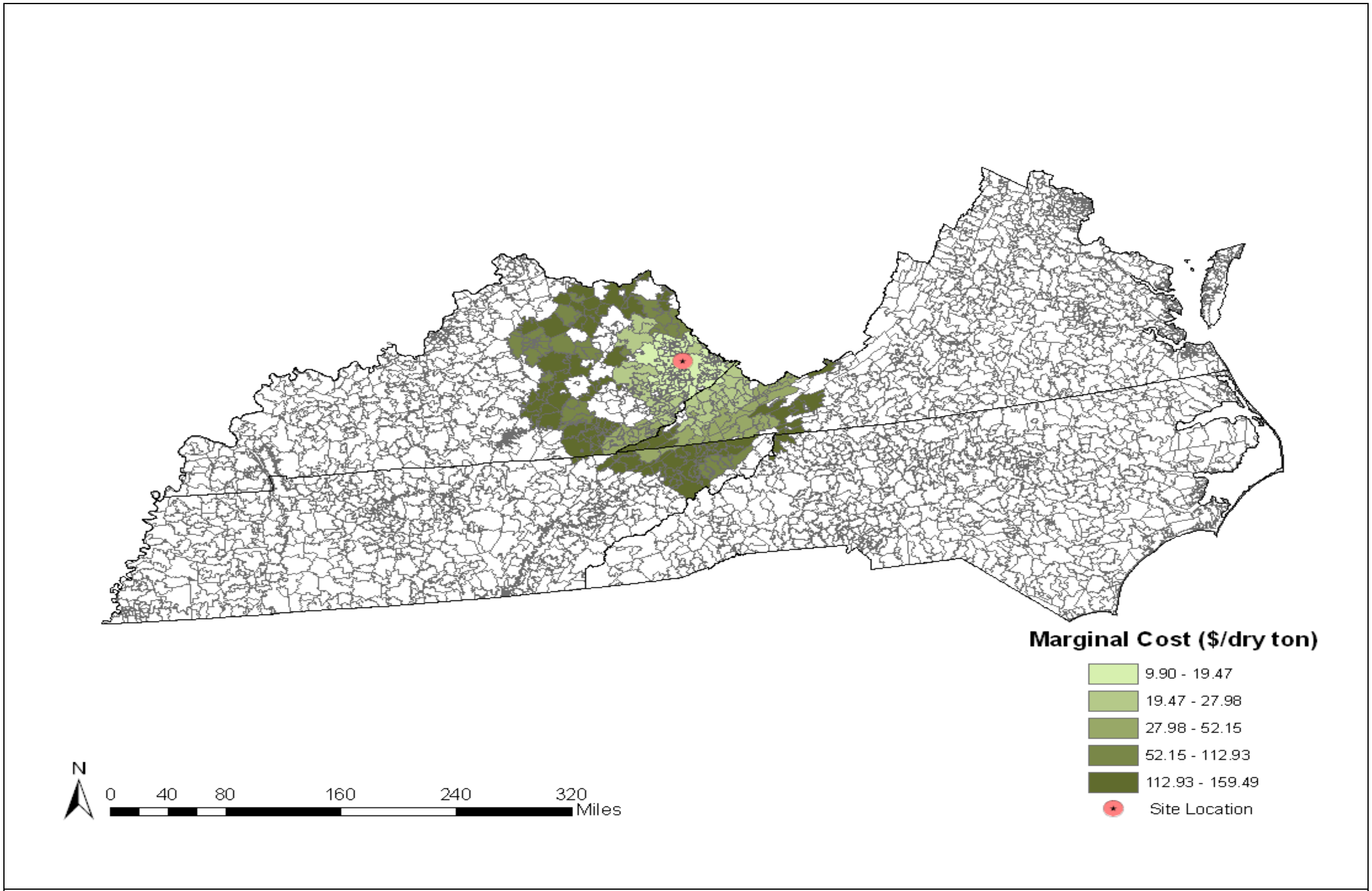

Figure C9. MC by ZCTA of total logging residues for the 41659 zip code bio-basin.

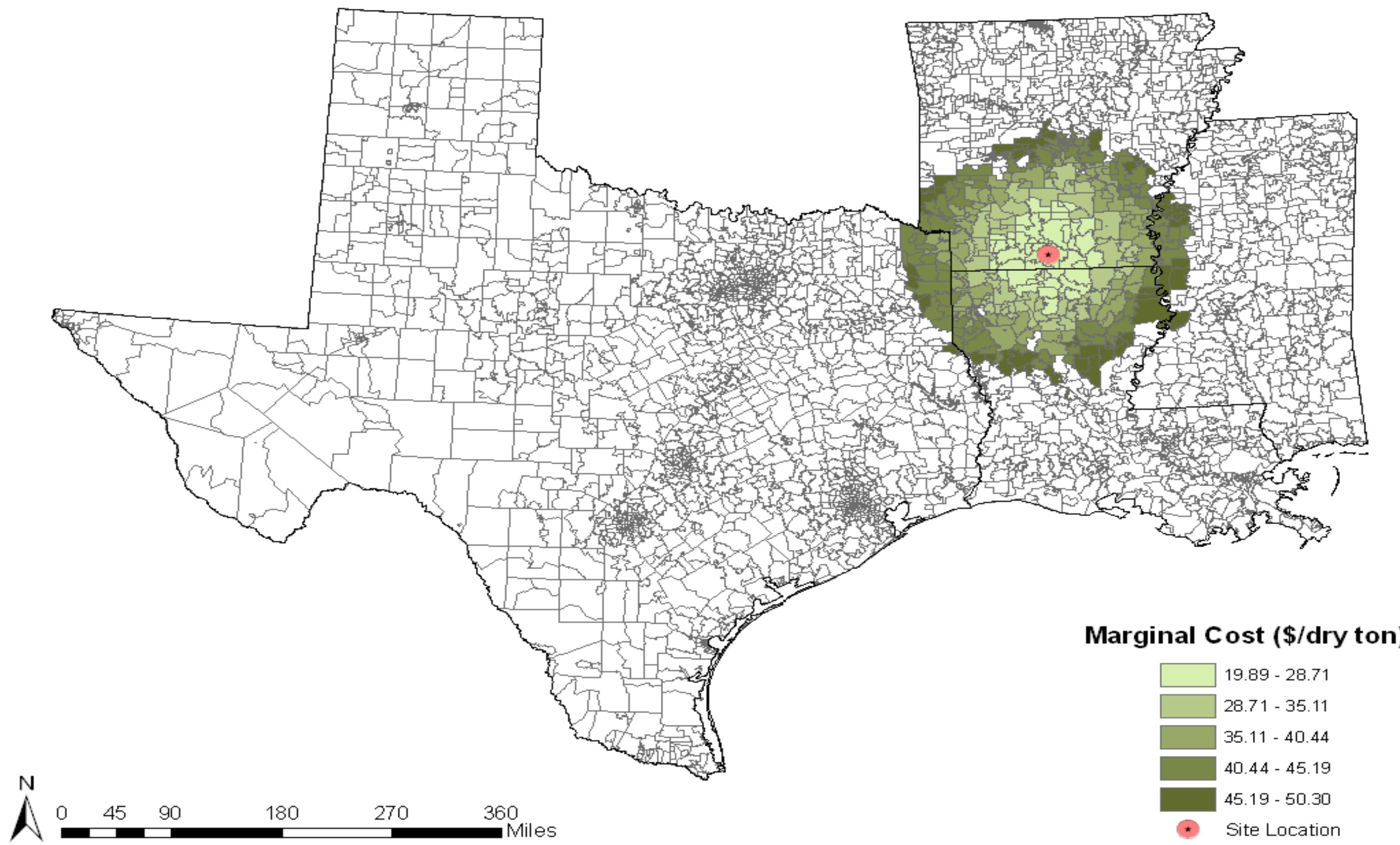

Figure C10. MC by ZCTA of at landing logging residues for the 71730 zip code bio-basin.

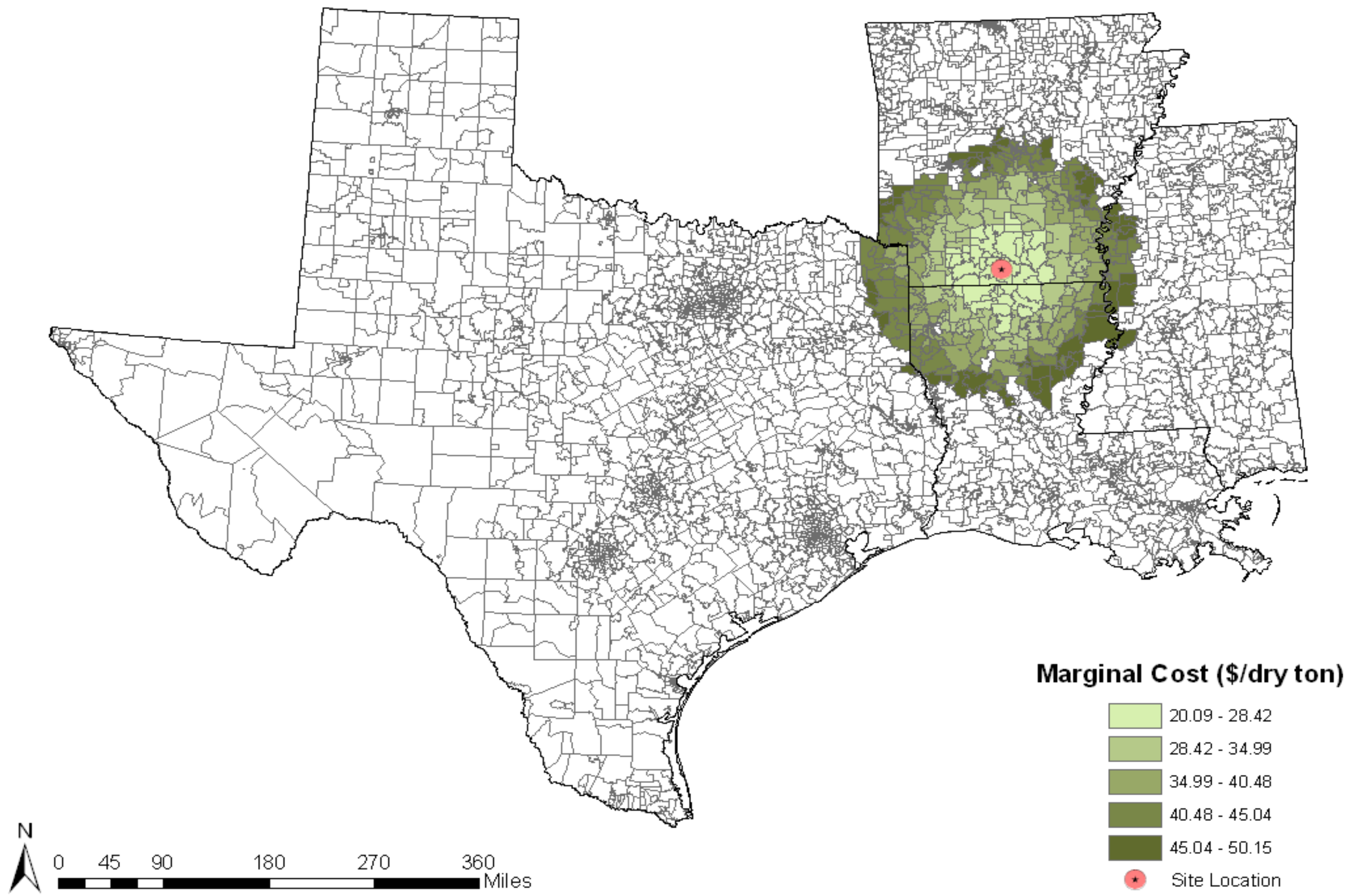

Figure C11. MC by ZCTA of at landing logging residues for the 71731 zip code bio-basin.

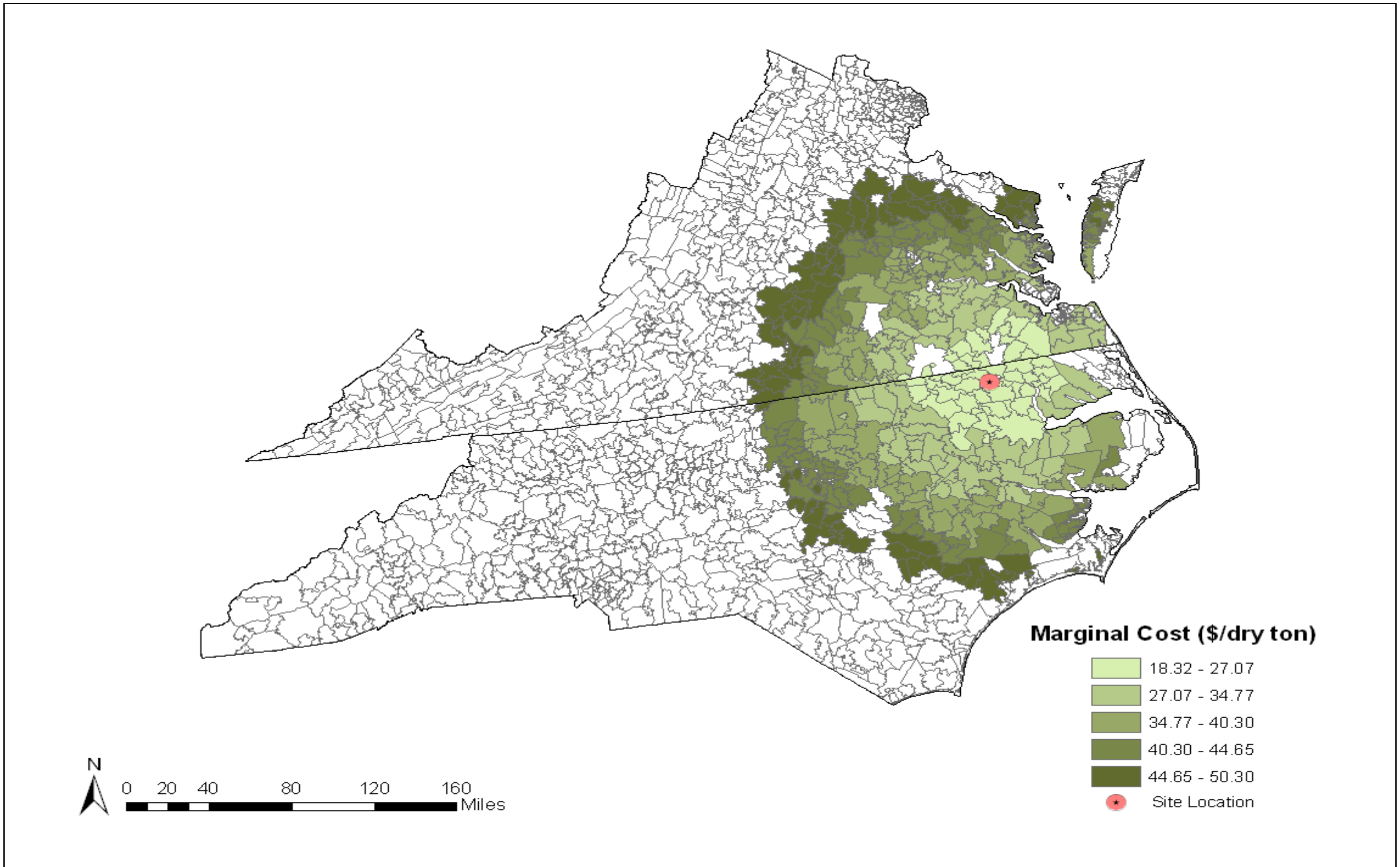

Figure C12. MC by ZCTA of at landing logging residues for the 27855 zip code bio-basin.

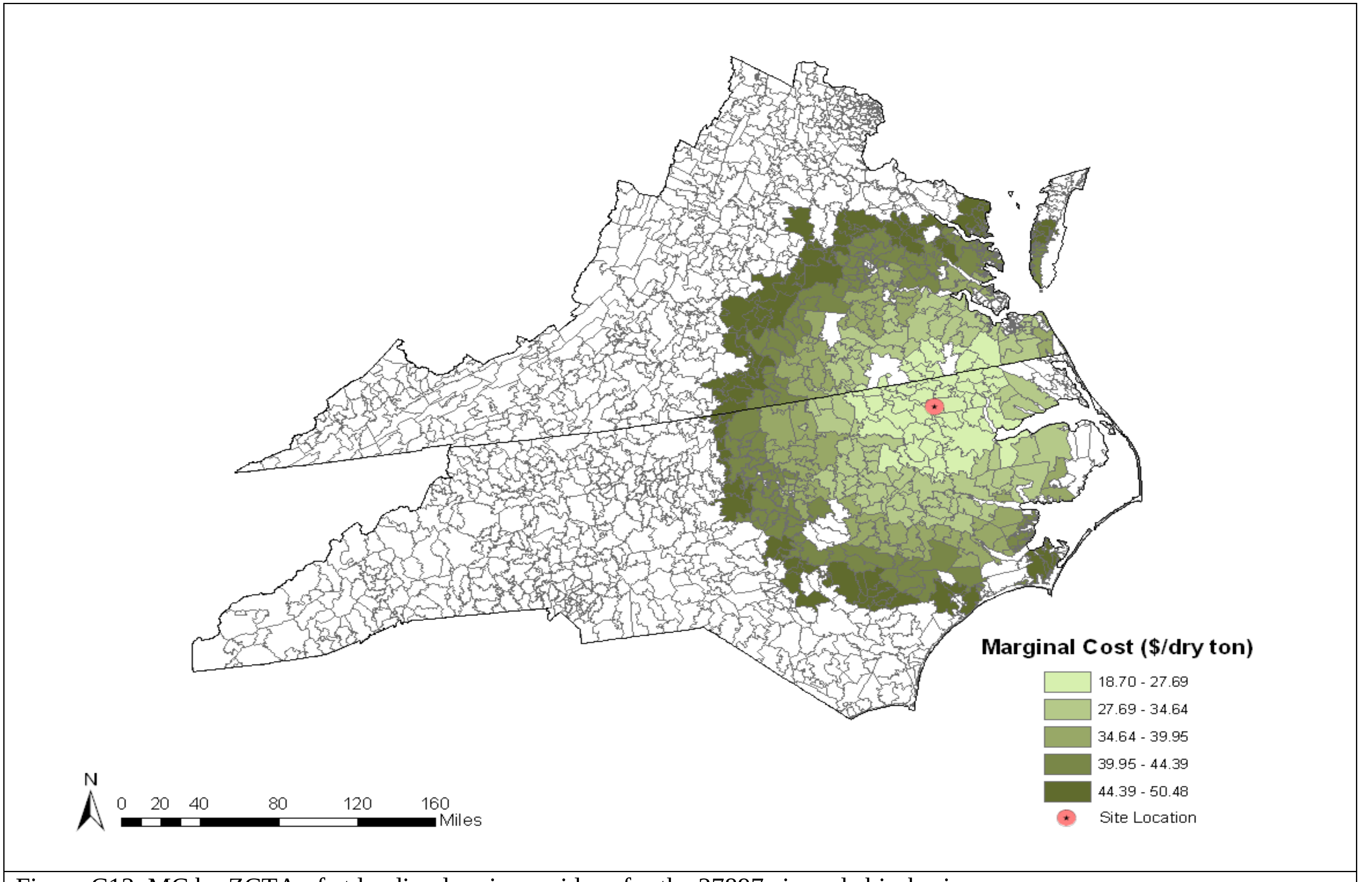

Figure C13. MC by ZCTA of at landing logging residues for the 27897 zip code bio-basin.

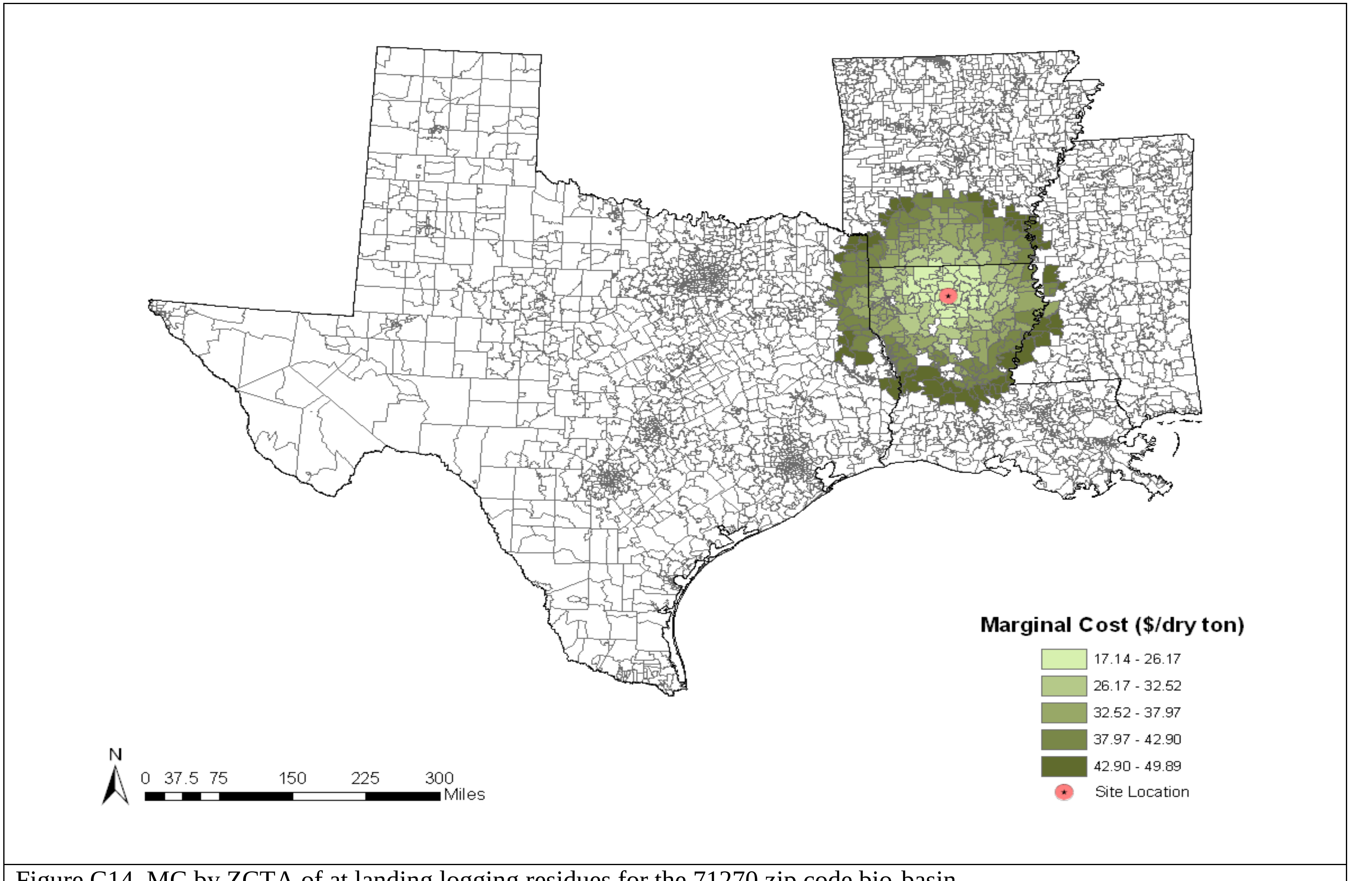

Figure C14. MC by ZCTA of at landing logging residues for the 71270 zip code bio-basin.

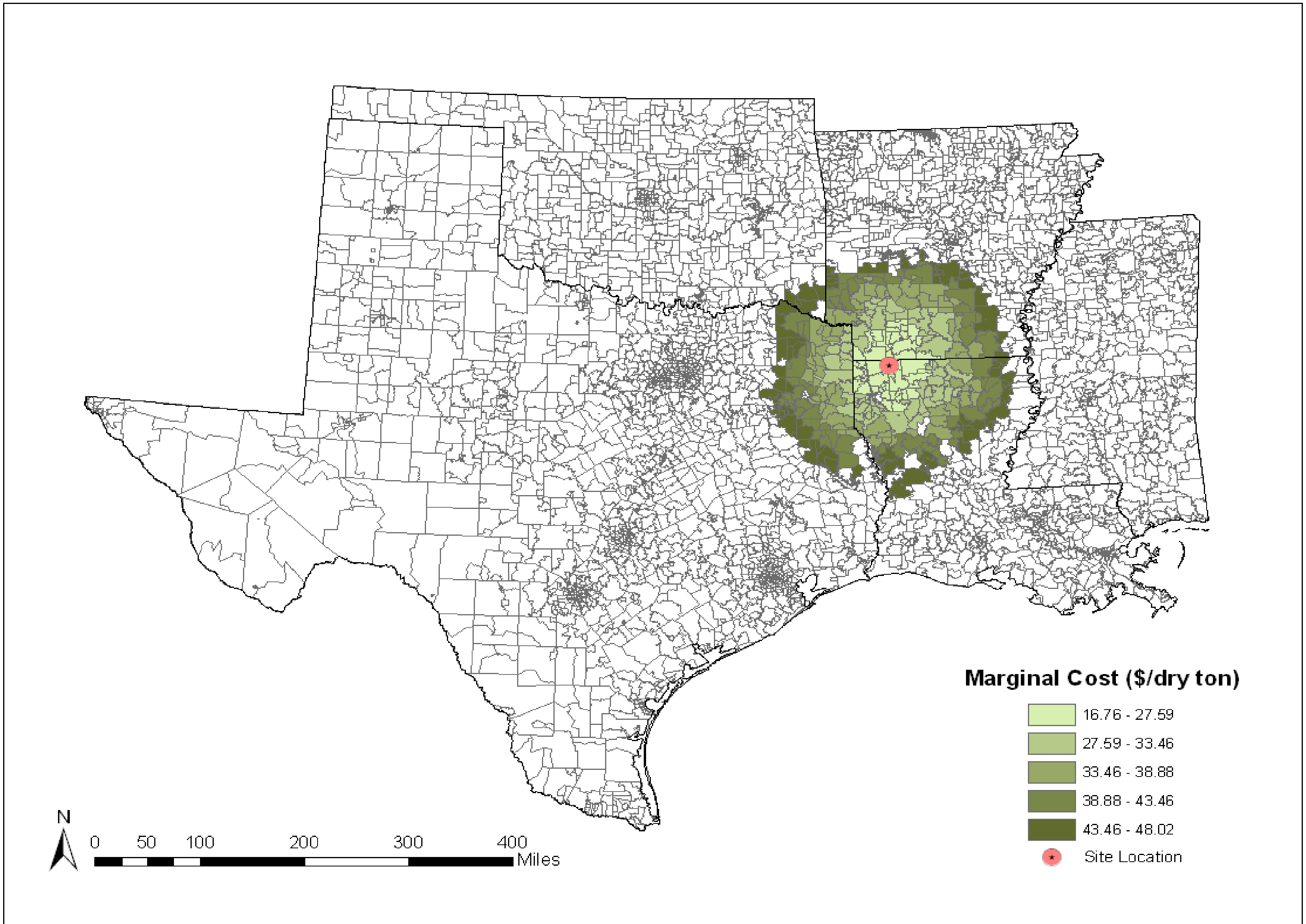

Figure C15. MC by ZCTA of at landing logging residues for the 71021 zip code bio-basin.

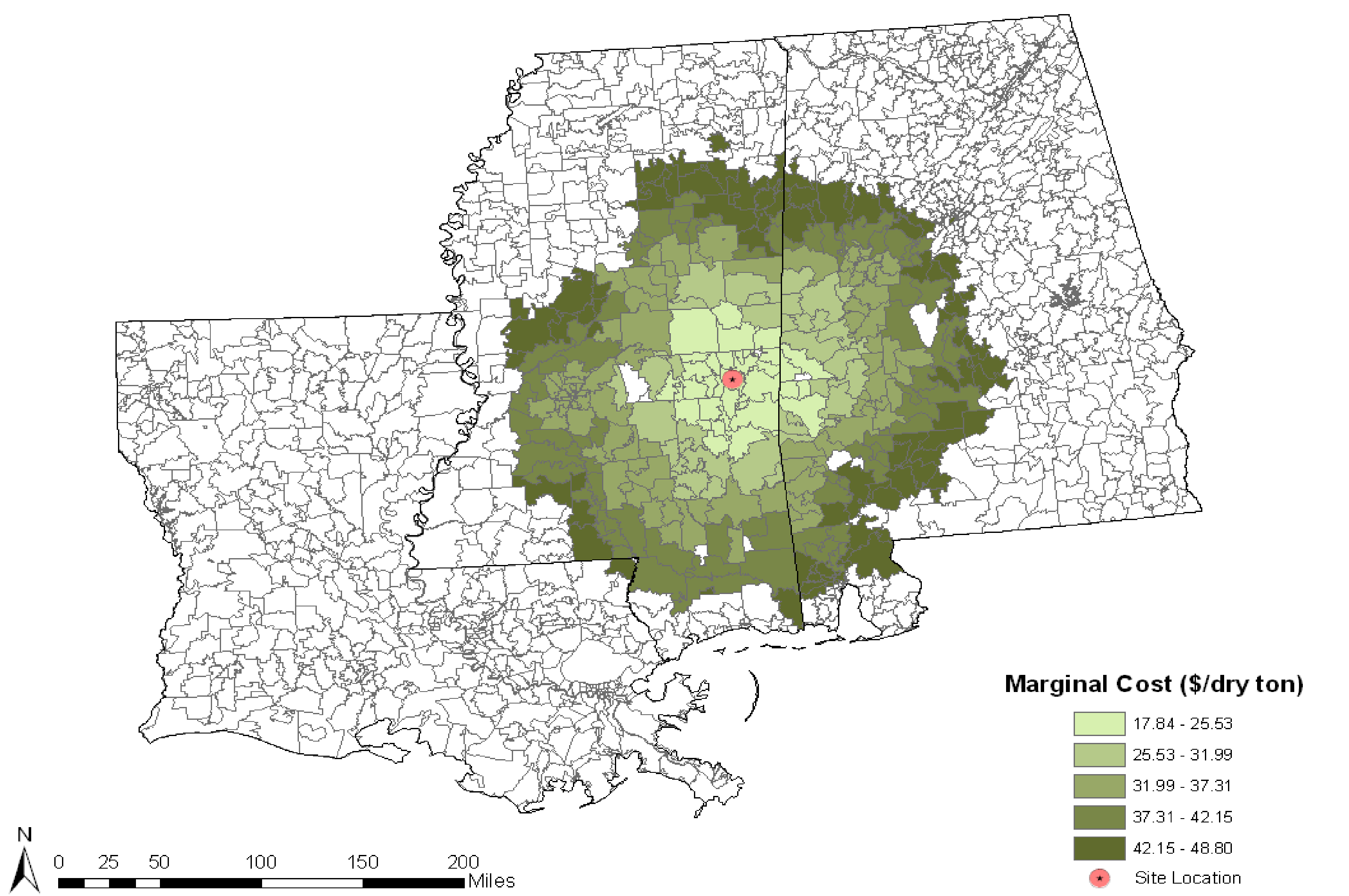

Figure C16. MC by ZCTA of at landing logging residues for the 39304 zip code bio-basin.

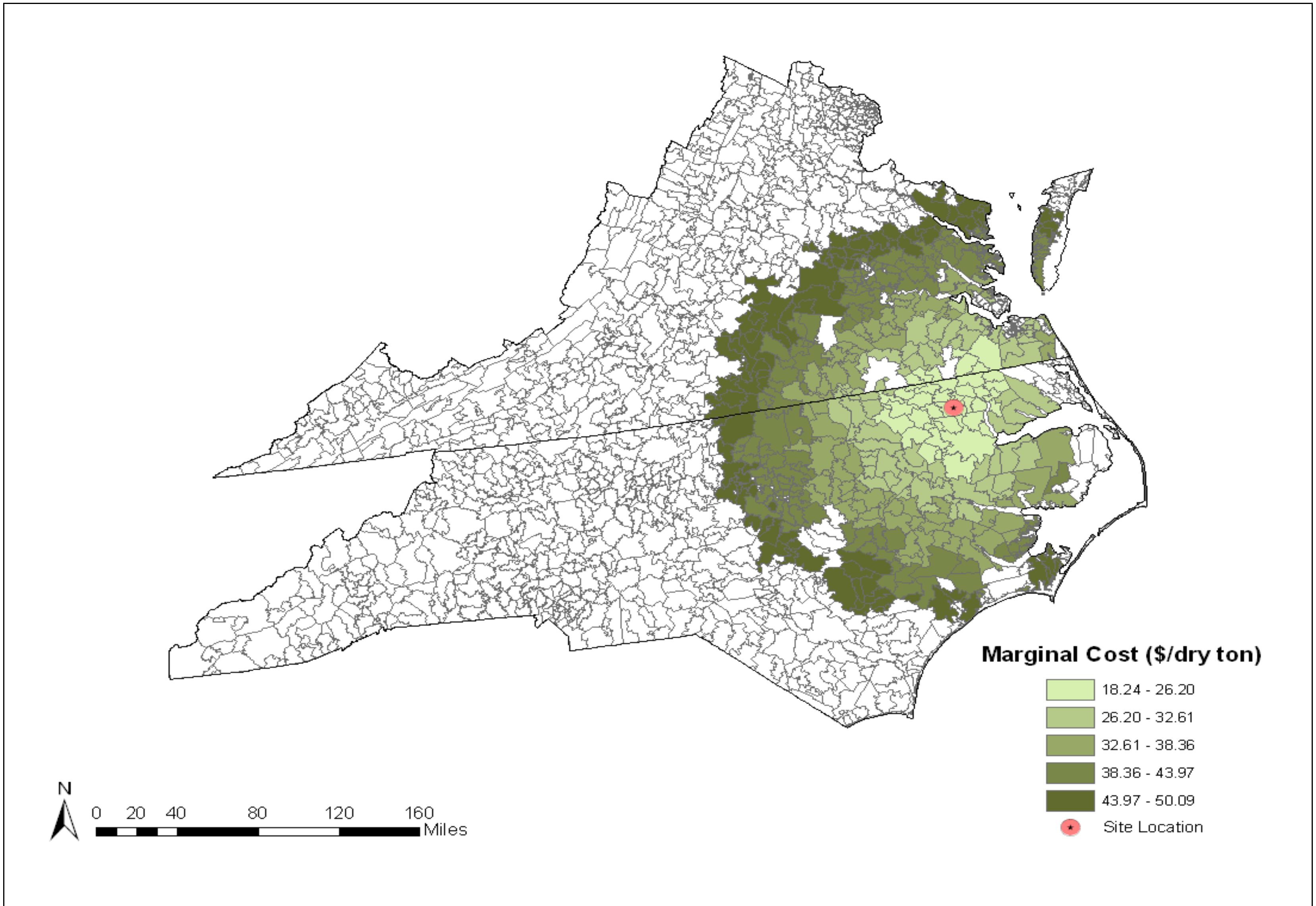

Figure C17. MC by ZCTA of at landing logging residues for the 27910 zip code bio-basin.

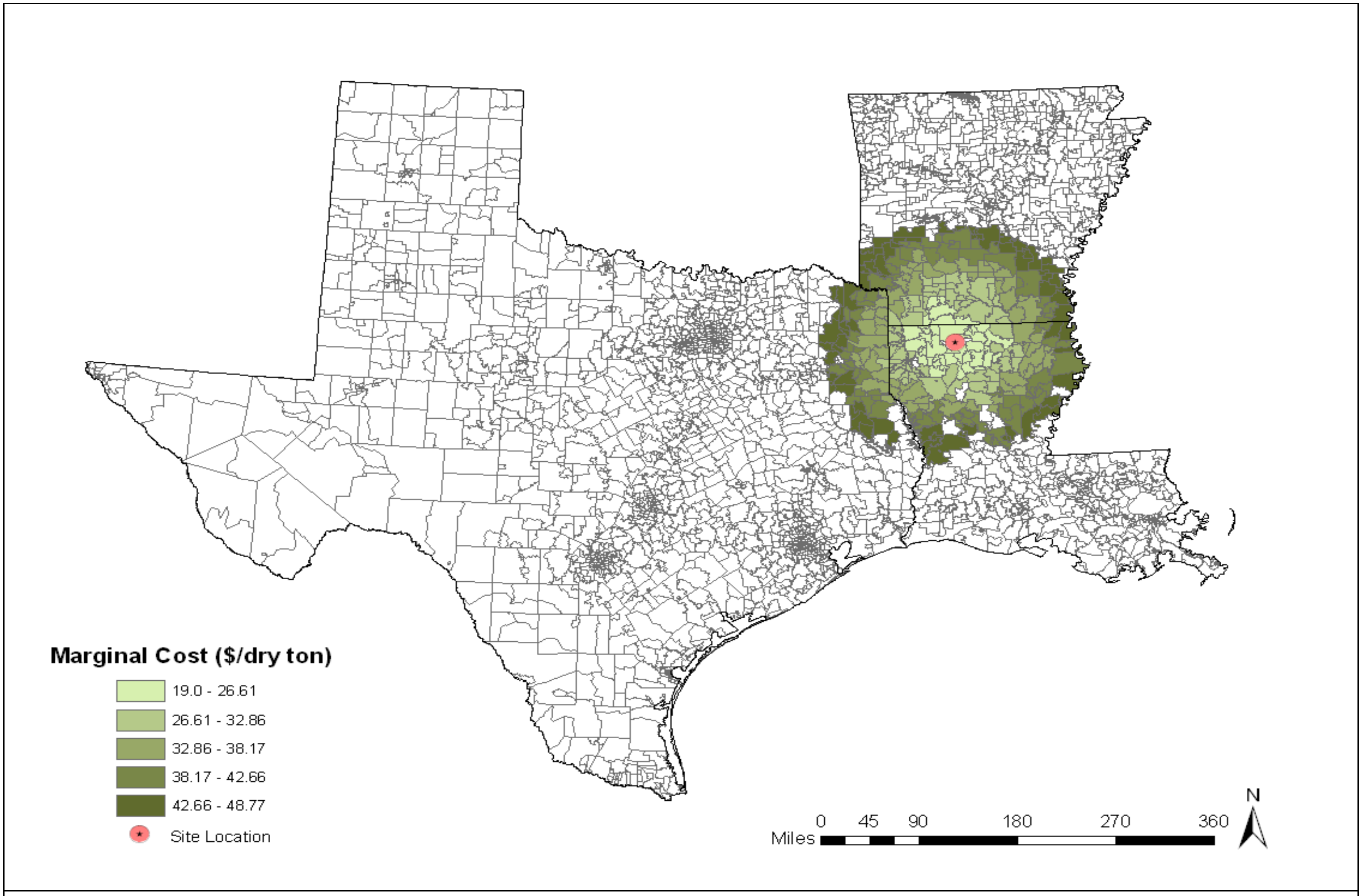

Figure C18. MC by ZCTA of at landing logging residues for the 71040 zip code bio-basin.

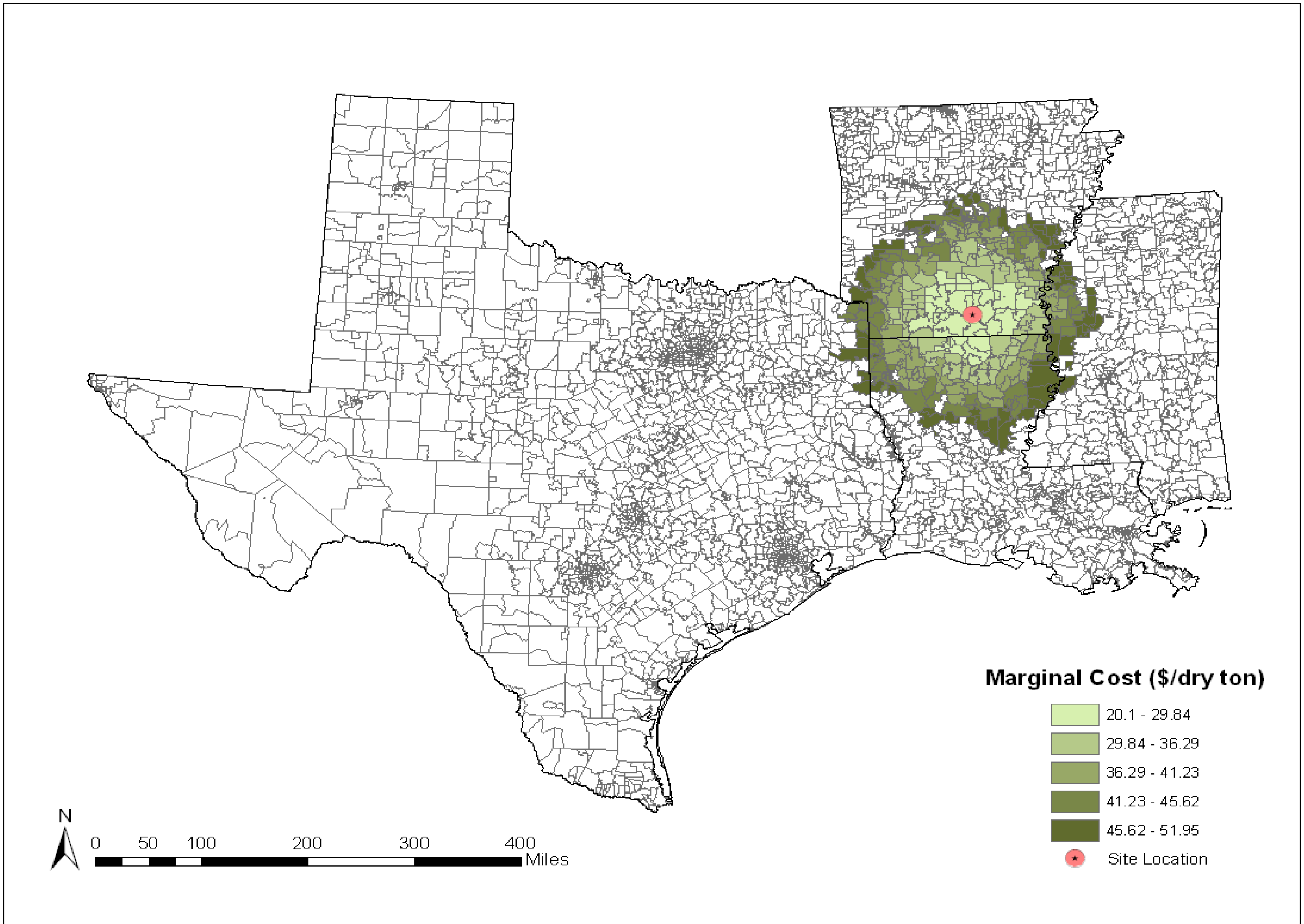

Figure C19. MC by ZCTA of at landing logging residues for the 71651 zip code bio-basin.

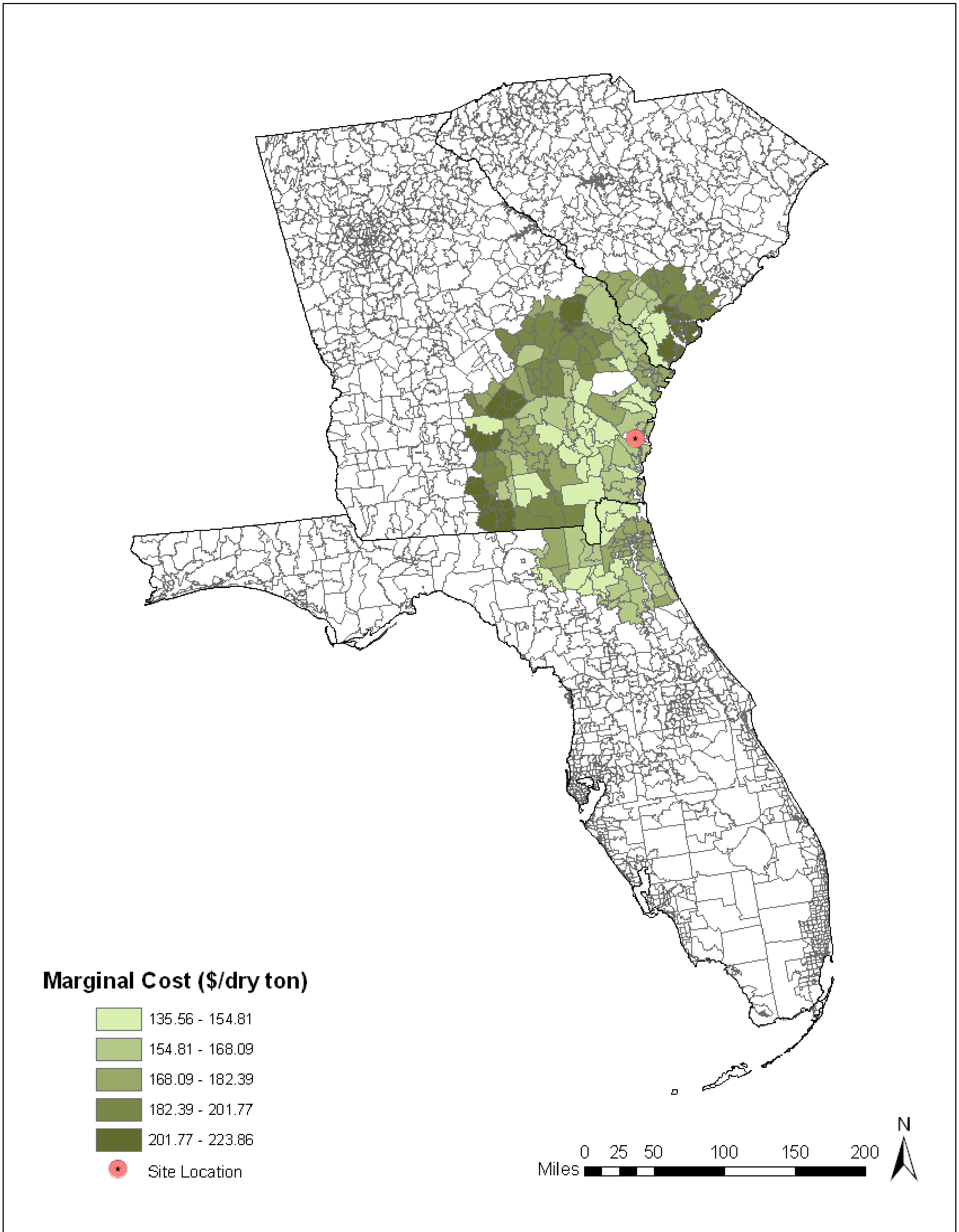

Figure C20. MC by ZCTA of in woods logging residues for the 31305 zip code bio-basin.

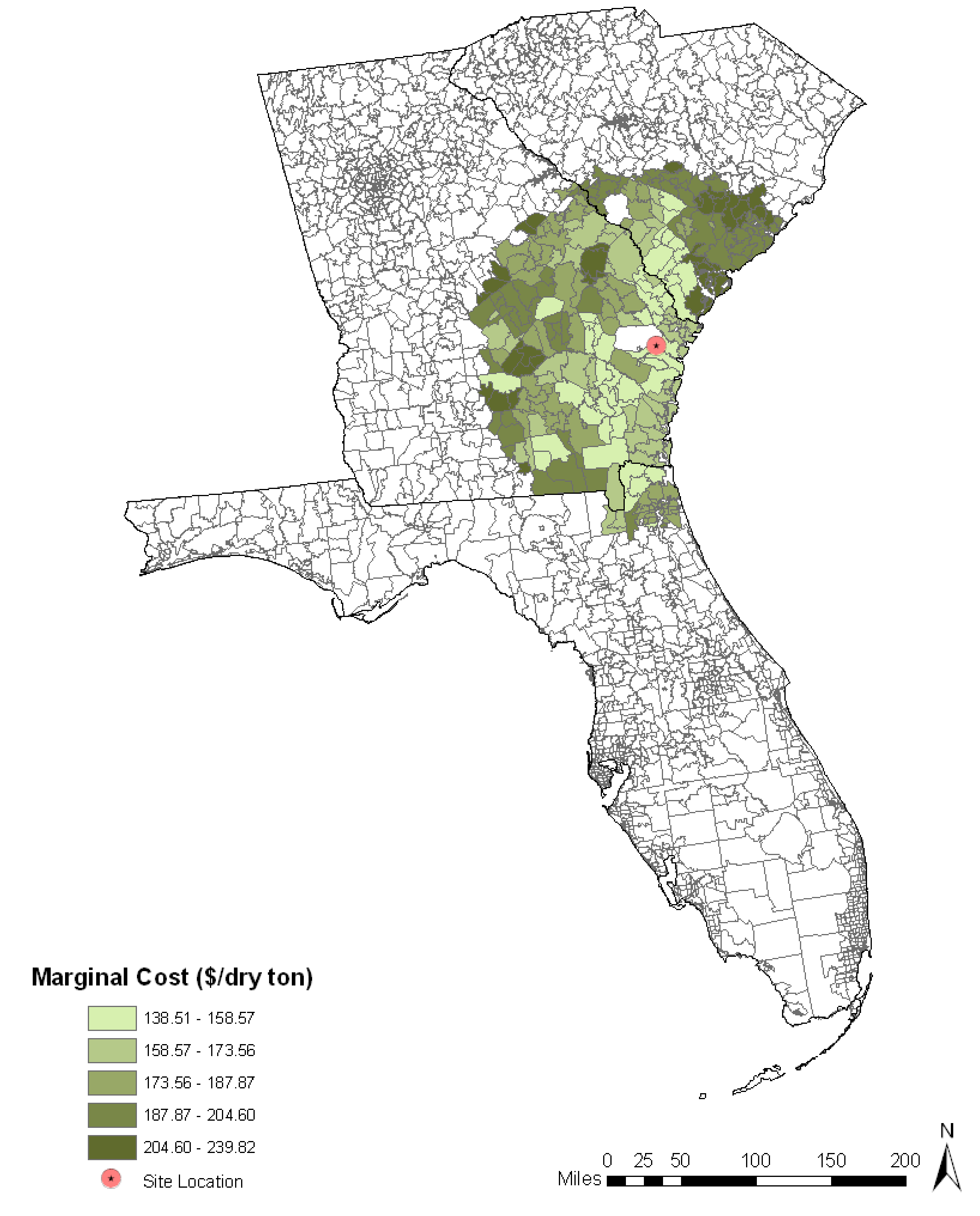

Figure C21. MC by ZCTA of in woods logging residues for the 31309 zip code bio-basin.

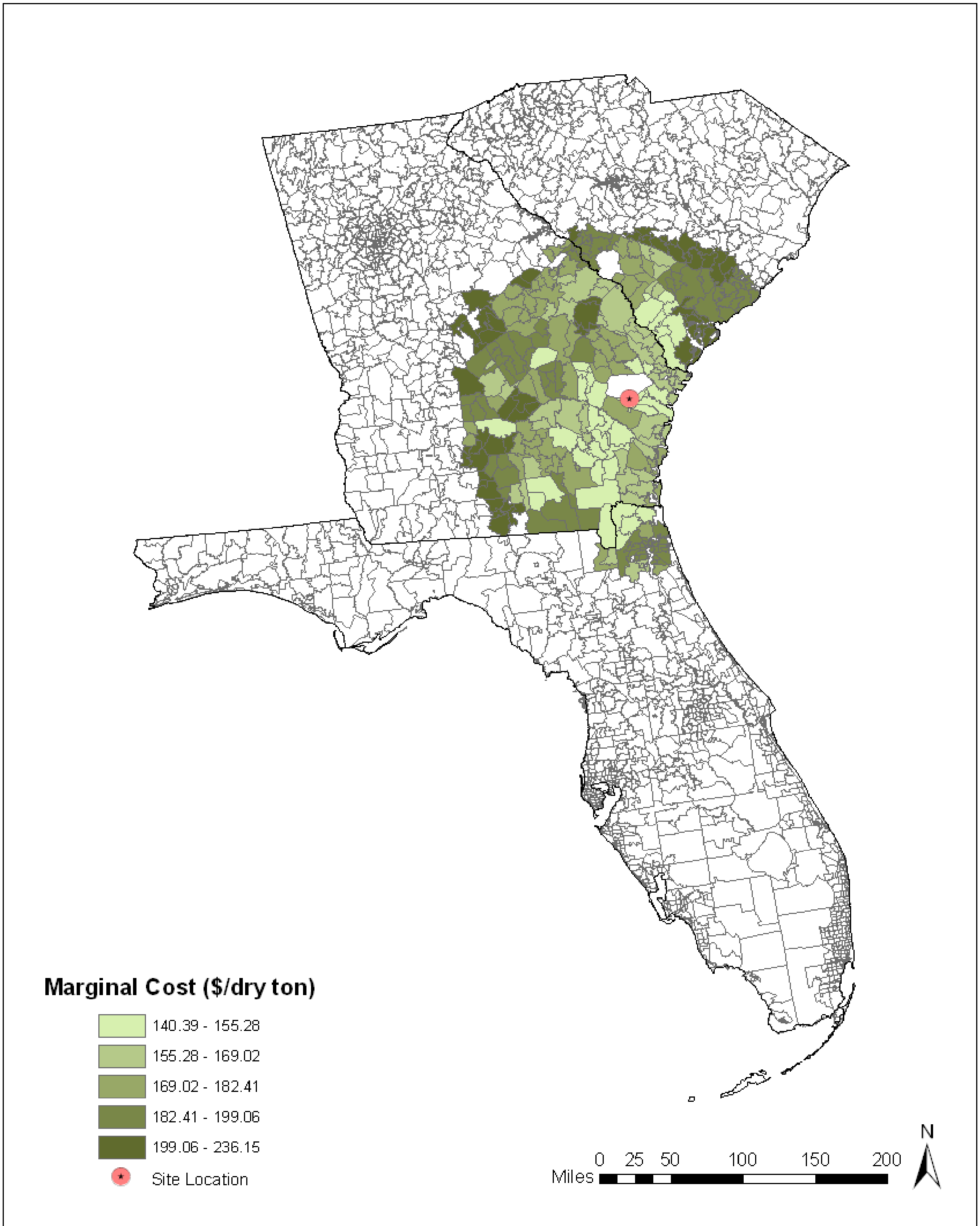

Figure C22. MC by ZCTA of in woods logging residues for the 31310 zip code bio-basin.

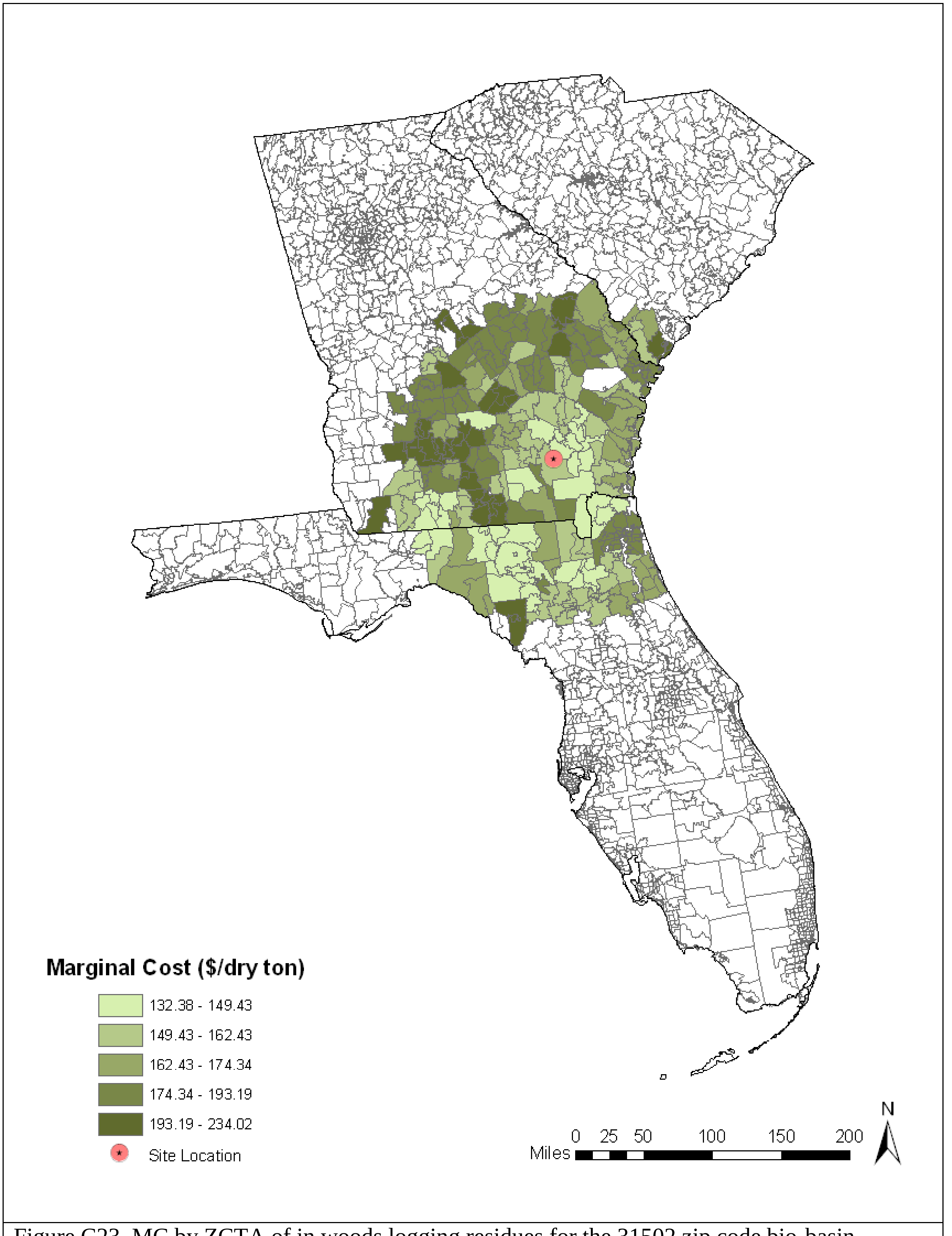

Figure C23. MC by ZCTA of in woods logging residues for the 31502 zip code bio-basin.

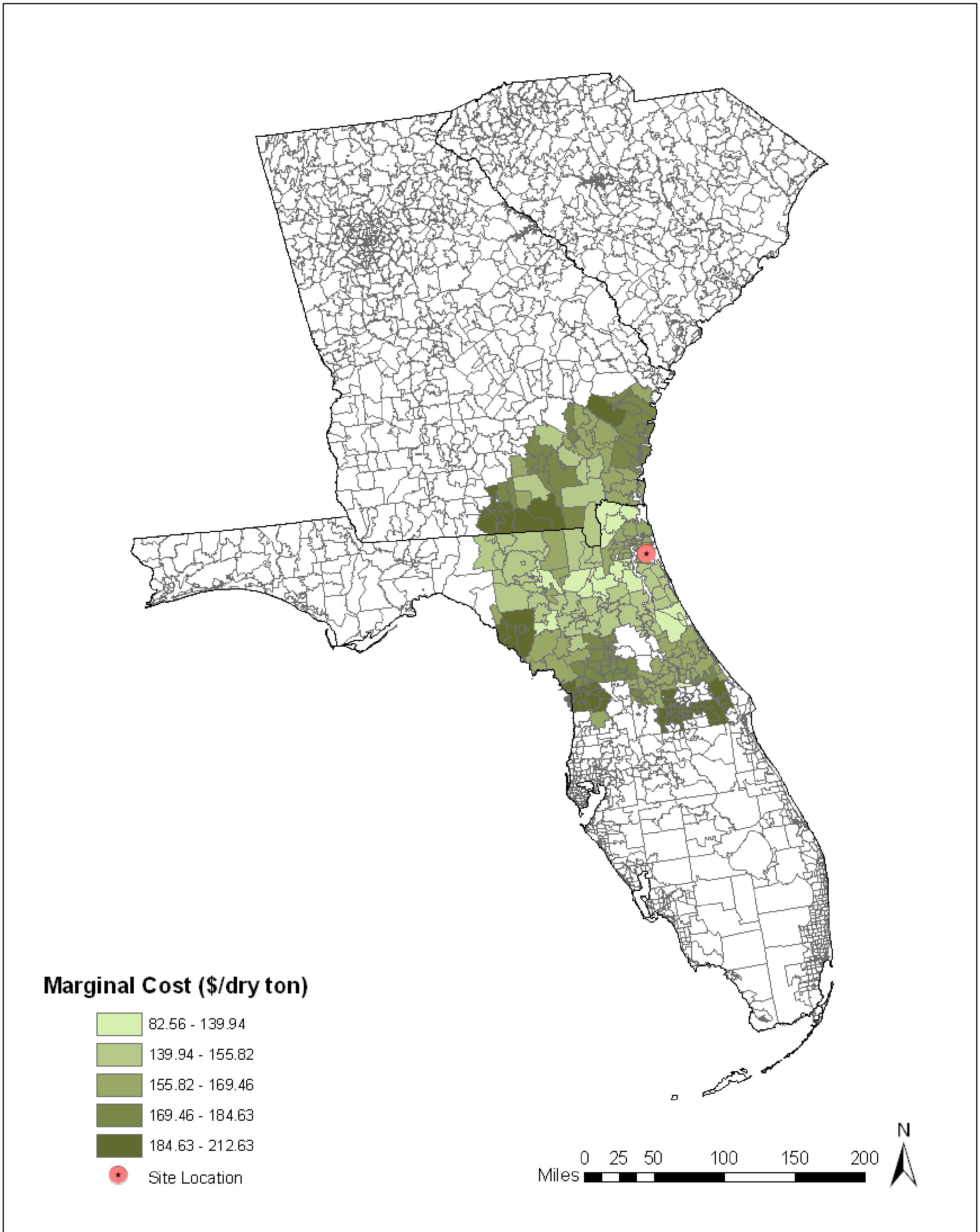

Figure C24. MC by ZCTA of in woods logging residues for the 32256 zip code bio-basin.

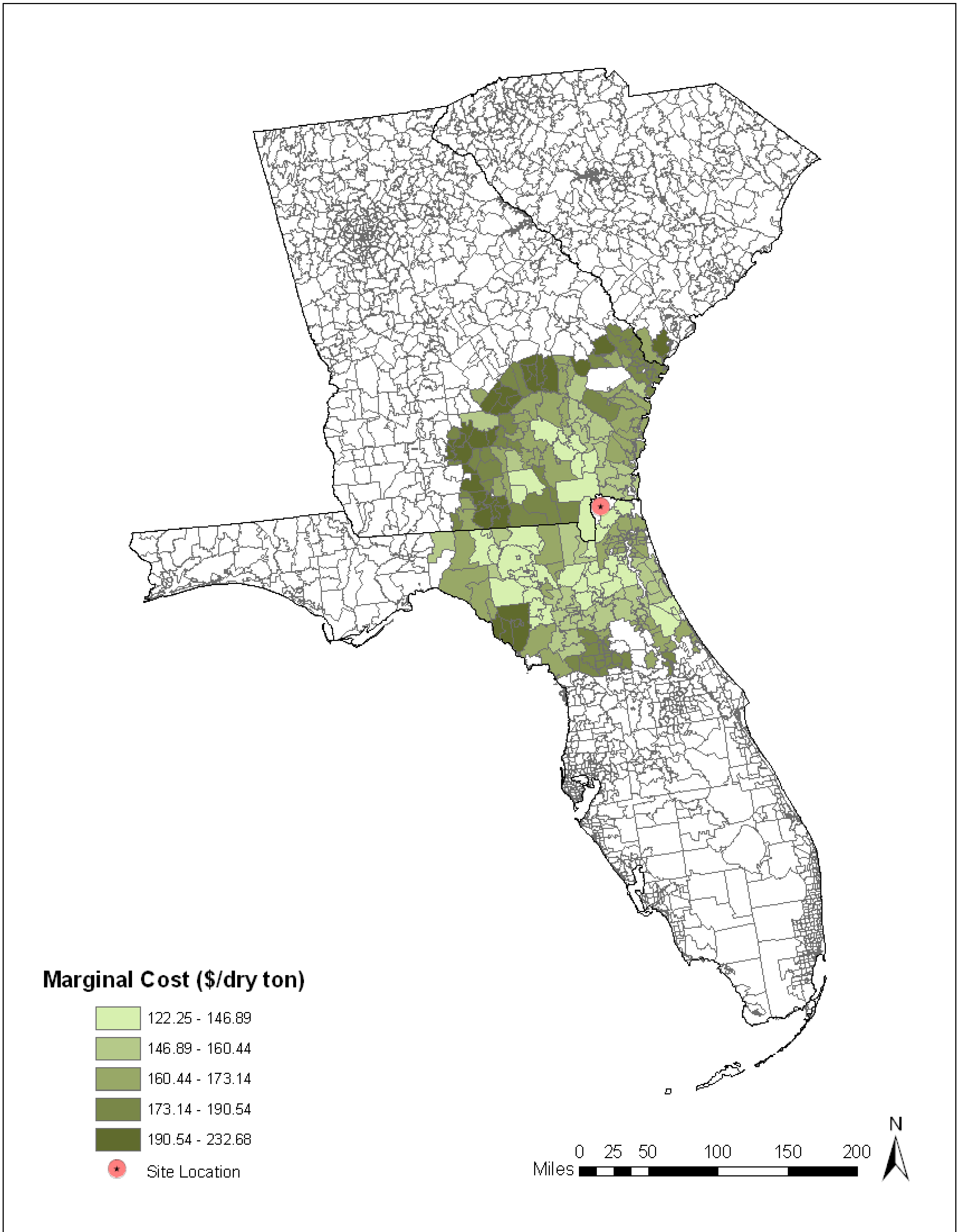

Figure C25. MC by ZCTA of in woods logging residues for the 32046 zip code bio-basin.

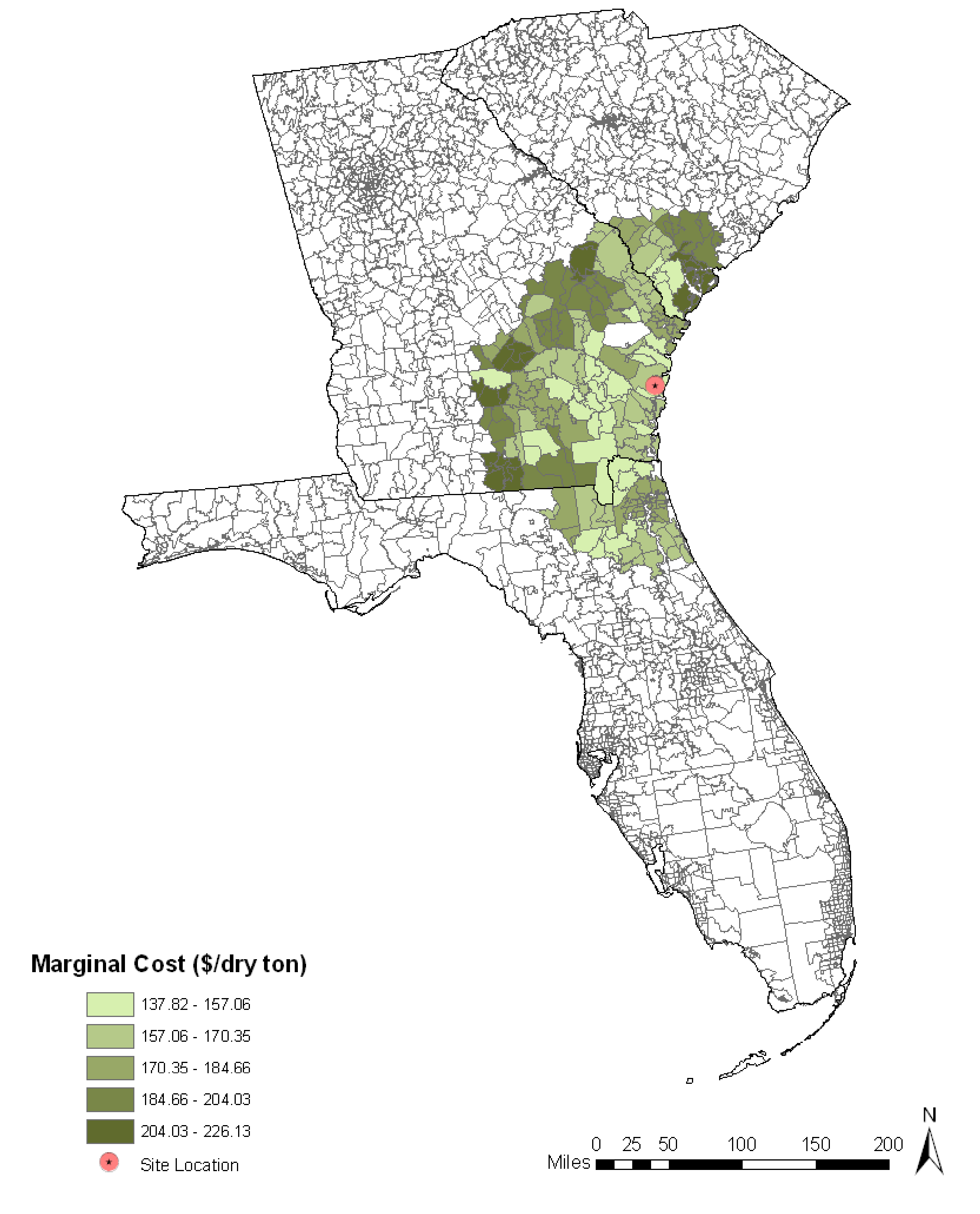

Figure C26. MC by ZCTA of in woods logging residues for the 31319 zip code bio-basin.

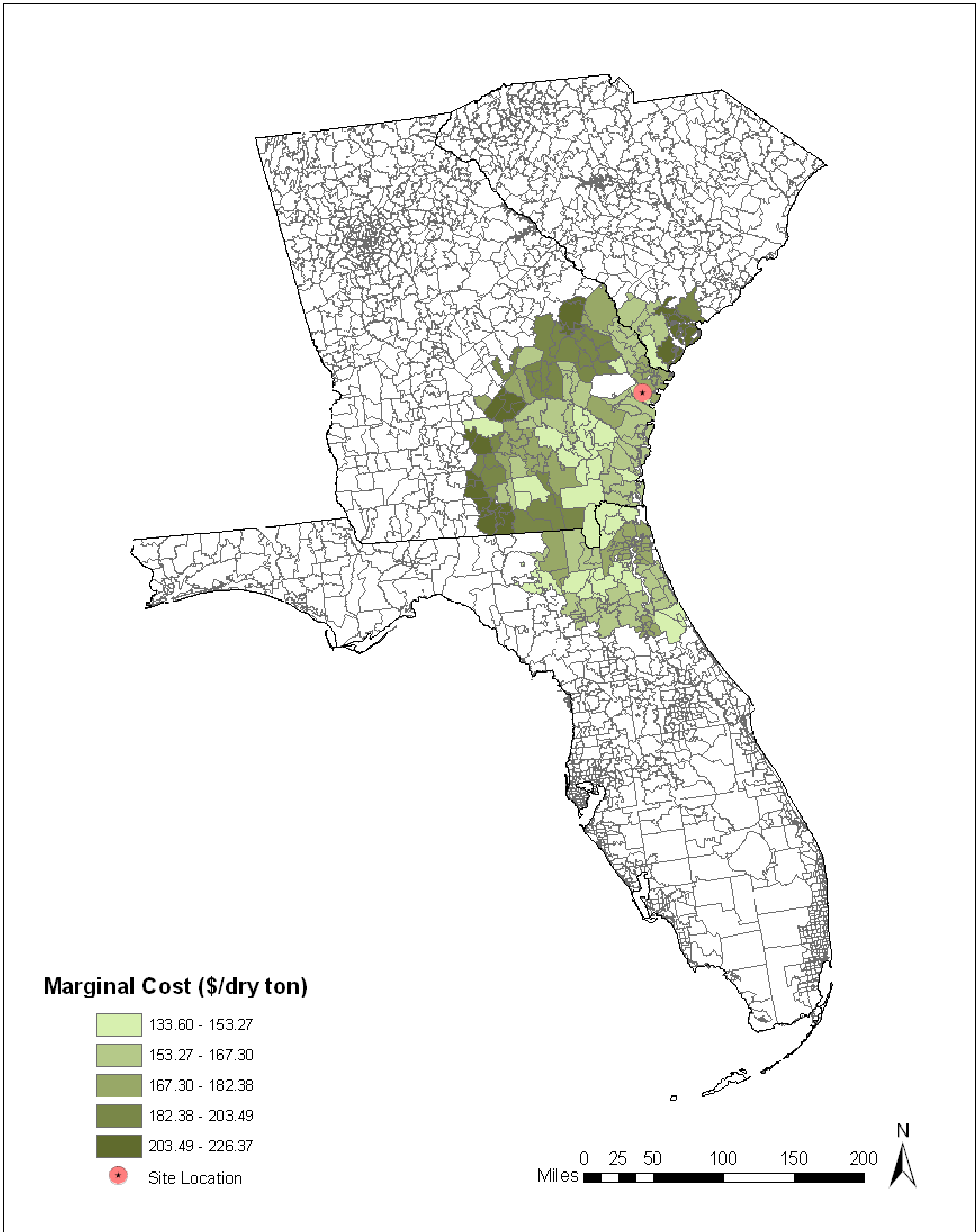

Figure C27. MC by ZCTA of in woods logging residues for the 31524 zip code bio-basin.

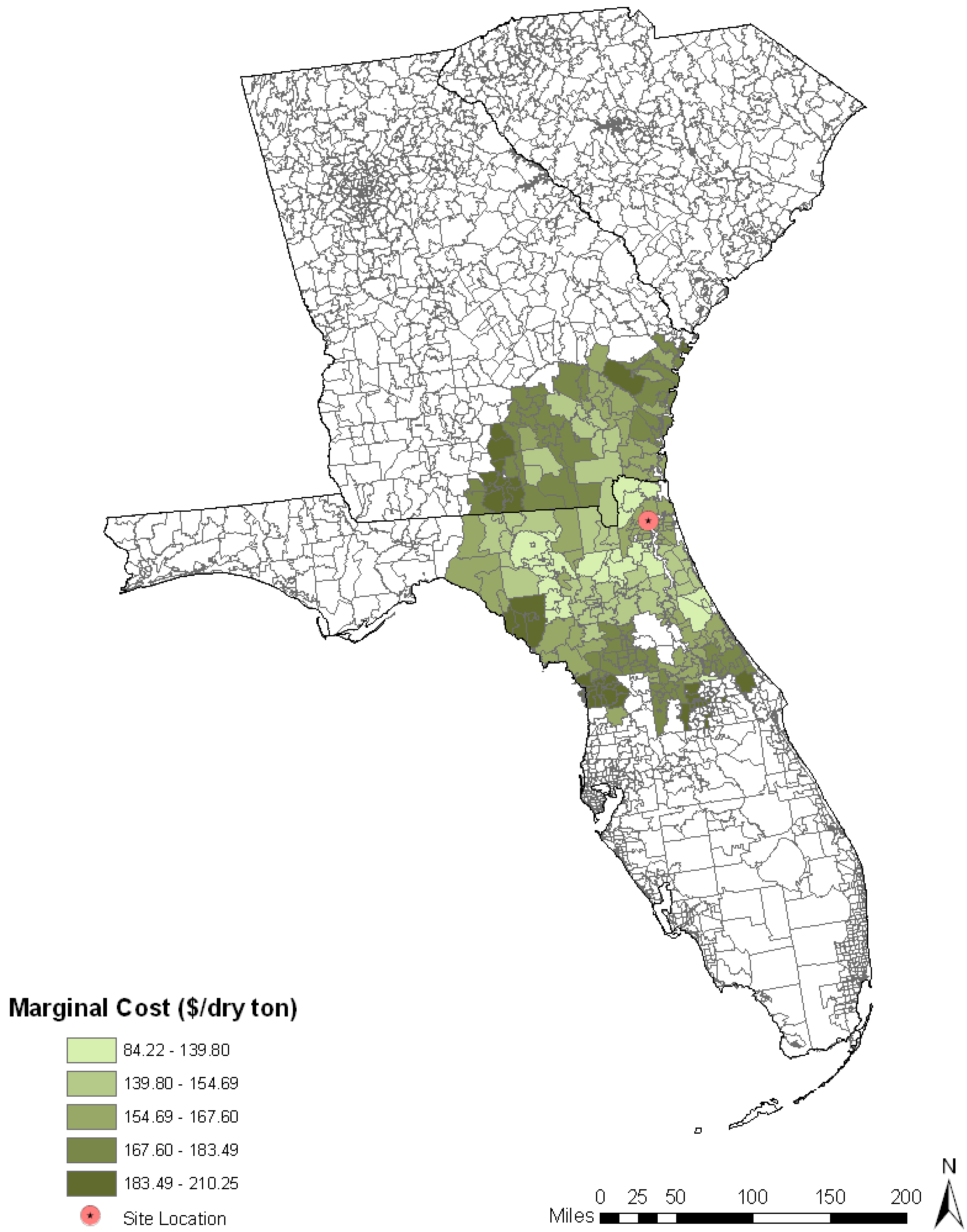

Figure C28. MC by ZCTA of in woods logging residues for the 32232 zip code bio-basin.

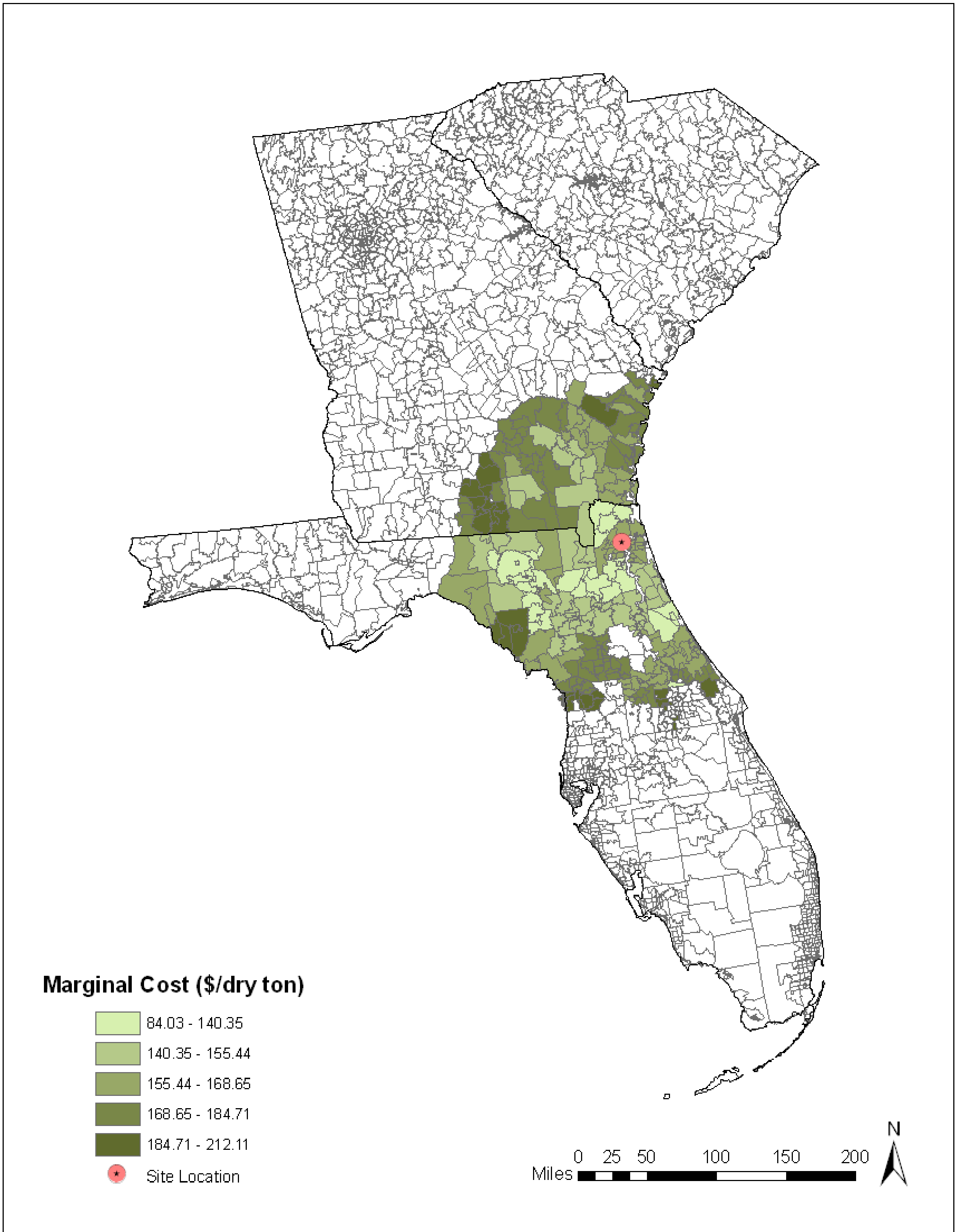

Figure C29. MC by ZCTA of in woods logging residues for the 32204 zip code bio-basin.

Appendix D

Bio-basin ZCTA maps for the top ten sites for agricultural residues for southern region with MCs

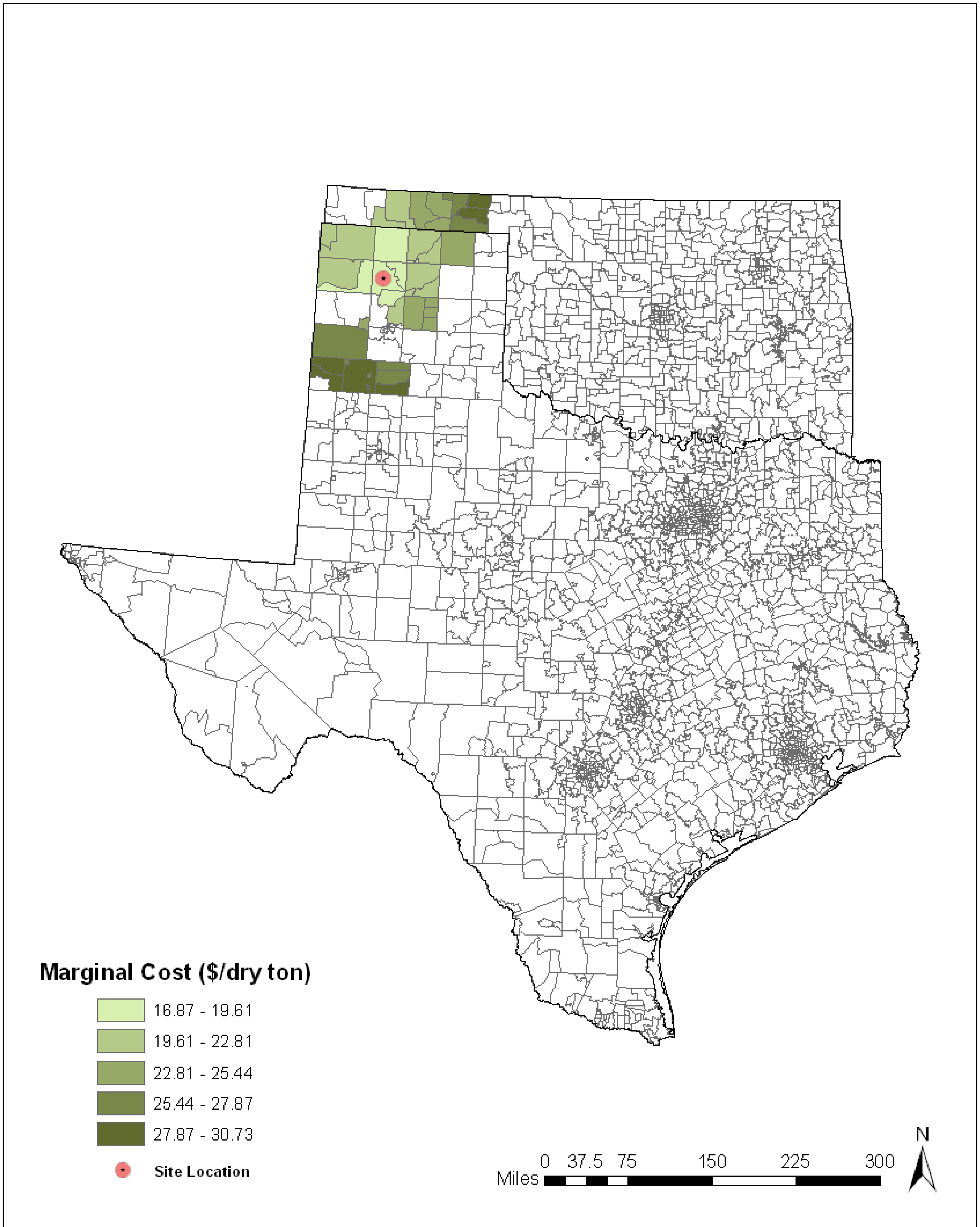

Figure D1. MC by ZCTA of corn stover for the 79013 zip code bio-basin.

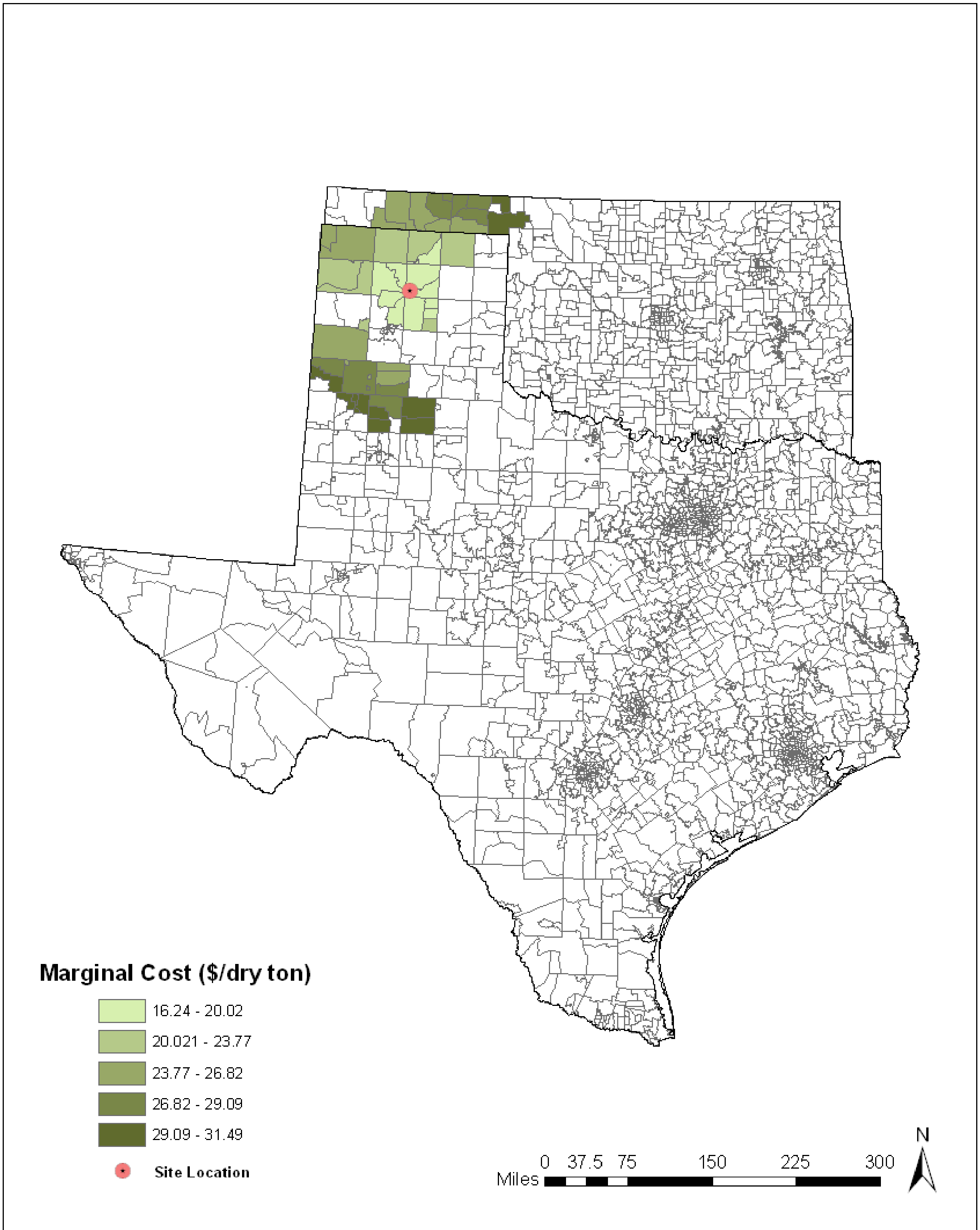

Figure D2. MC by ZCTA of corn stover for the 79078 zip code bio-basin.

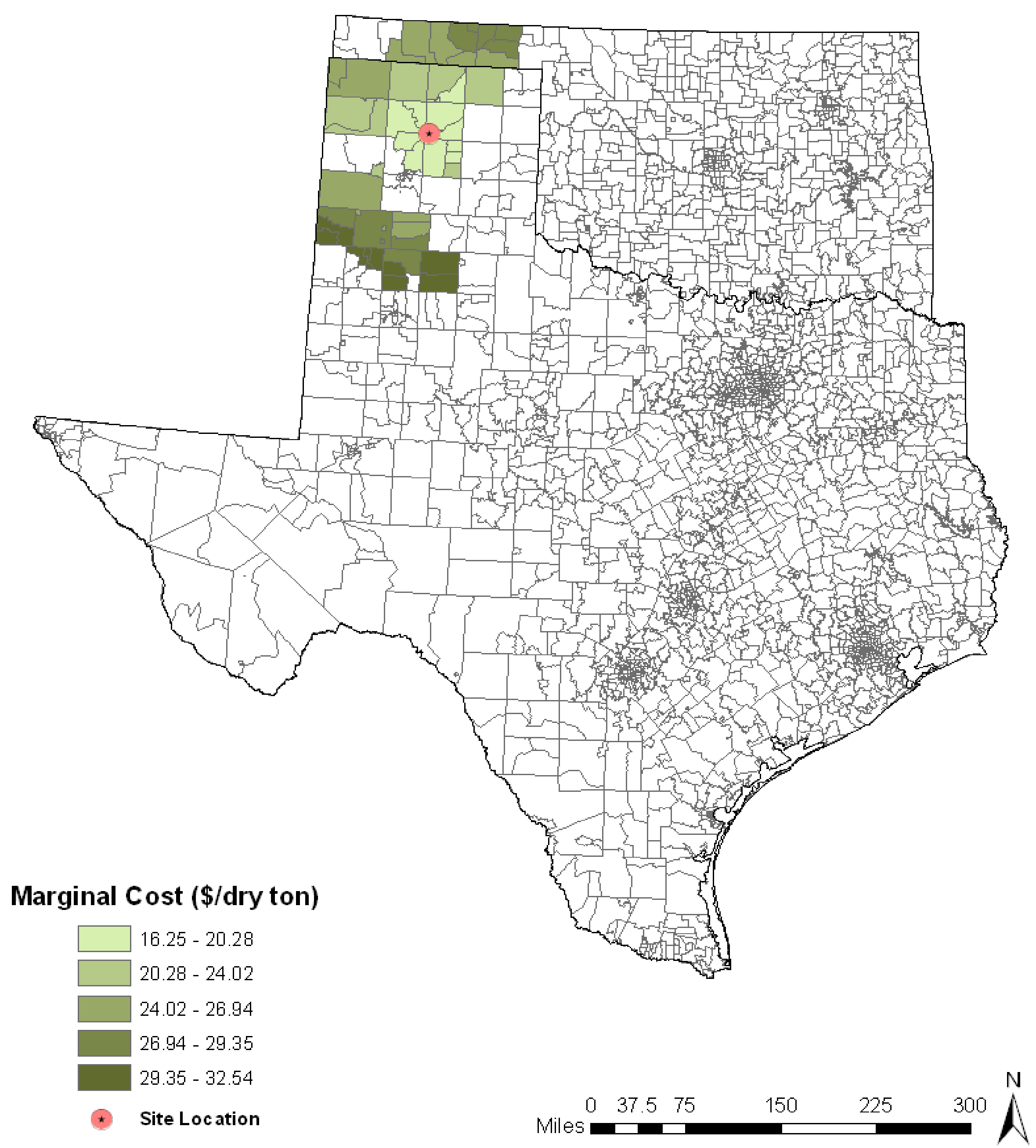

Figure D3. MC by ZCTA of corn stover for the 79036 zip code bio-basin.

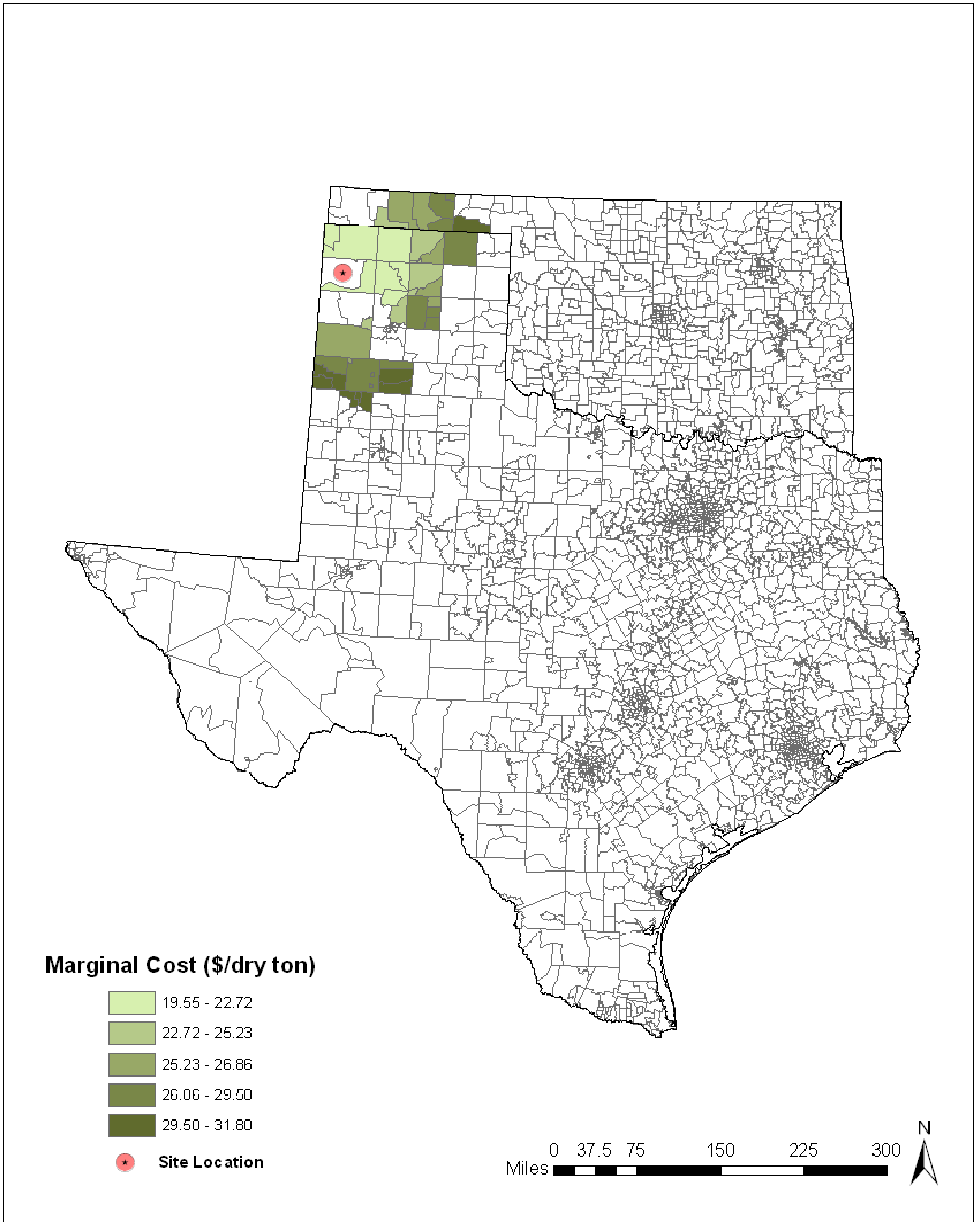

Figure D4. MC by ZCTA of corn stover for the 79044 zip code bio-basin.

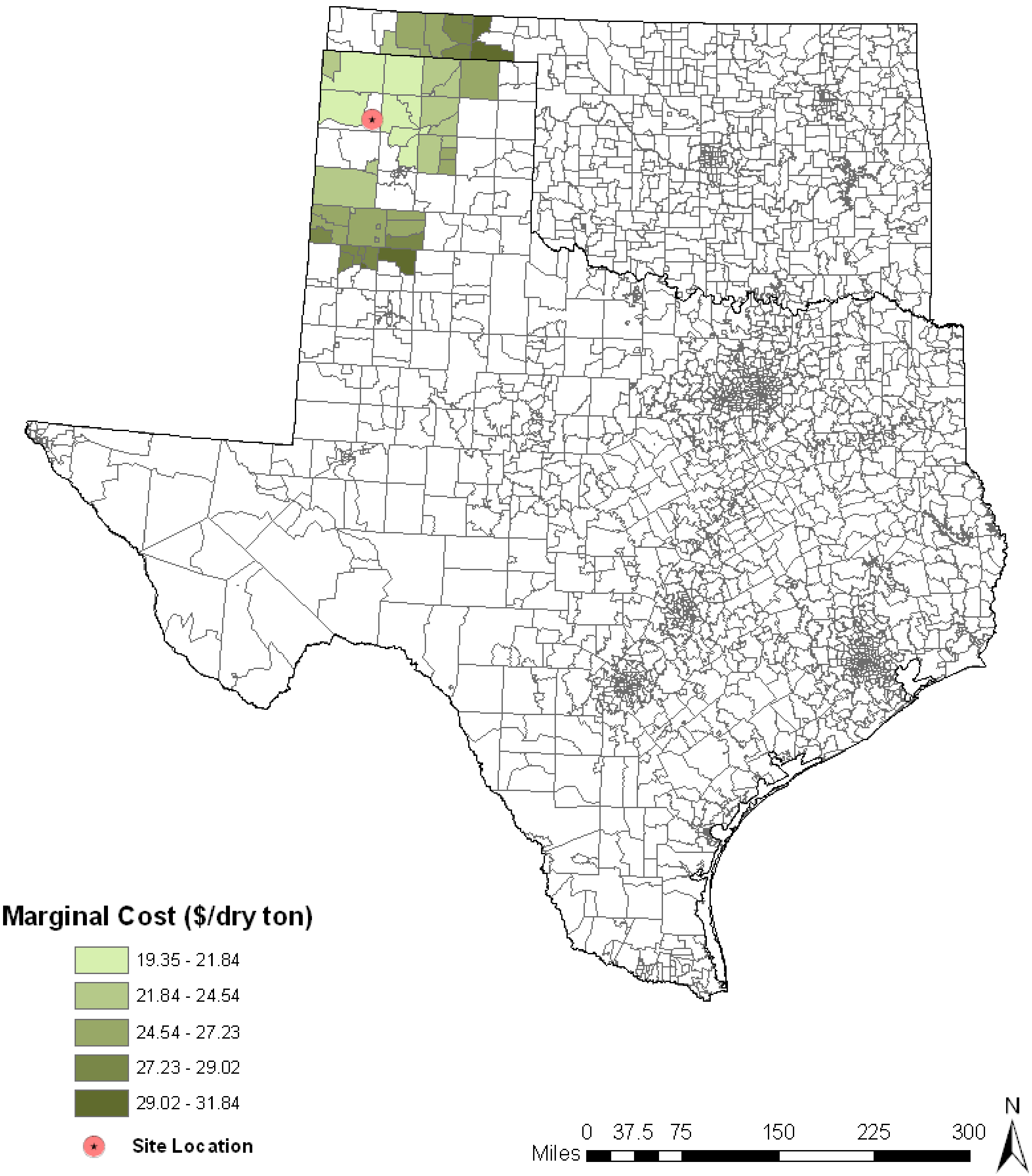

Figure D5. MC by ZCTA of corn stover for the 79018 zip code bio-basin.

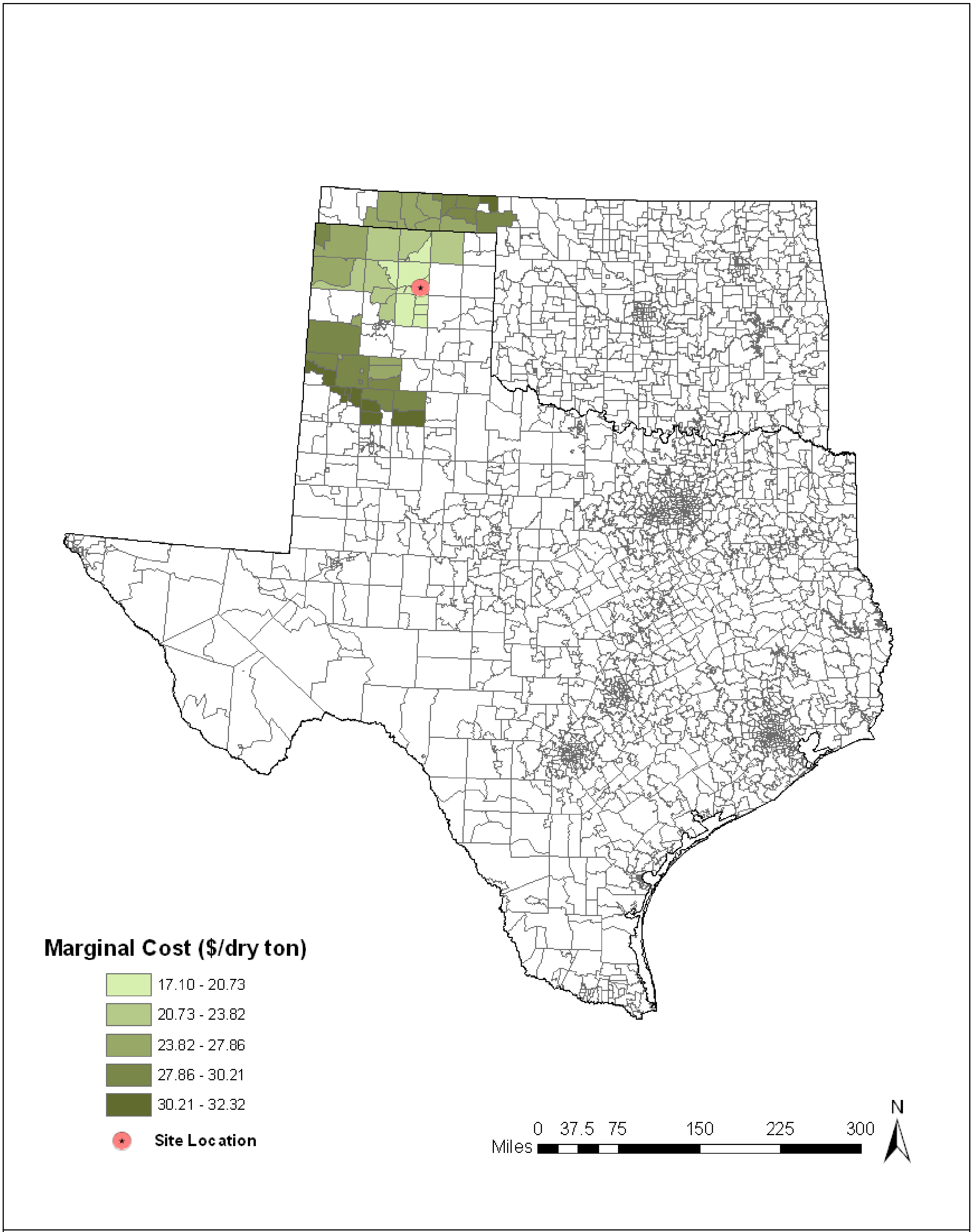

Figure D6. MC by ZCTA of corn stover for the 79007 zip code bio-basin.

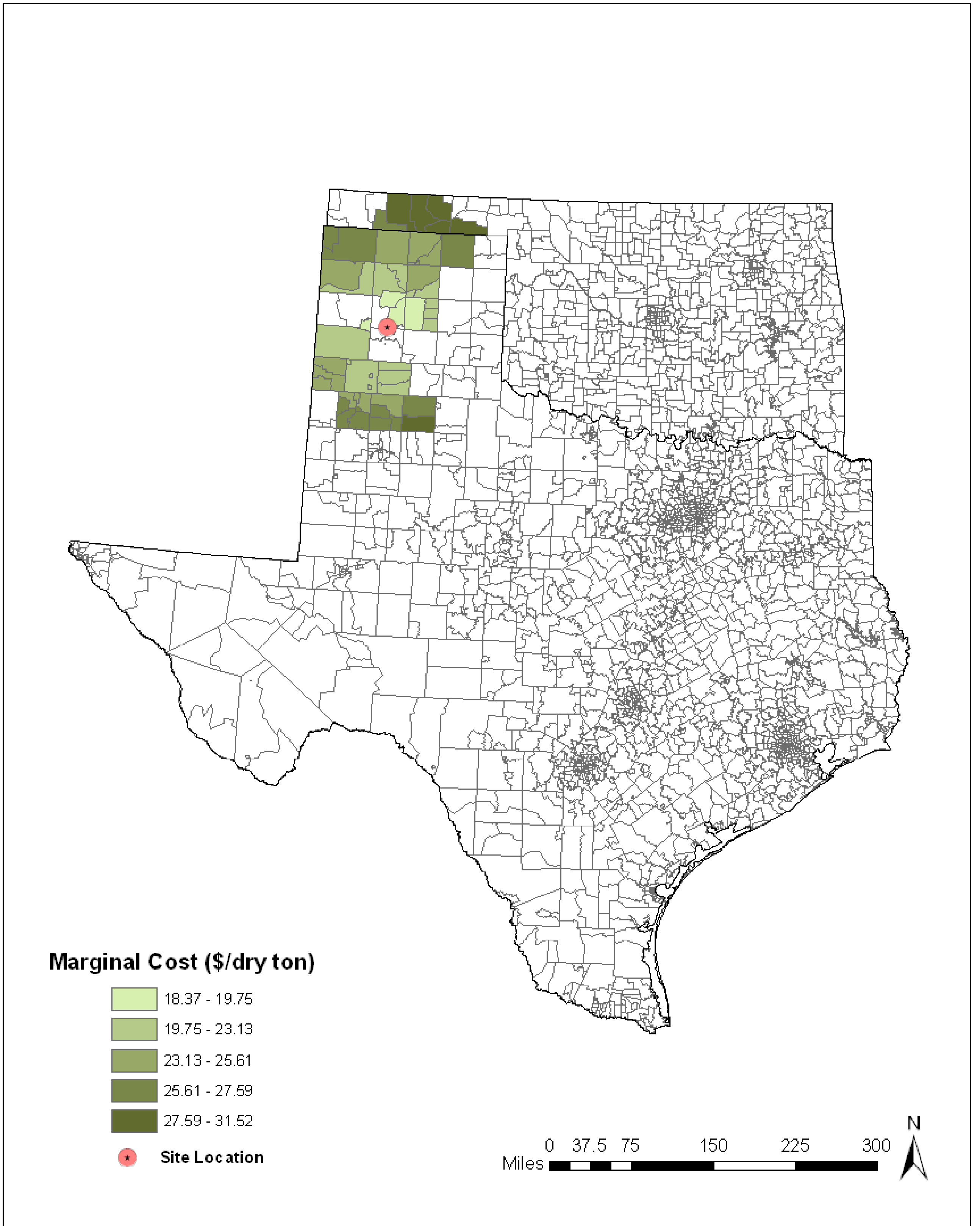

Figure D7. MC by ZCTA of corn stover for the 79116 zip code bio-basin.

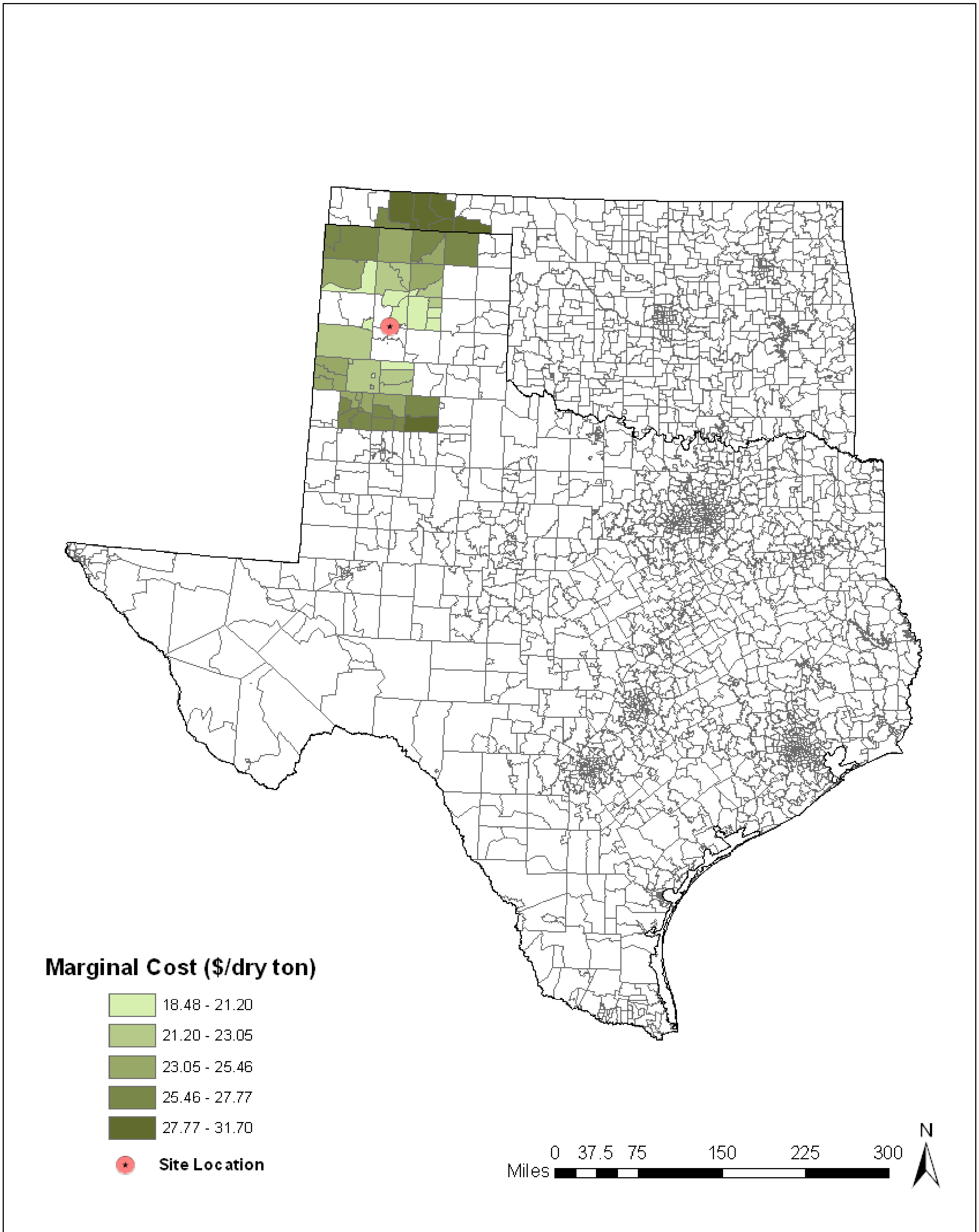

Figure D8. MC by ZCTA of corn stover for the 79106 zip code bio-basin.

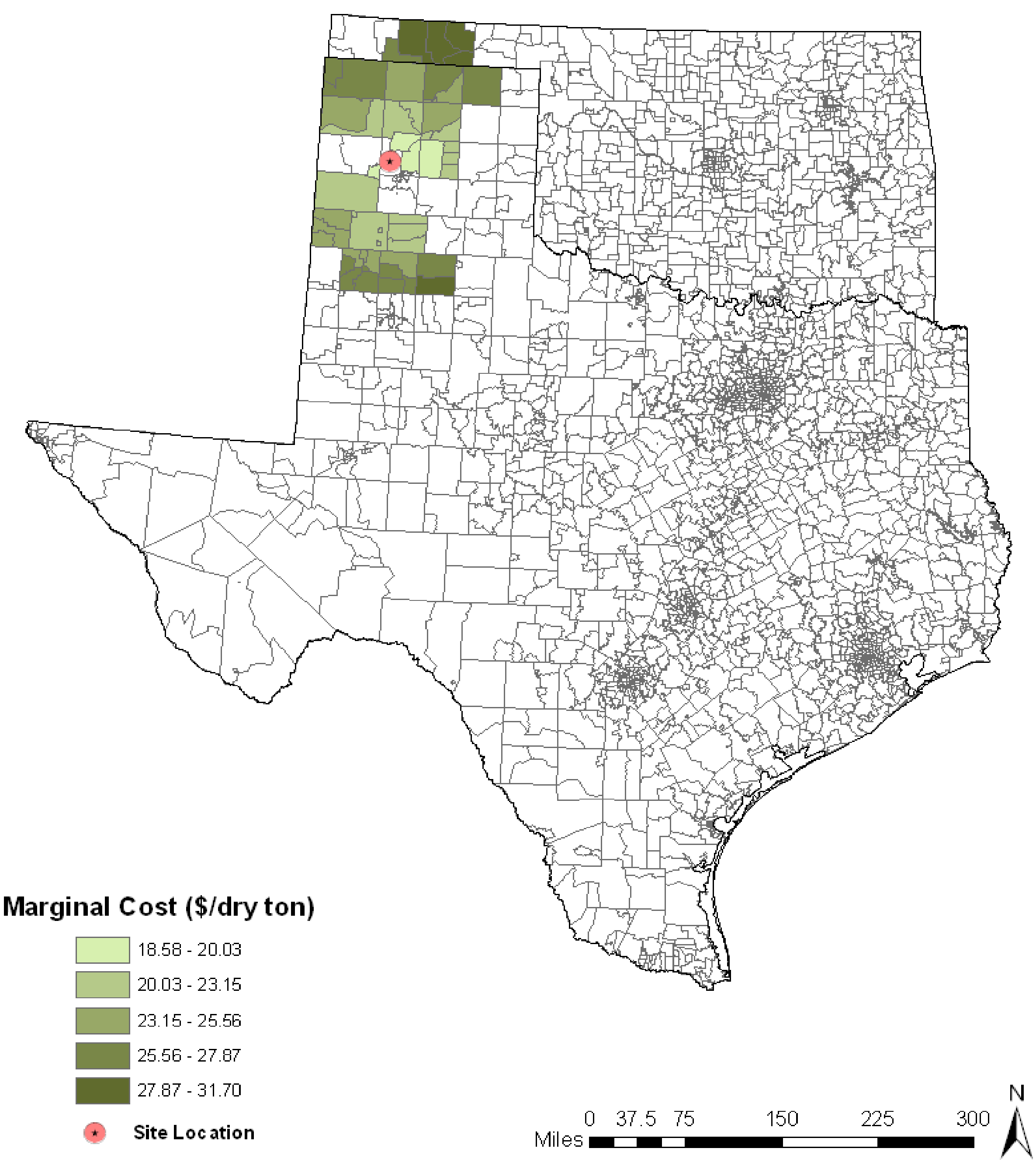

Figure D9. MC by ZCTA of corn stover for the 79159 zip code bio-basin.

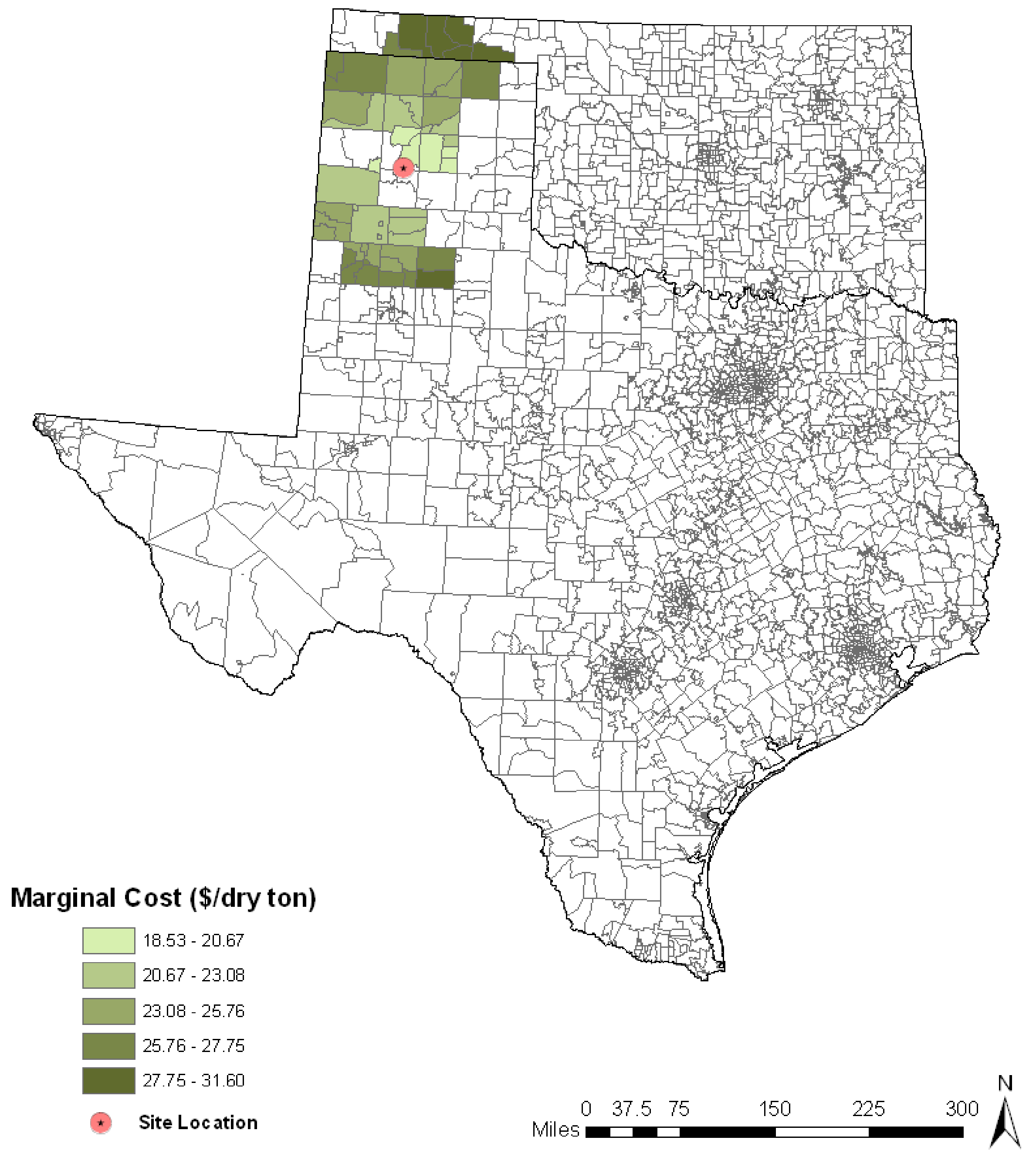

Figure D10. MC by ZCTA of corn stover for the 79102 zip code bio-basin.

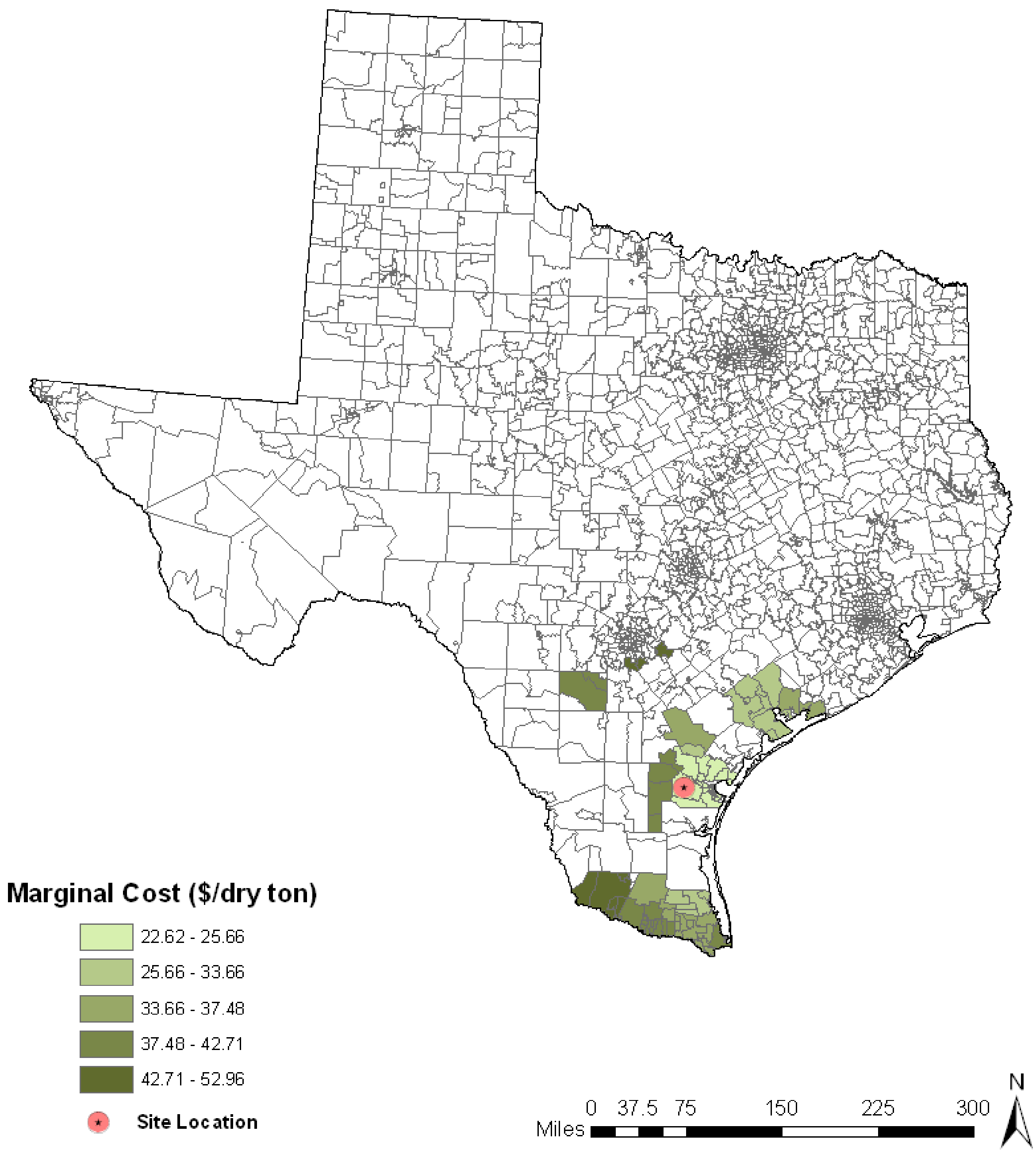

Figure D11. MC by ZCTA of sorghum straw for the 78351 zip code bio-basin.

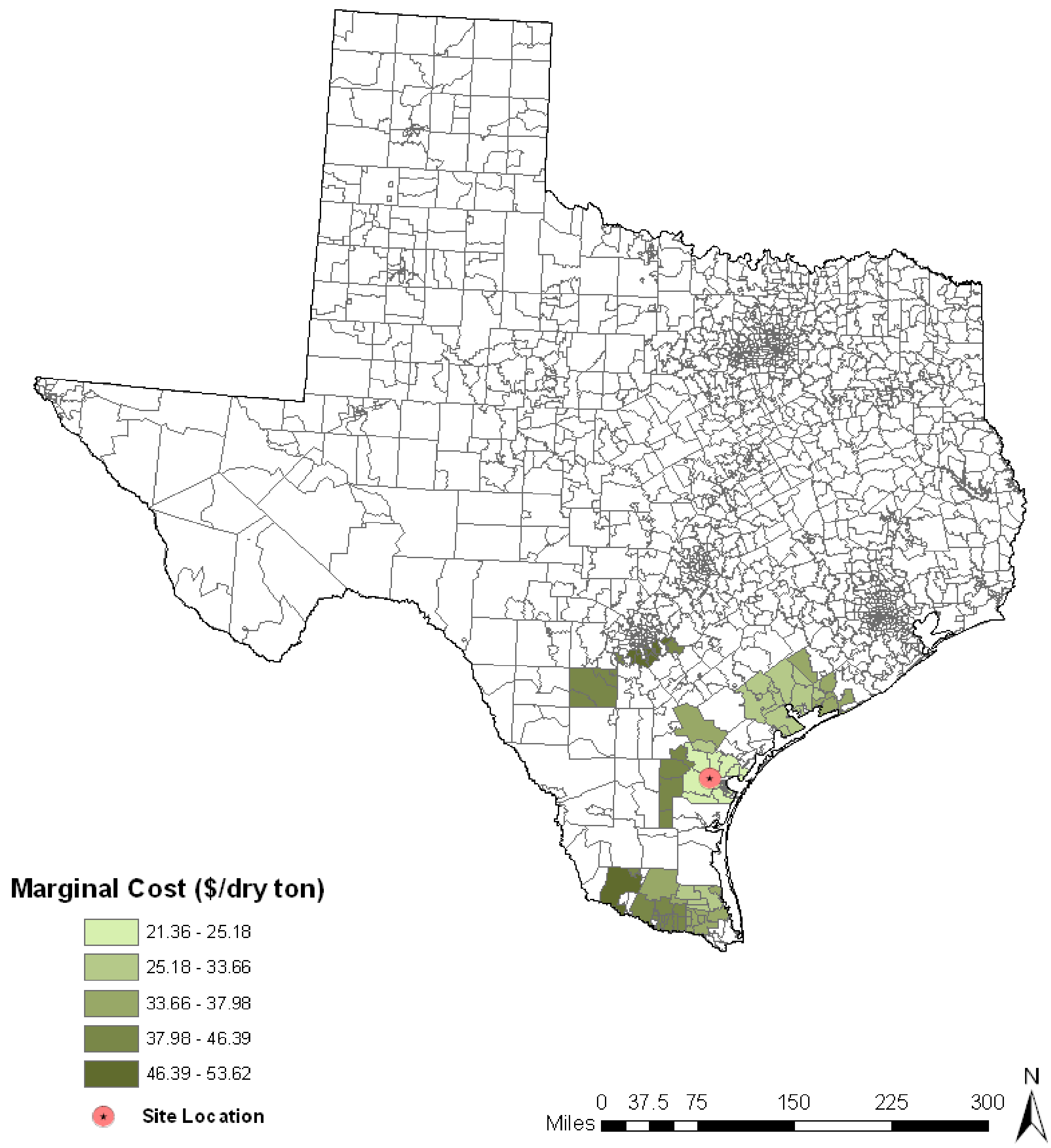

Figure D12. MC by ZCTA of sorghum straw for the 78410 zip code bio-basin.

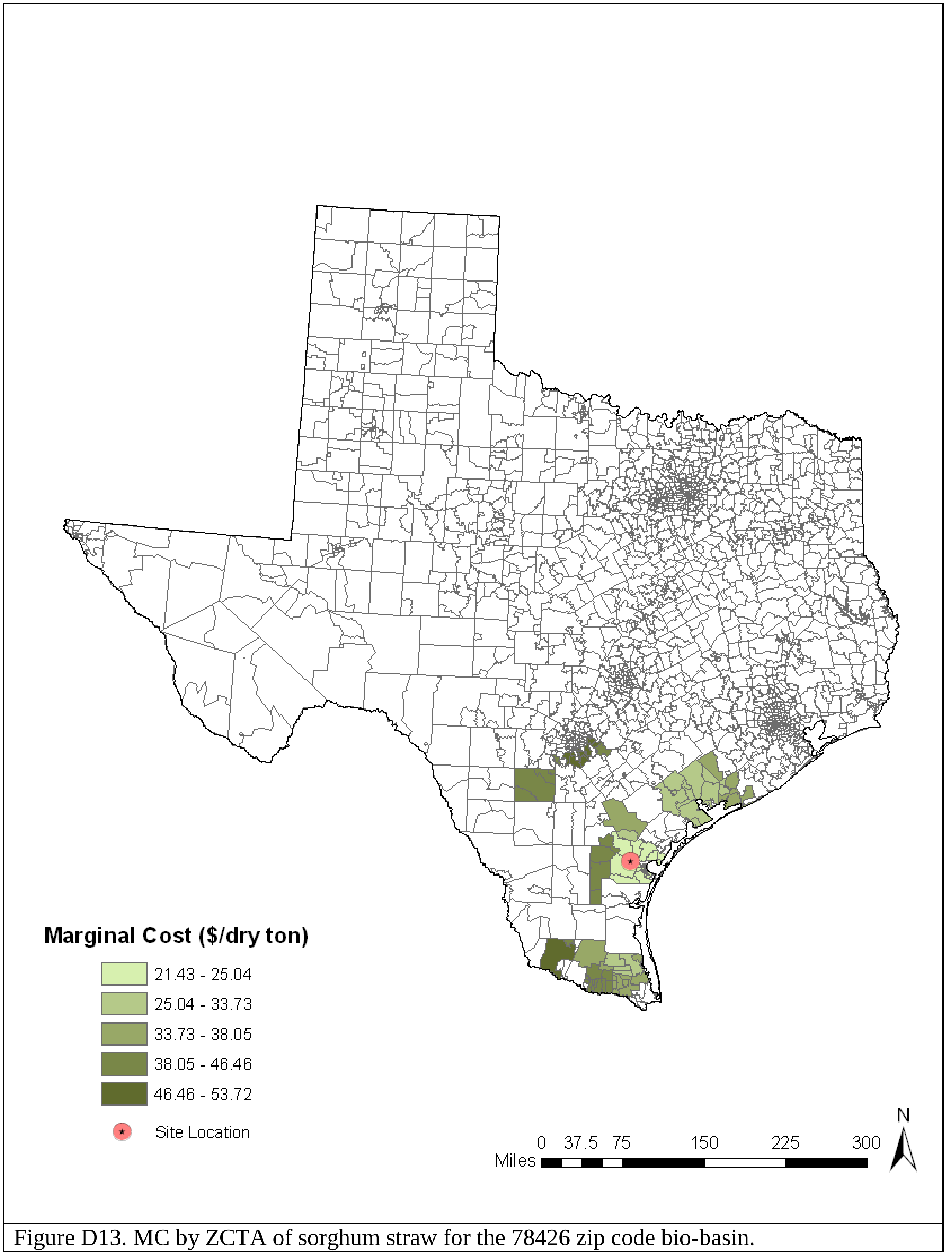

Figure D13. MC by ZCTA of sorghum straw for the 78426 zip code bio-basin.

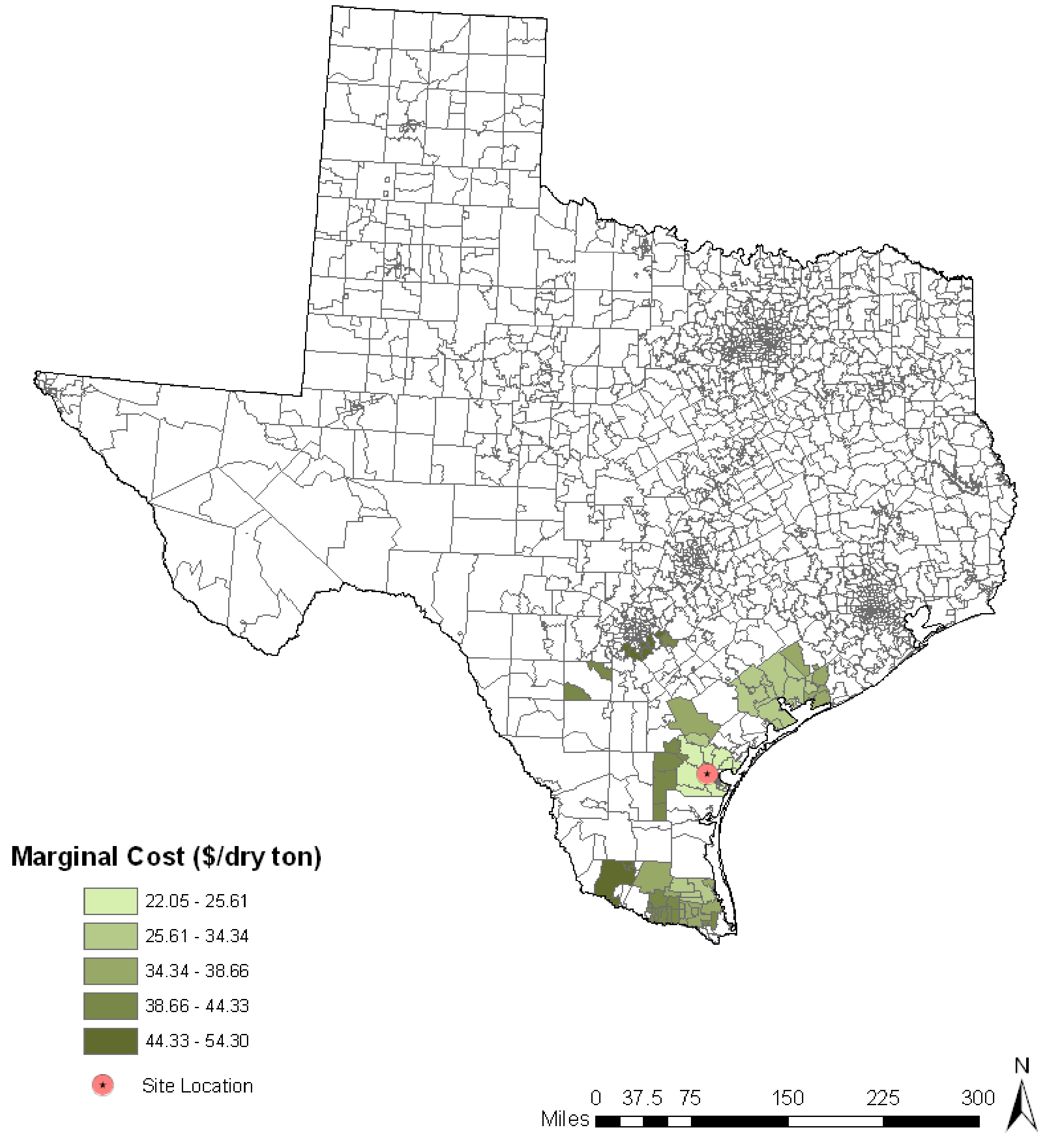

Figure D14. MC by ZCTA of sorghum straw for the 78409 zip code bio-basin.

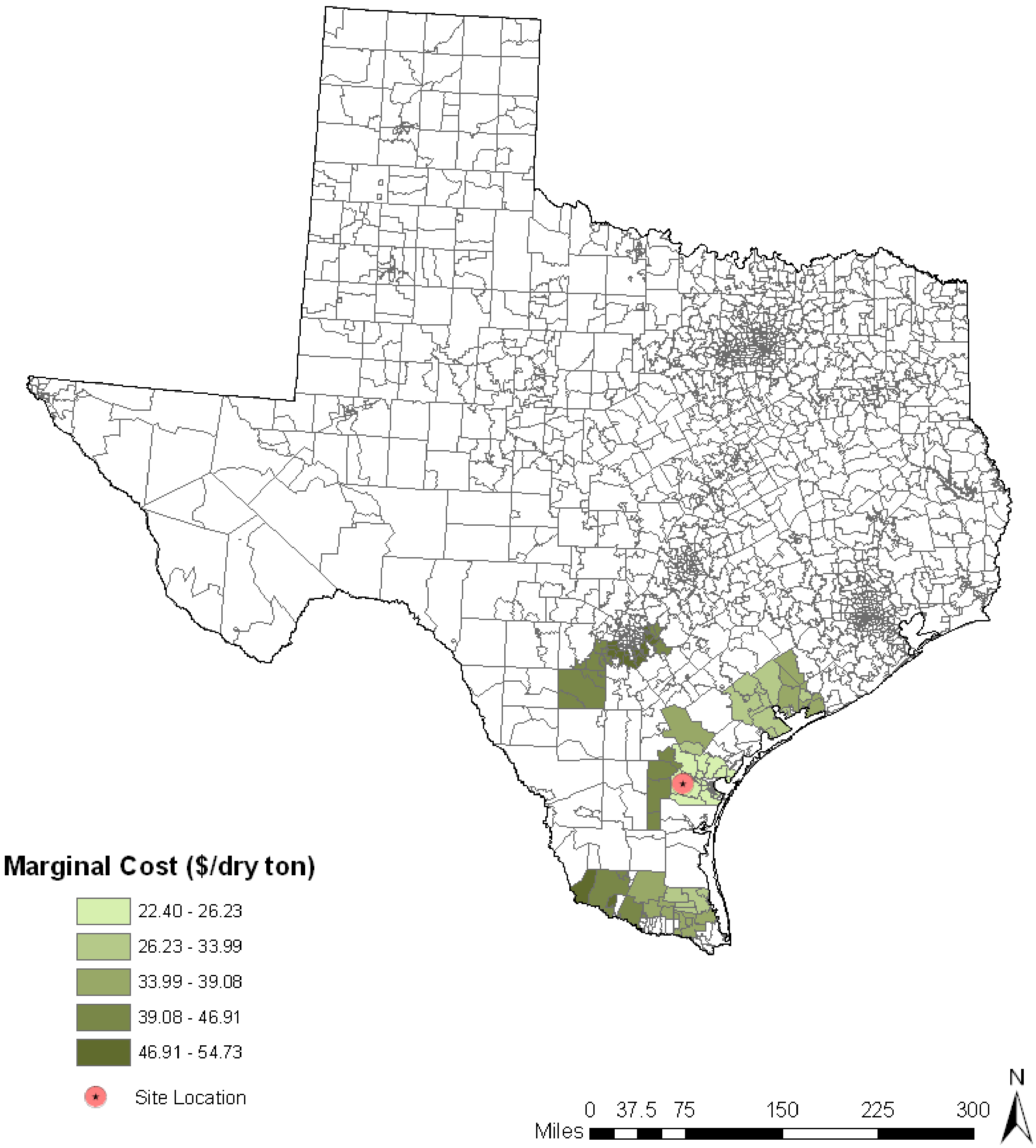

Figure D15. MC by ZCTA of sorghum straw for the 78339 zip code bio-basin.

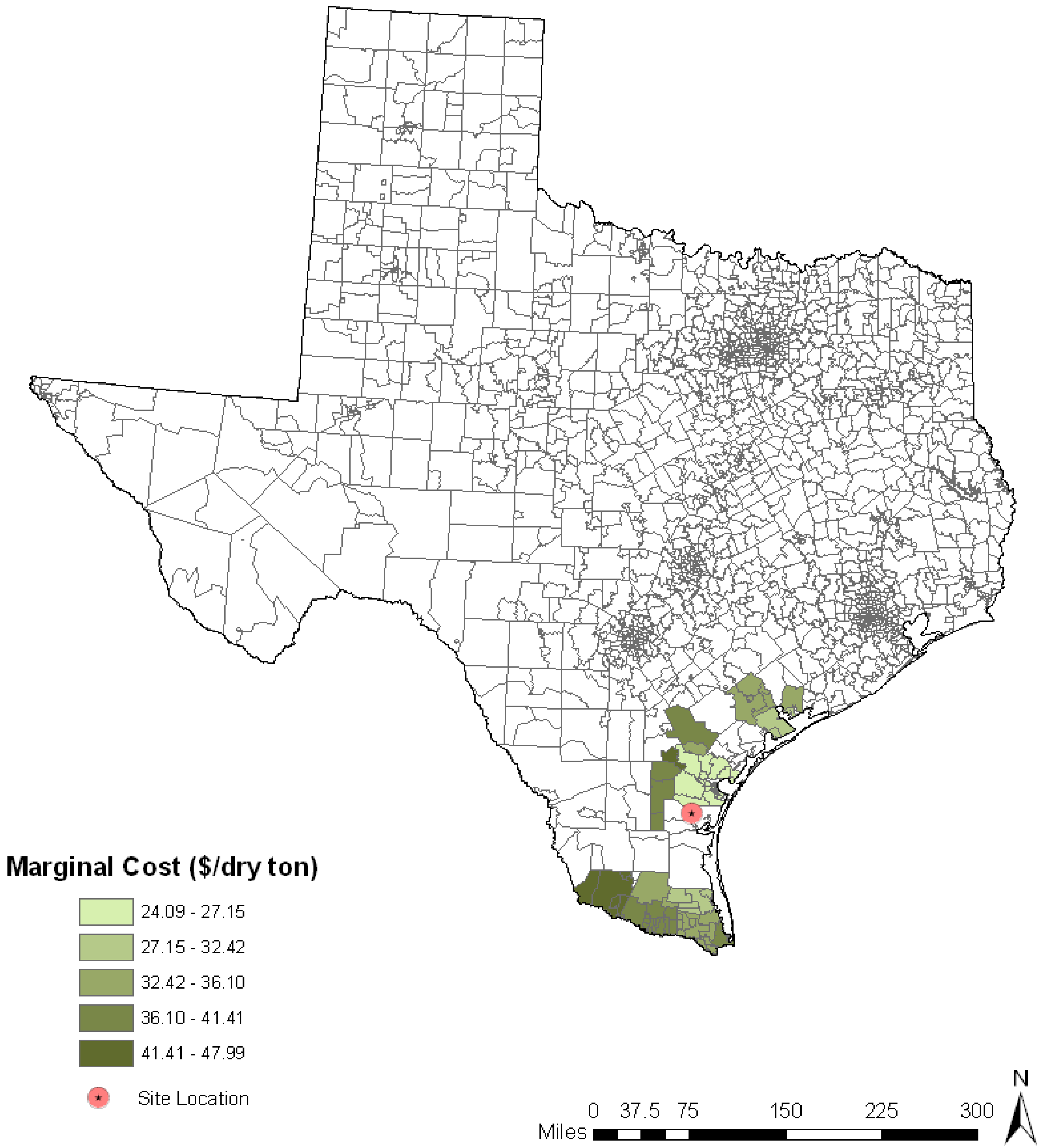

Figure D16. MC by ZCTA of sorghum straw for the 78364 zip code bio-basin.

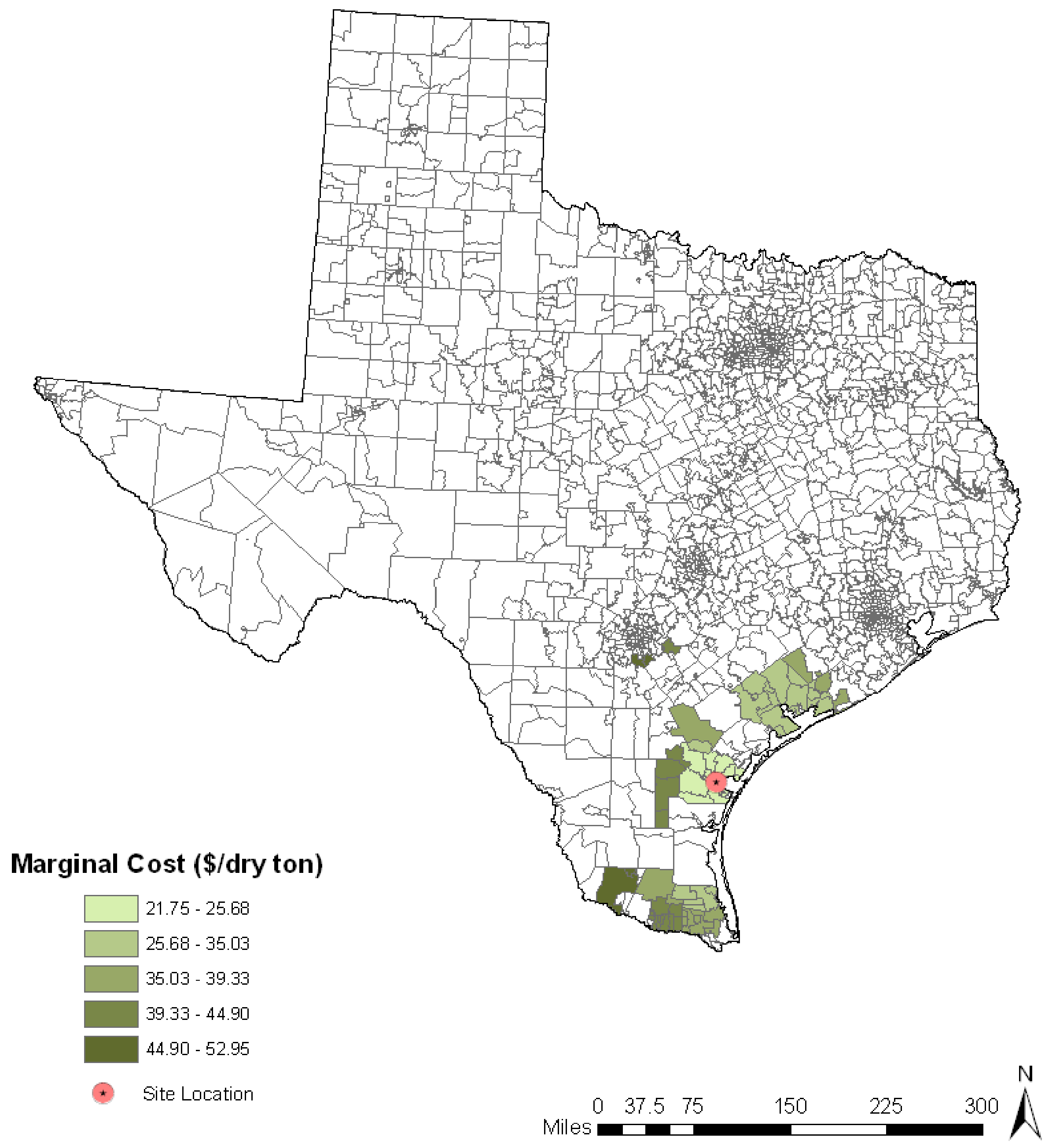

Figure D17. MC by ZCTA of sorghum straw for the 78405 zip code bio-basin.

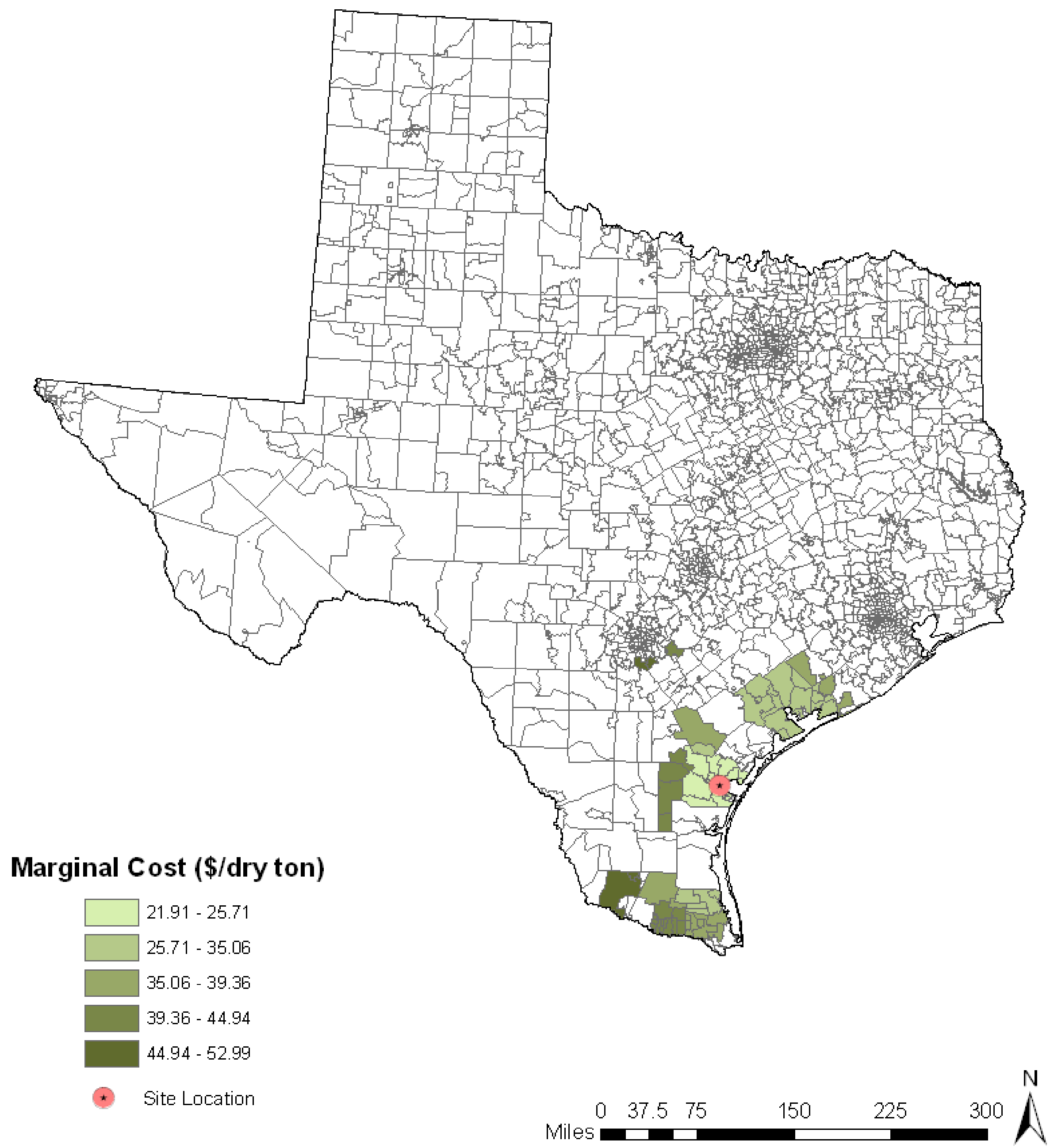

Figure D18. MC by ZCTA of sorghum straw for the 78416 zip code bio-basin.

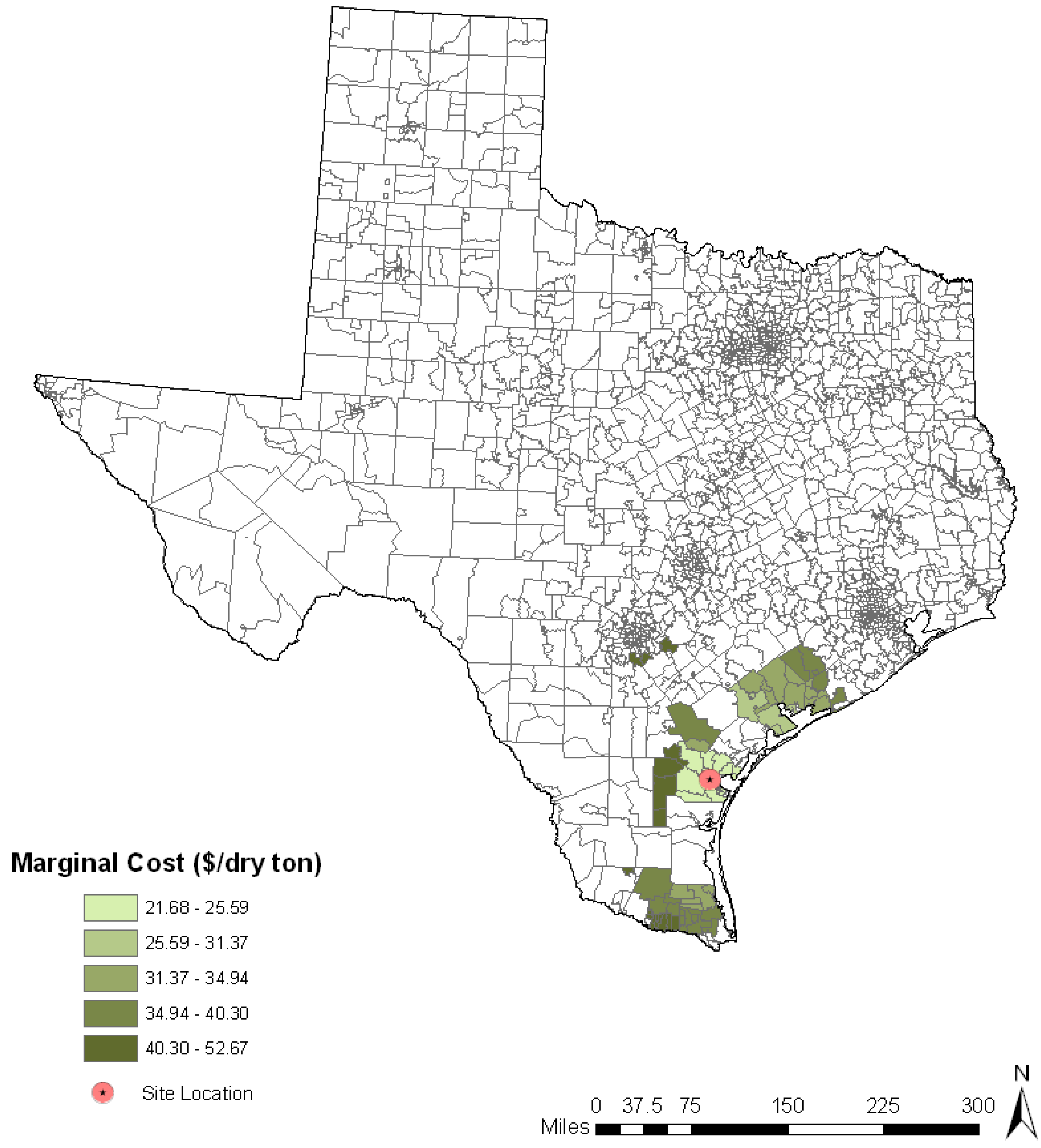

Figure D19. MC by ZCTA of sorghum straw for the 78408 zip code bio-basin.

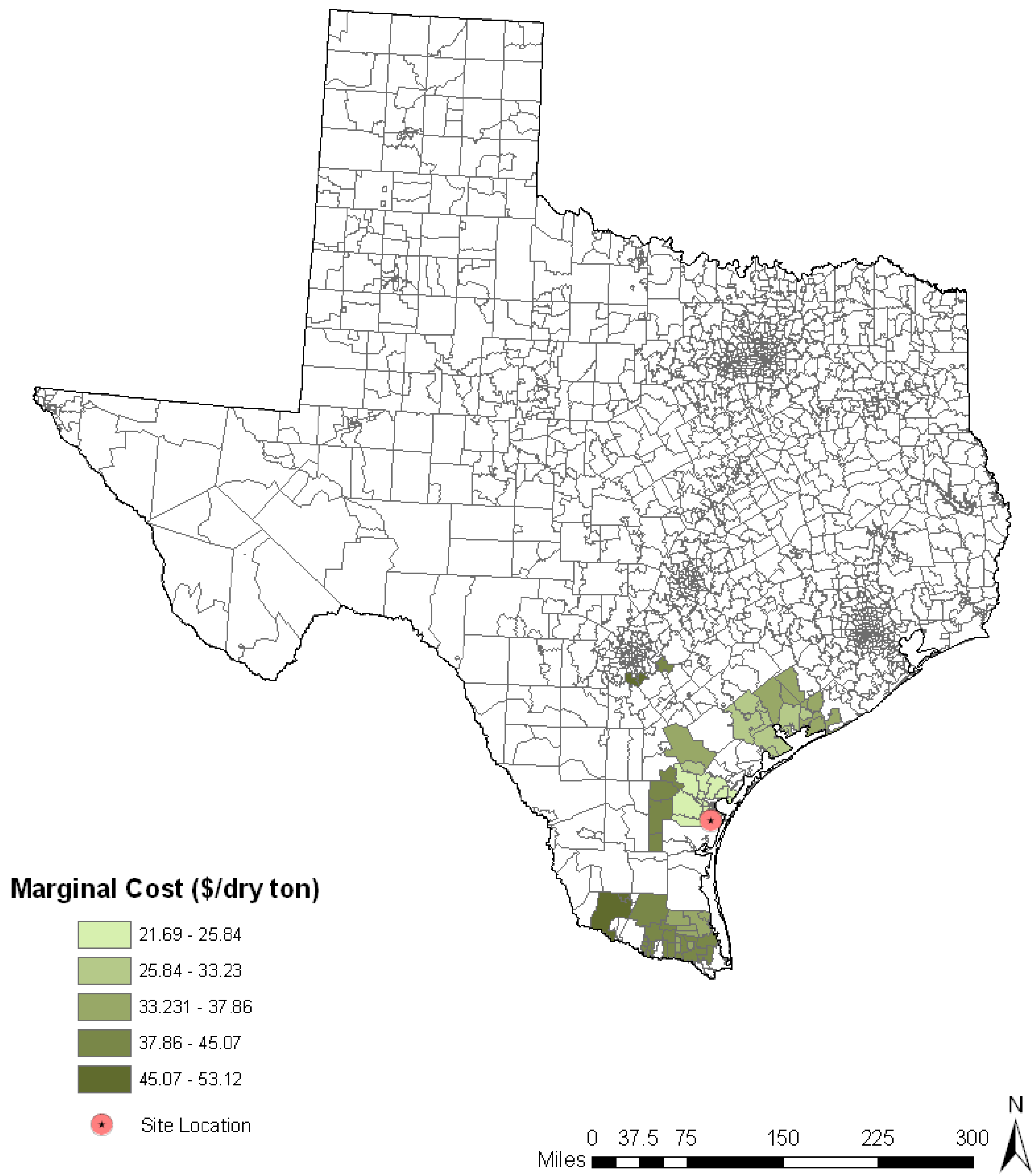

Figure D20. MC by ZCTA of sorghum straw for the 78467 zip code bio-basin.

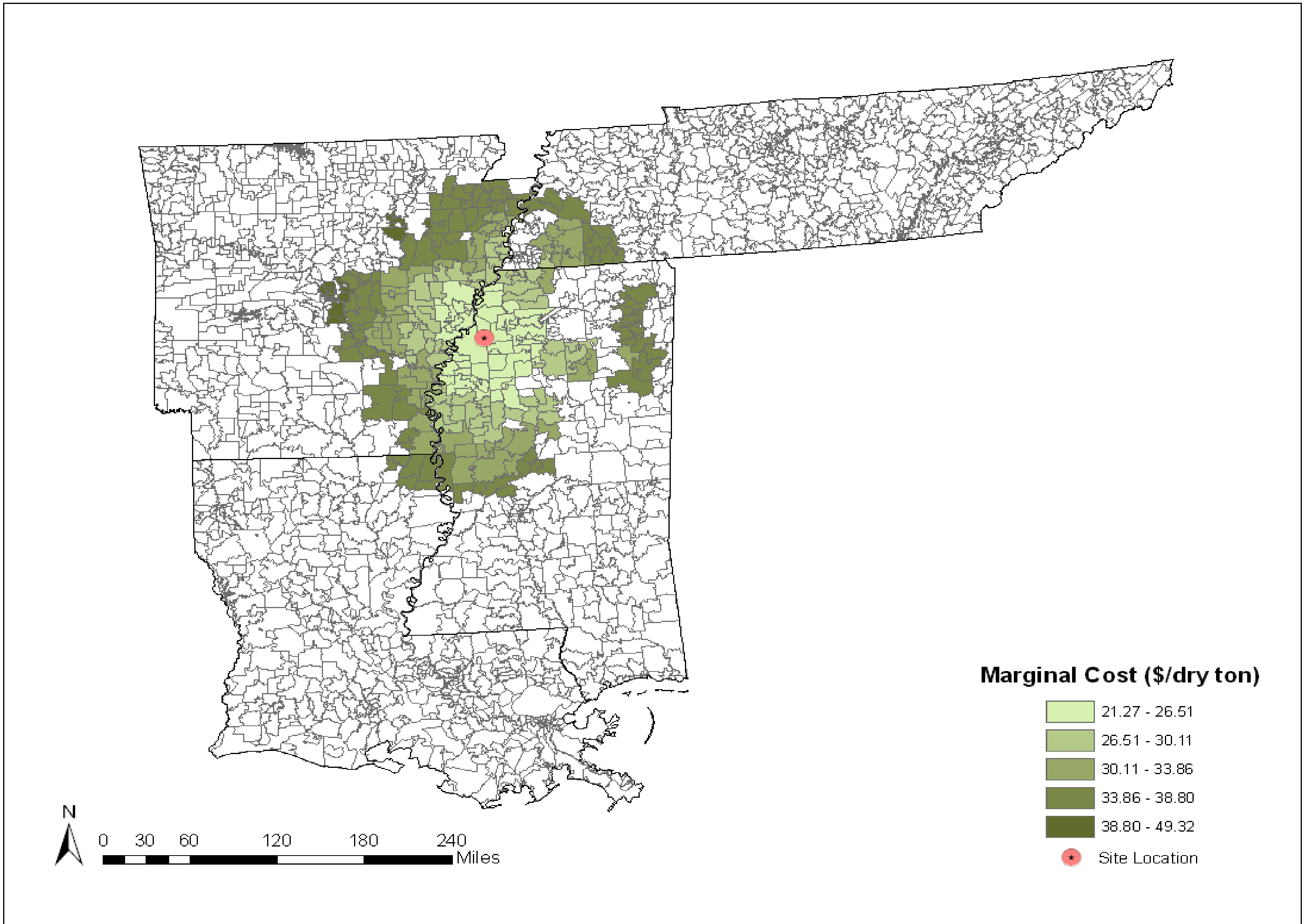

Figure D21. MC by ZCTA of wheat straw for the 38645 zip code bio-basin.

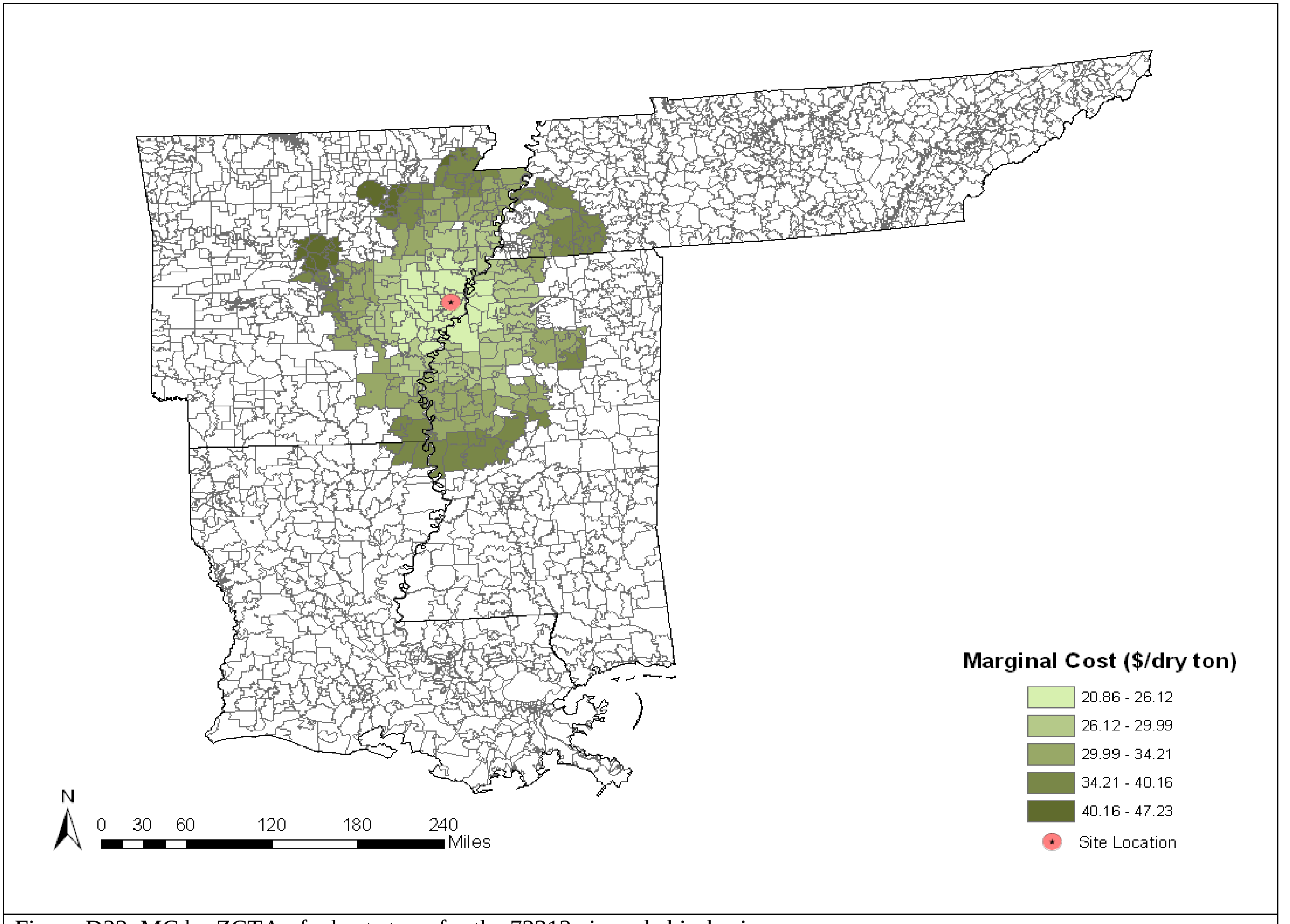

Figure D22. MC by ZCTA of wheat straw for the 72312 zip code bio-basin.

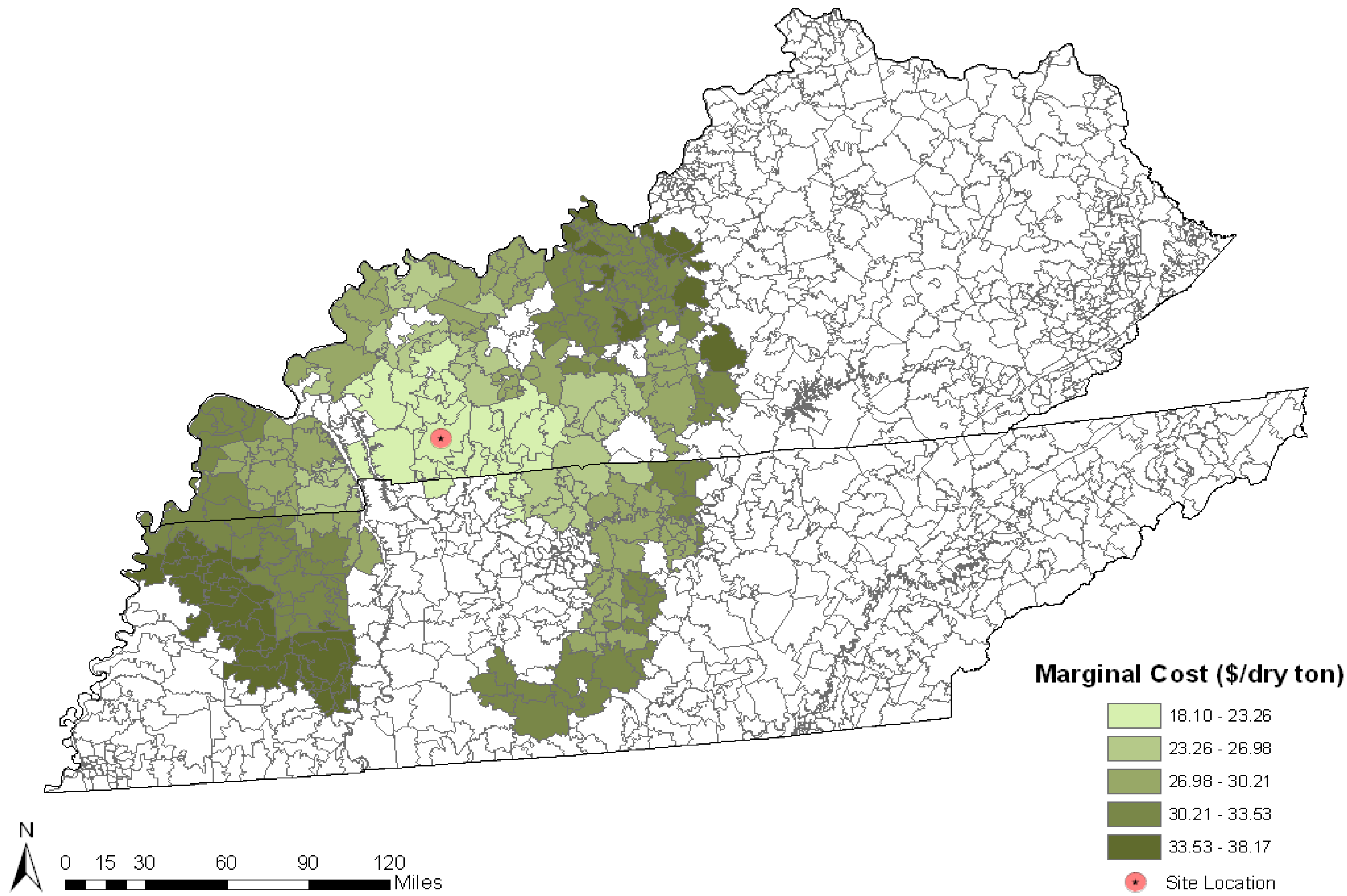

Figure D23. MC by ZCTA of wheat straw for the 42241 zip code bio-basin.

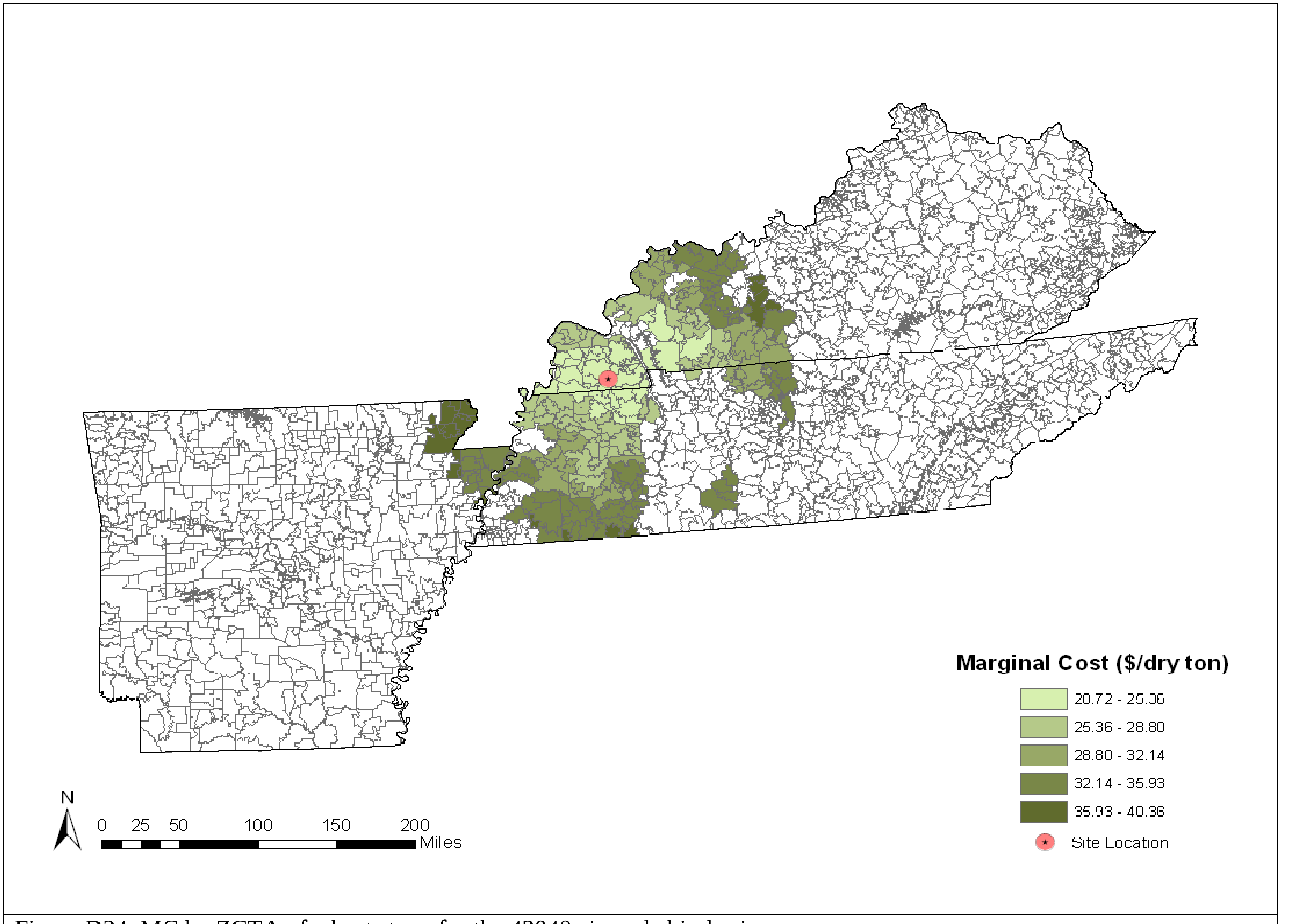

Figure D24. MC by ZCTA of wheat straw for the 42040 zip code bio-basin.

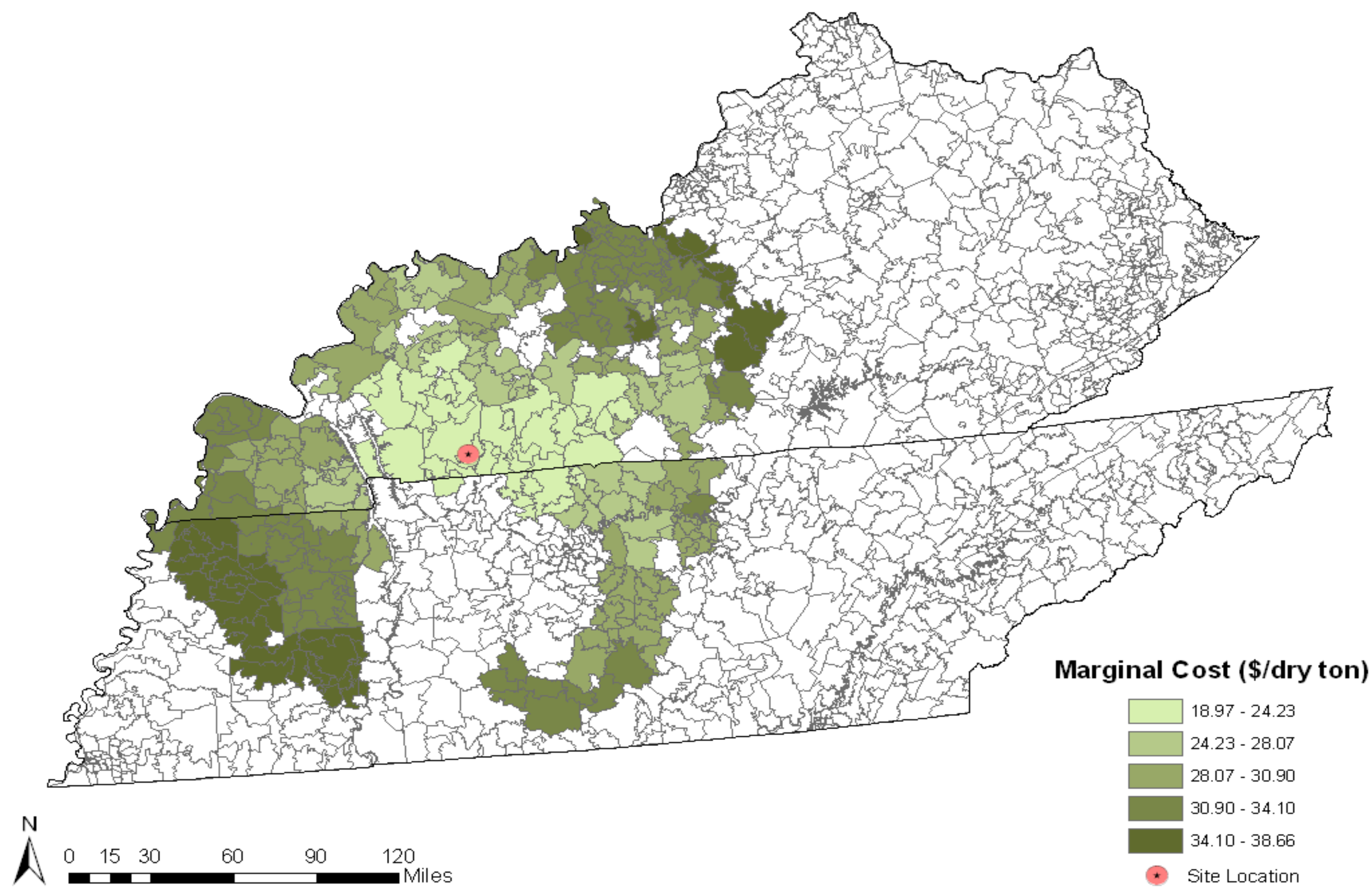

Figure D25. MC by ZCTA of wheat straw for the 42221 zip code bio-basin.

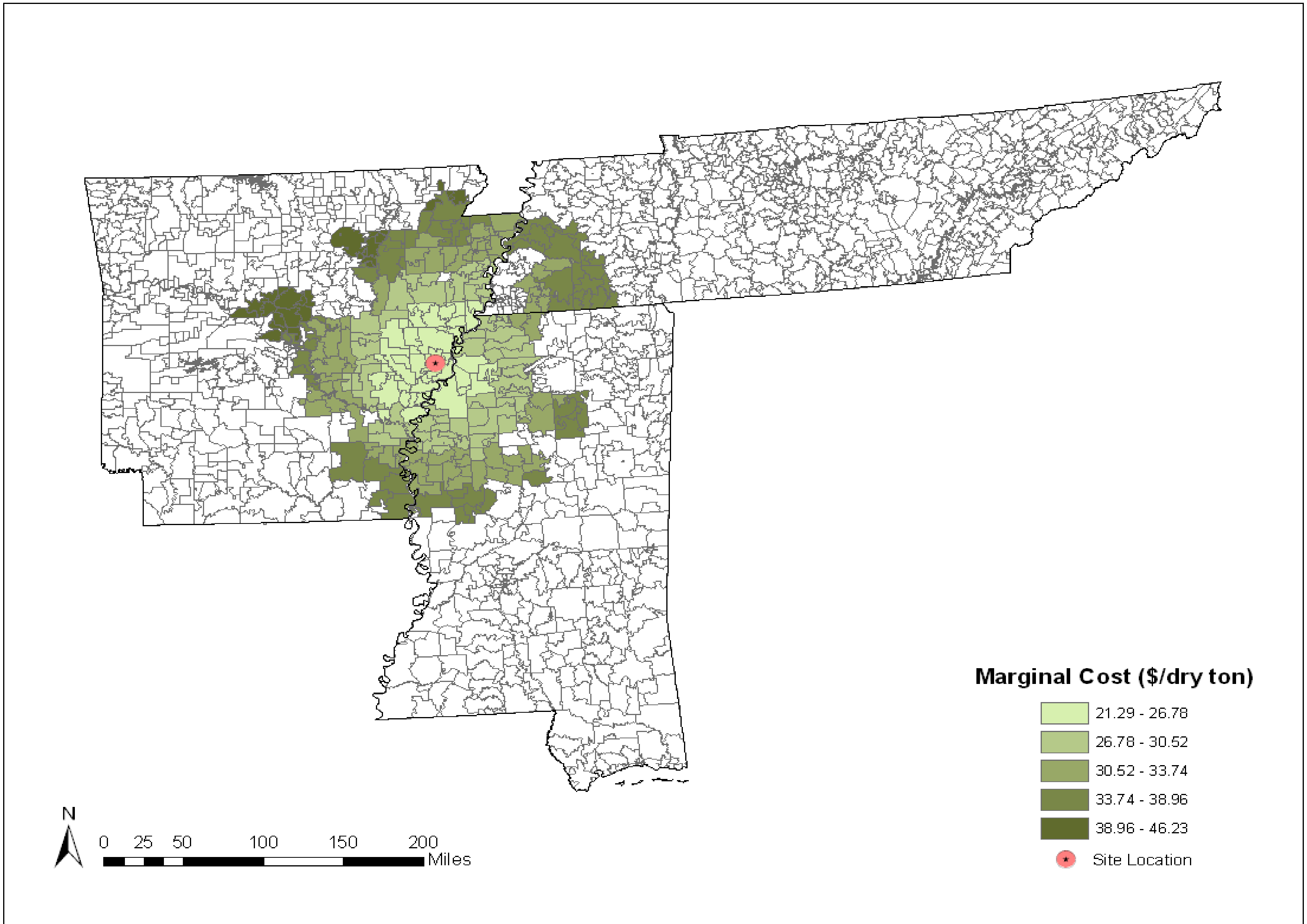

Figure D26. MC by ZCTA of wheat straw for the 72352 zip code bio-basin.

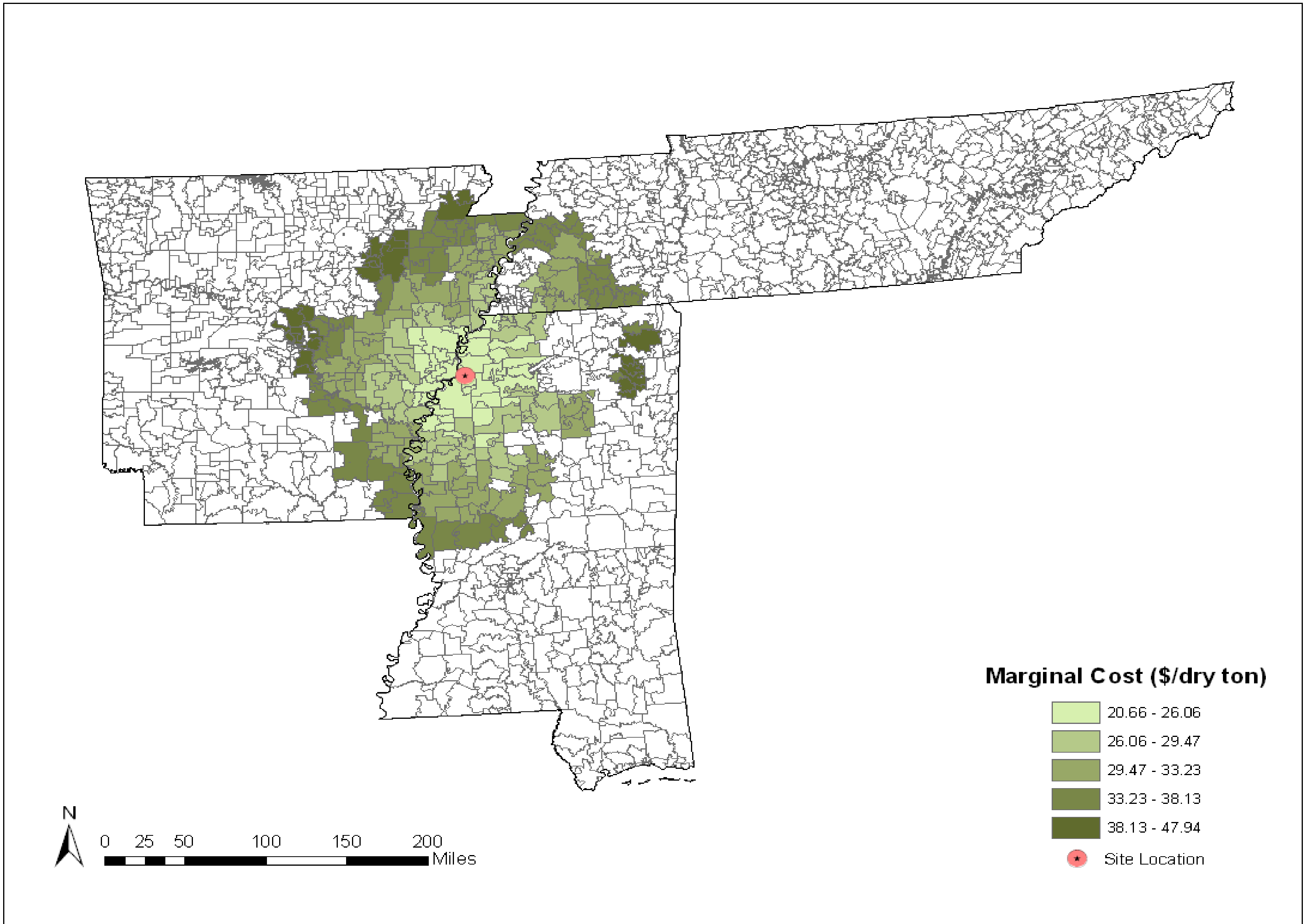

Figure D27. MC by ZCTA of wheat straw for the 38644 zip code bio-basin.

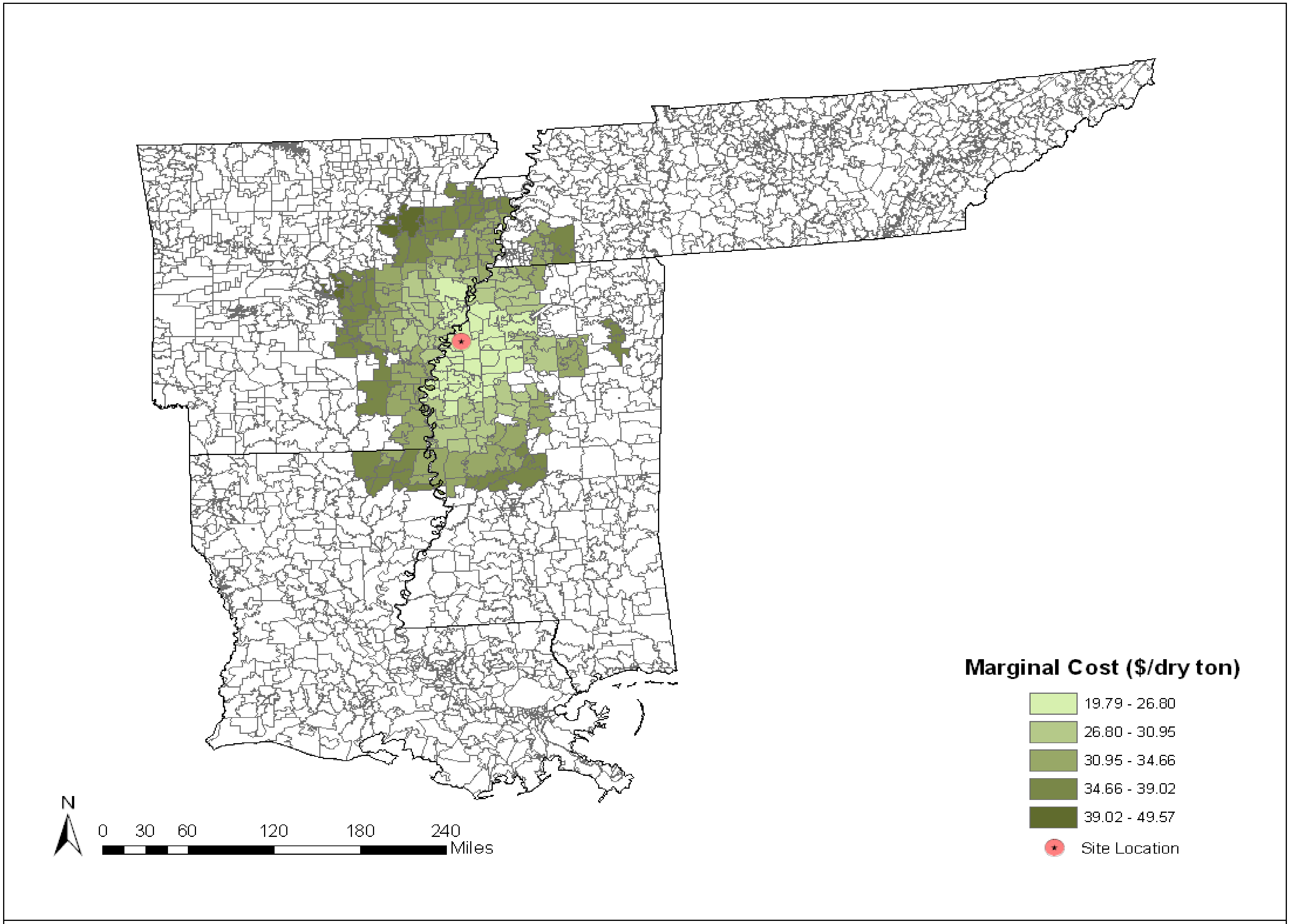

Figure D28. MC by ZCTA of wheat straw for the 38767 zip code bio-basin.

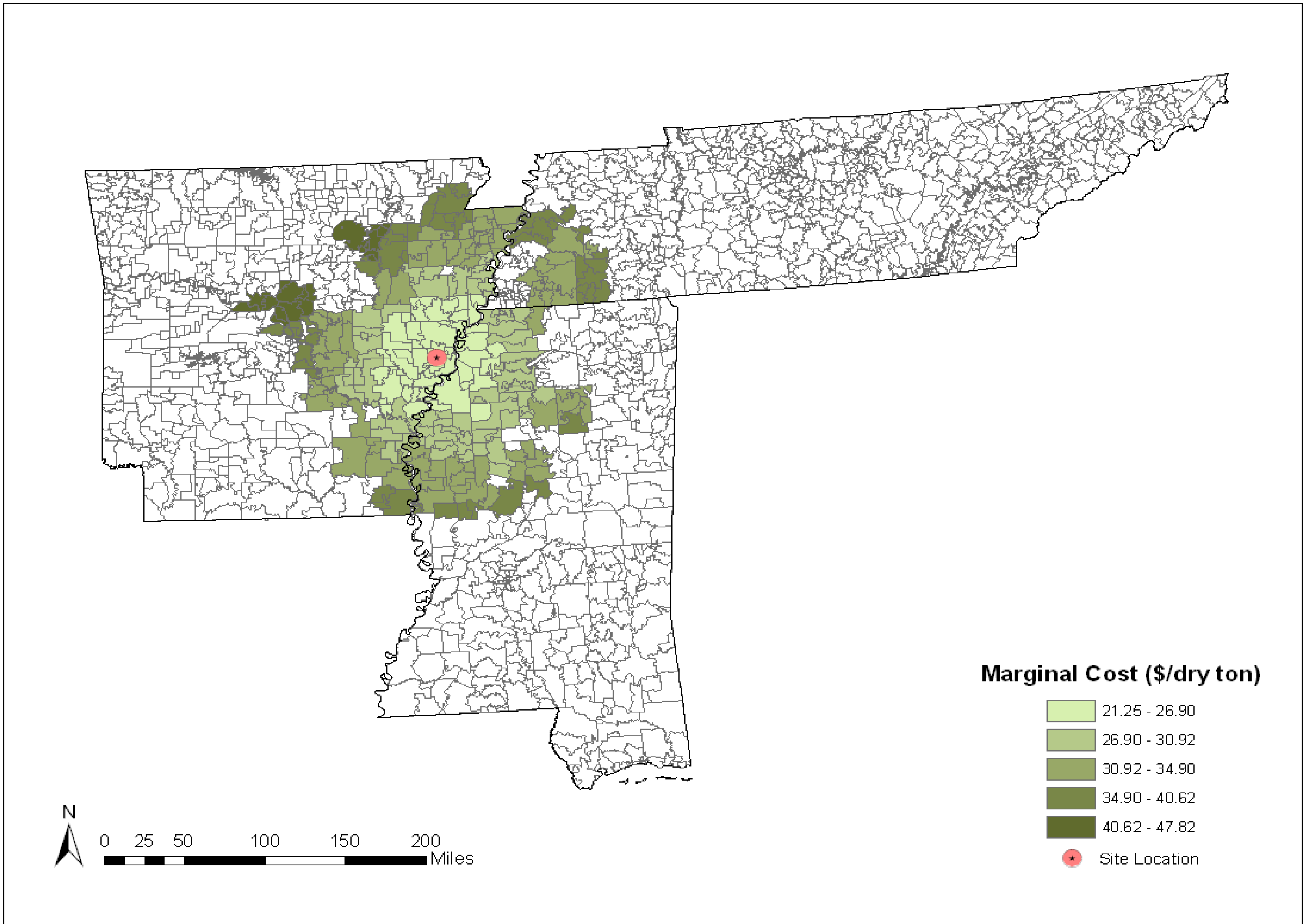

Figure D29. MC by ZCTA of wheat straw for the 72355 zip code bio-basin.

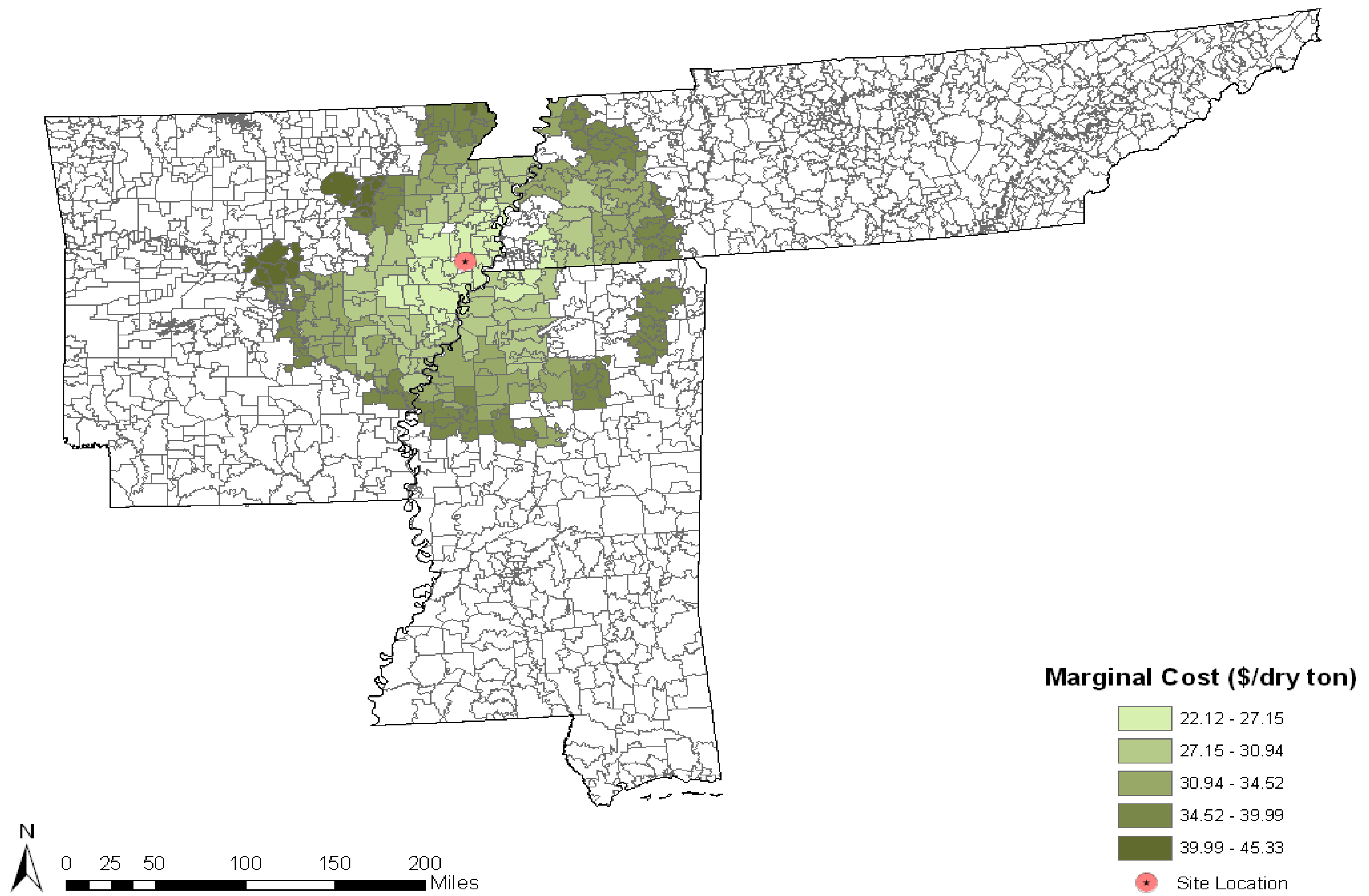

Figure D30. MC by ZCTA of wheat straw for the 72346 zip code bio-basin.

Appendix E

Bio-basin ZCTA maps for the top ten sites for total mill residues, hardwood mill residues, and softwood mill residues for northern region with MCs.

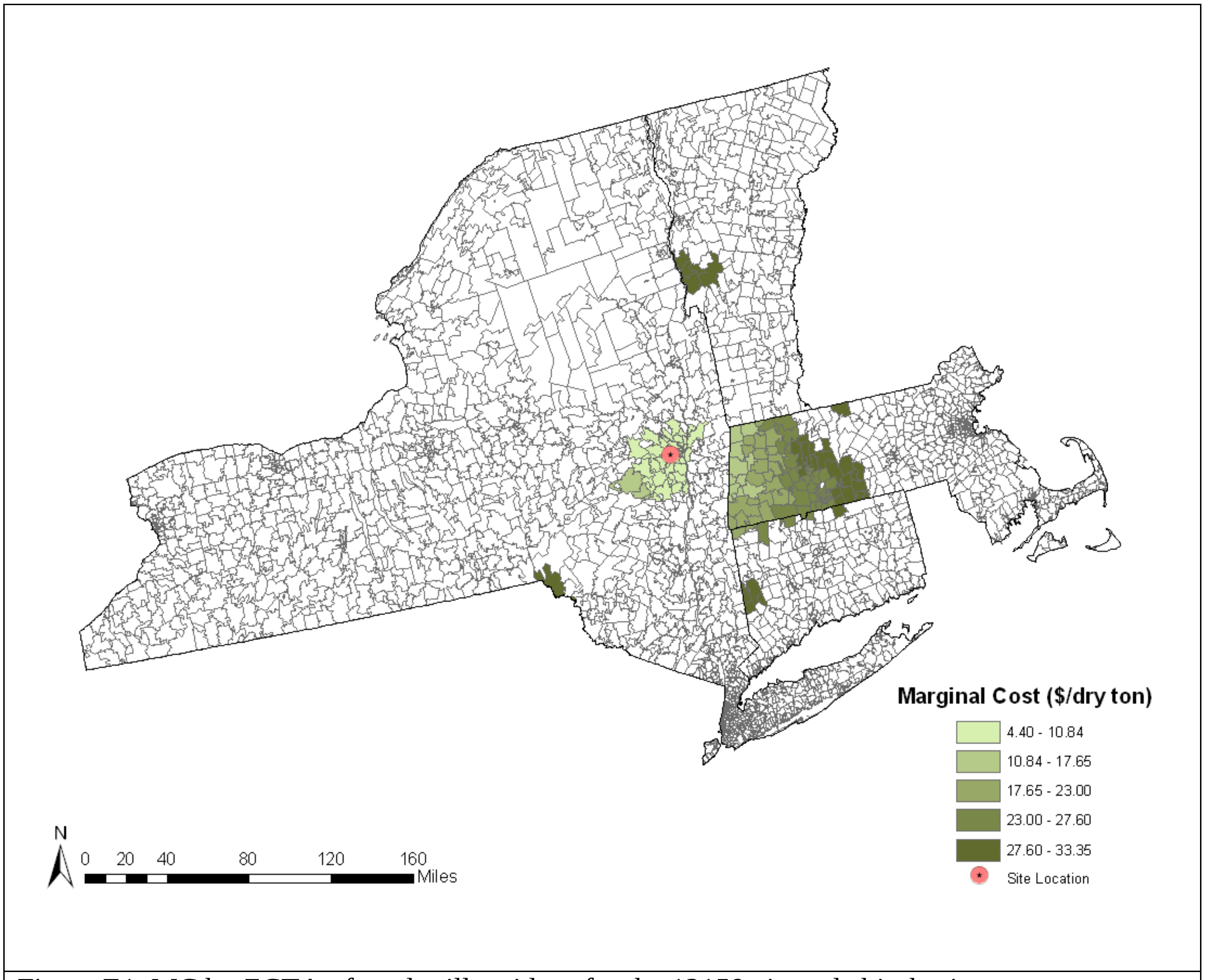

Figure E1. MC by ZCTA of total mill residues for the 12159 zip code bio-basin.

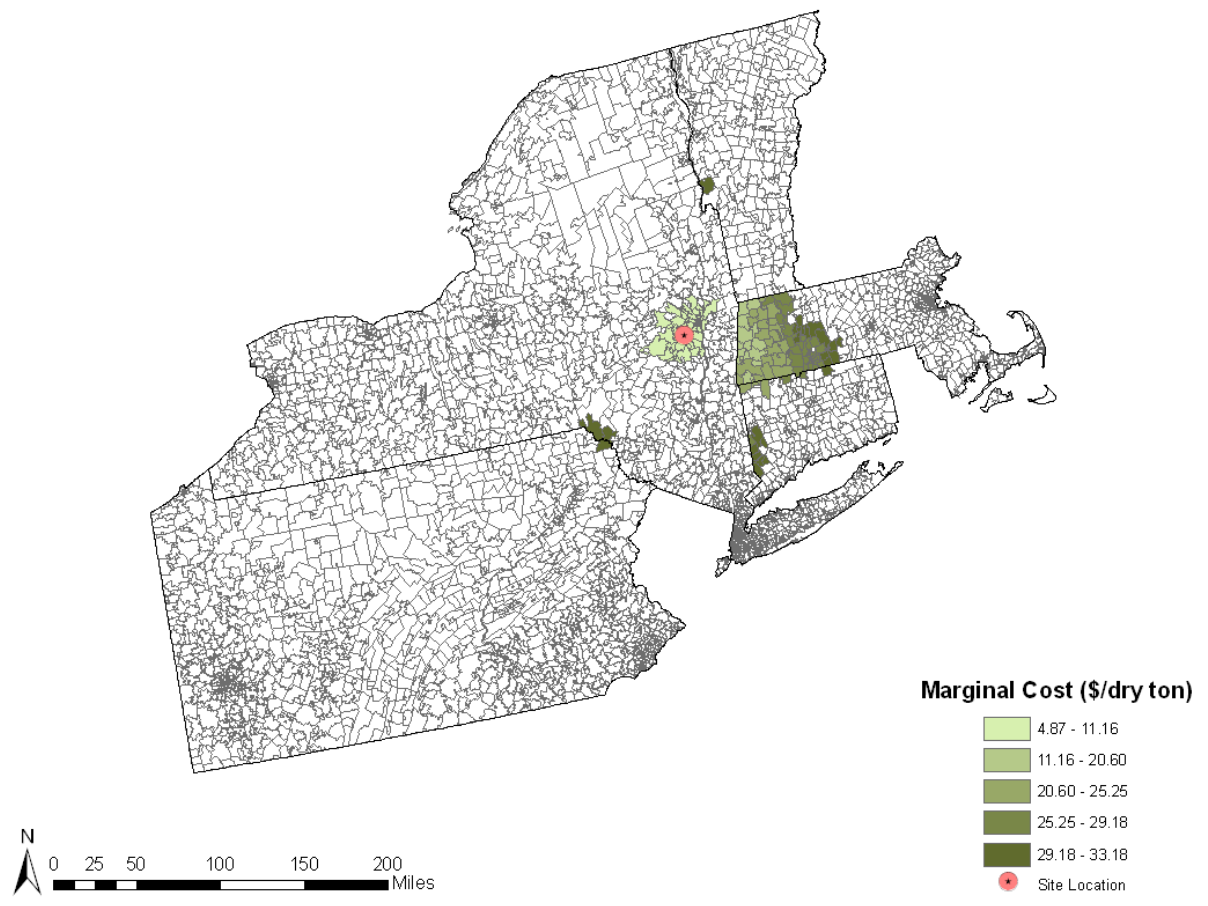

Figure E2. MC by ZCTA of total mill residues for the 12041 zip code bio-basin.

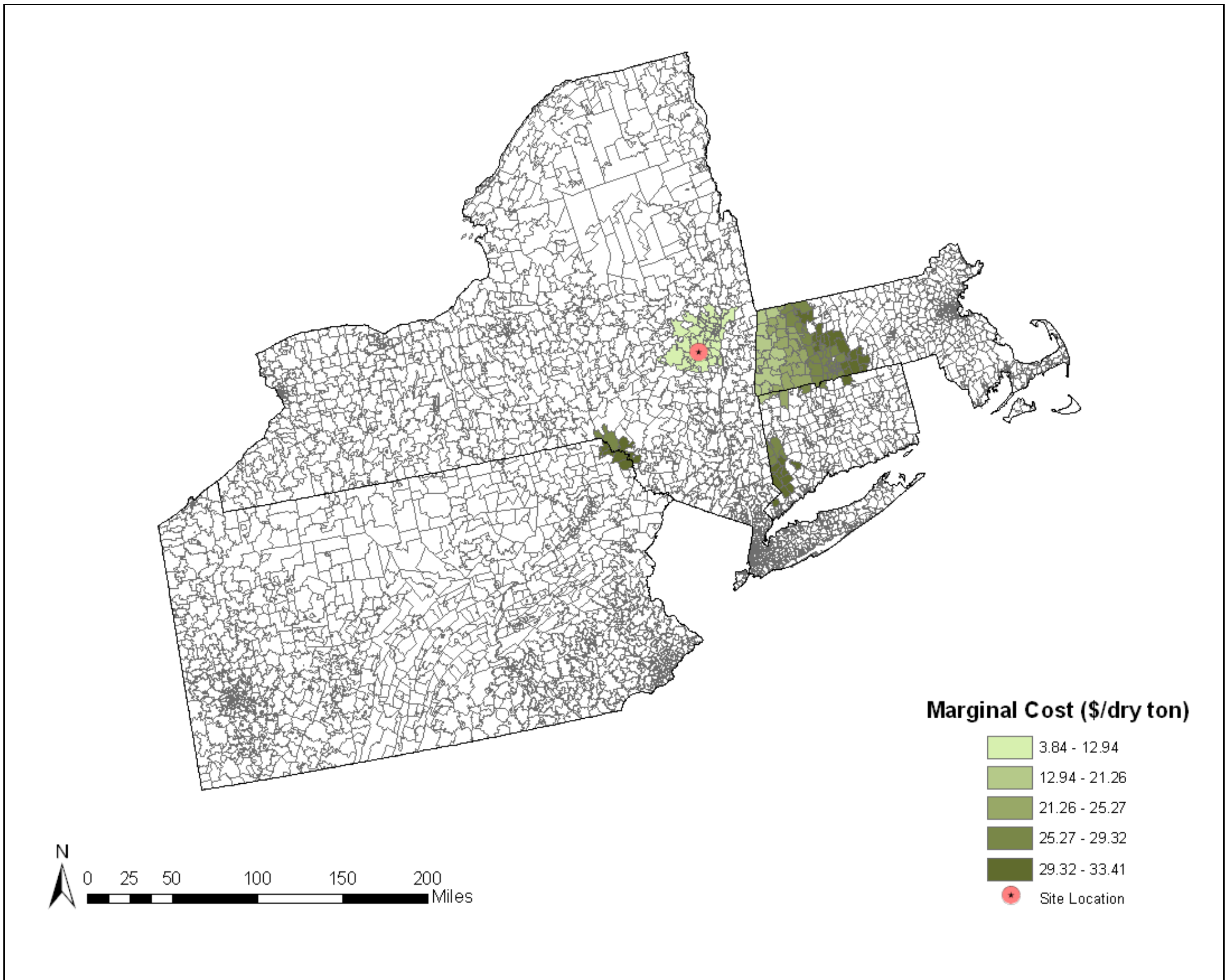

Figure E3. MC by ZCTA of total mill residues for the 12055 zip code (12193 ZCTA) bio-basin.

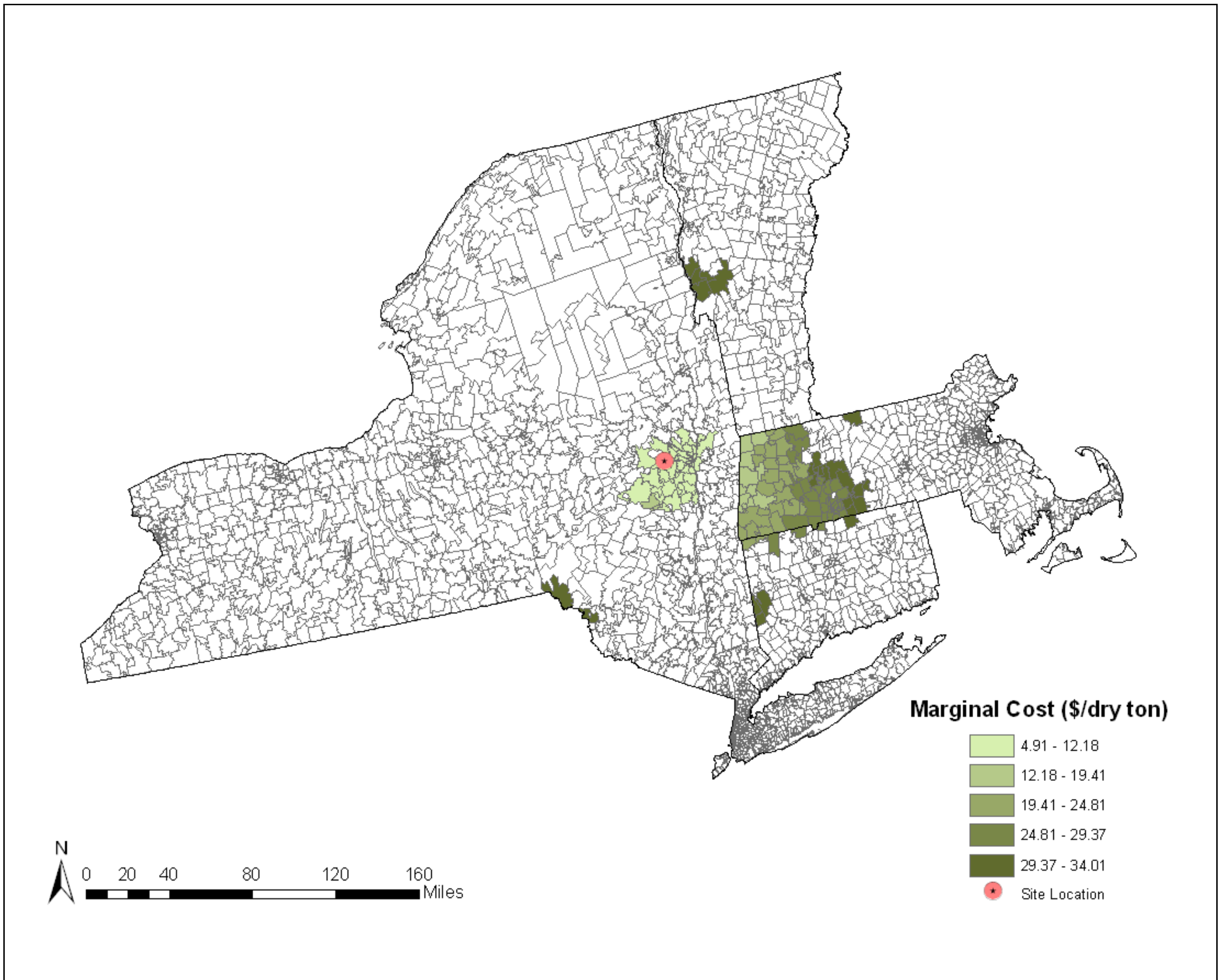

Figure E4. MC by ZCTA of total mill residues for the 12085 zip code (12009 ZCTA) bio-basin.

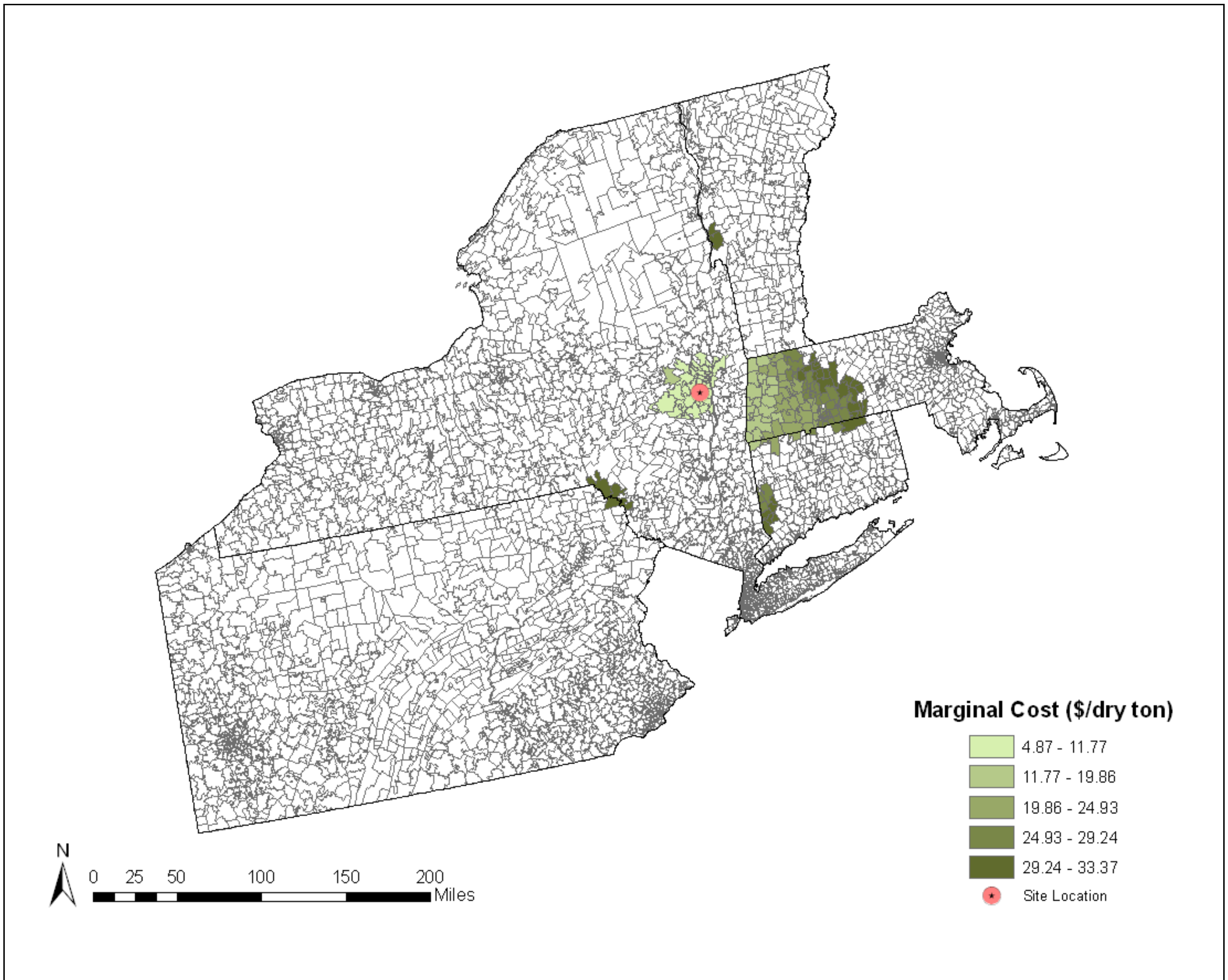

Figure E5. MC by ZCTA of total mill residues for the 12067 zip code bio-basin.

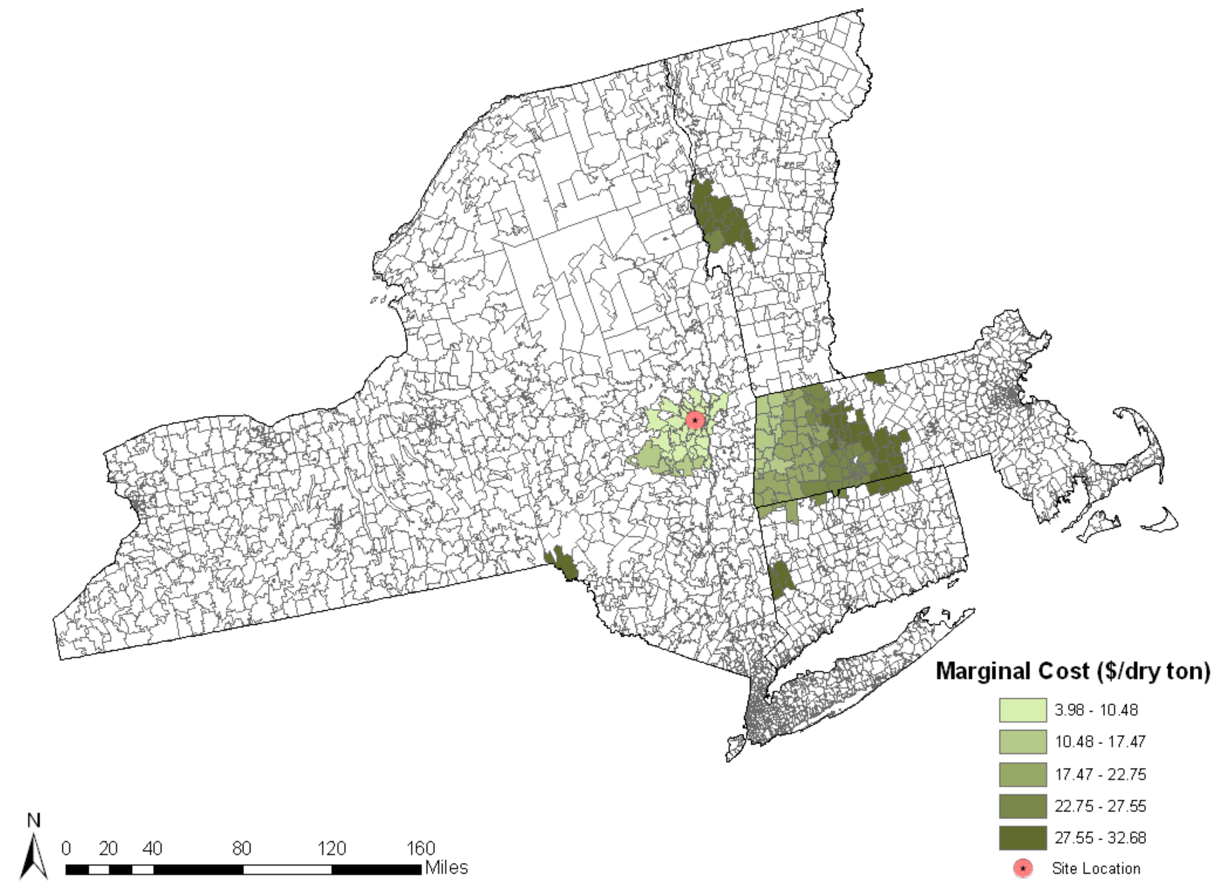

Figure E6. MC by ZCTA of total mill residues for the 12203 zip code bio-basin.

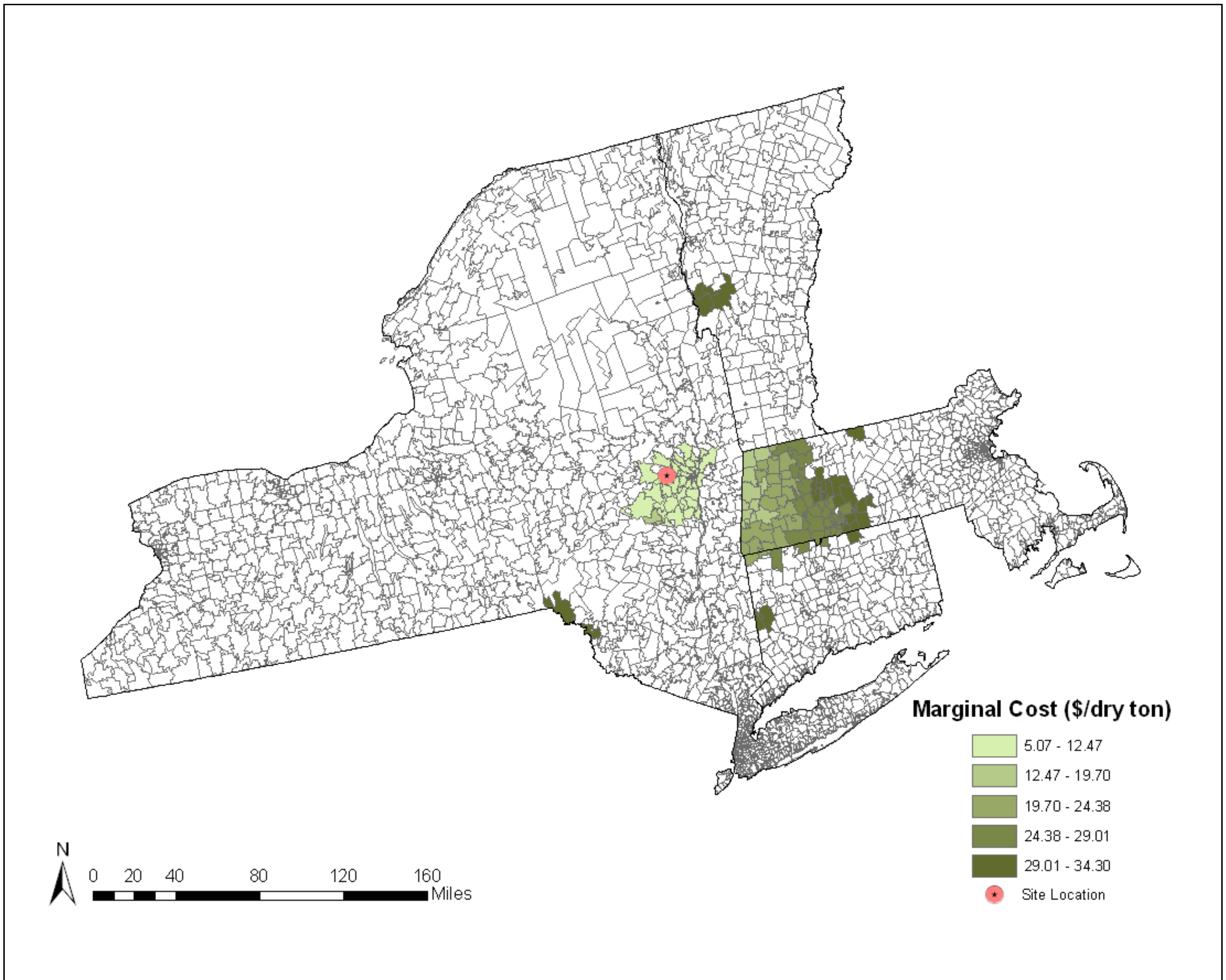

Figure E7. MC by ZCTA of total mill residues for the 12009 zip code bio-basin.

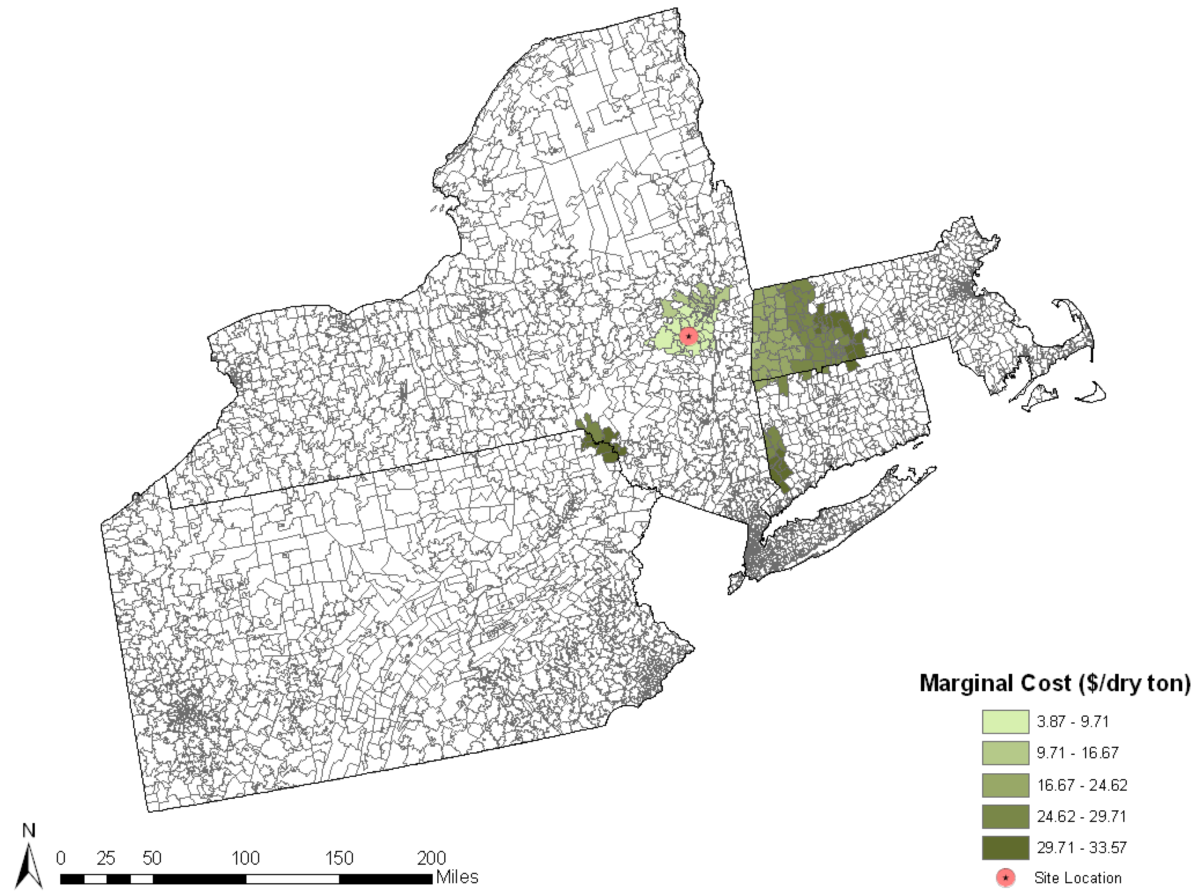

Figure E8. MC by ZCTA of total mill residues for the 12193 zip code bio-basin.

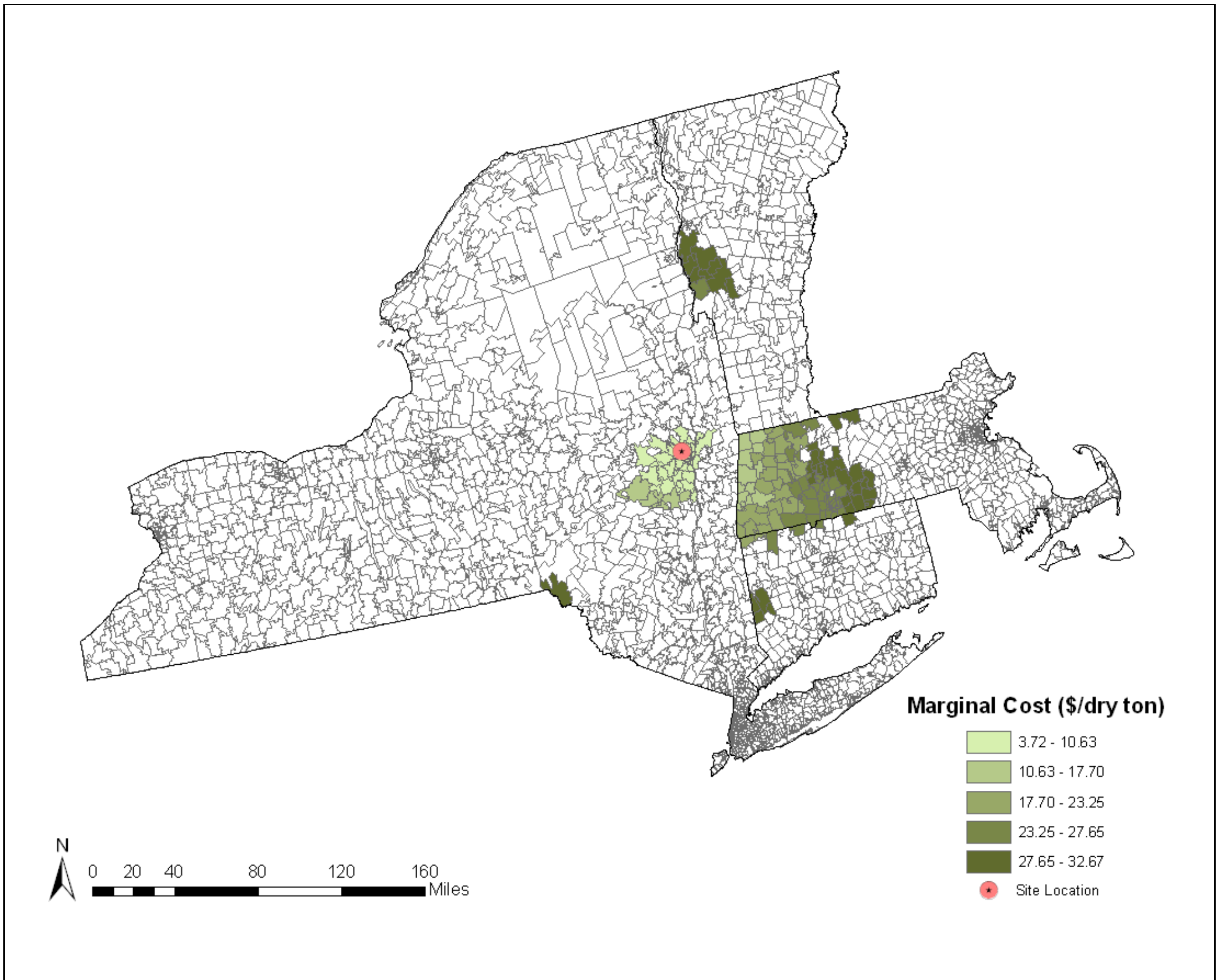

Figure E9. MC by ZCTA of total mill residues for the 12212 zip code (12005 ZCTA) bio-basin.

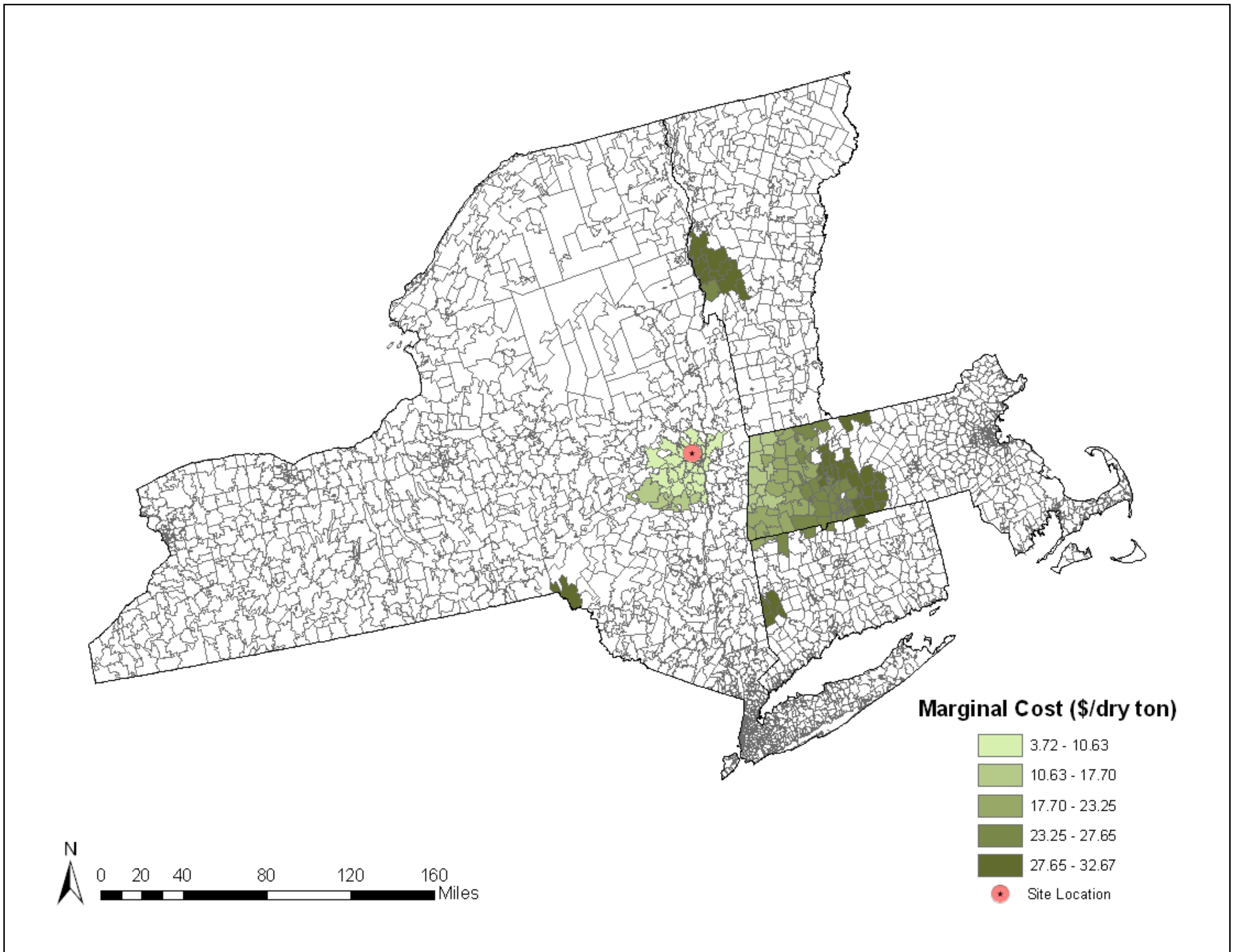

Figure E10. MC by ZCTA of total mill residues for the 12288 zip code (12005 ZCTA) bio-basin.

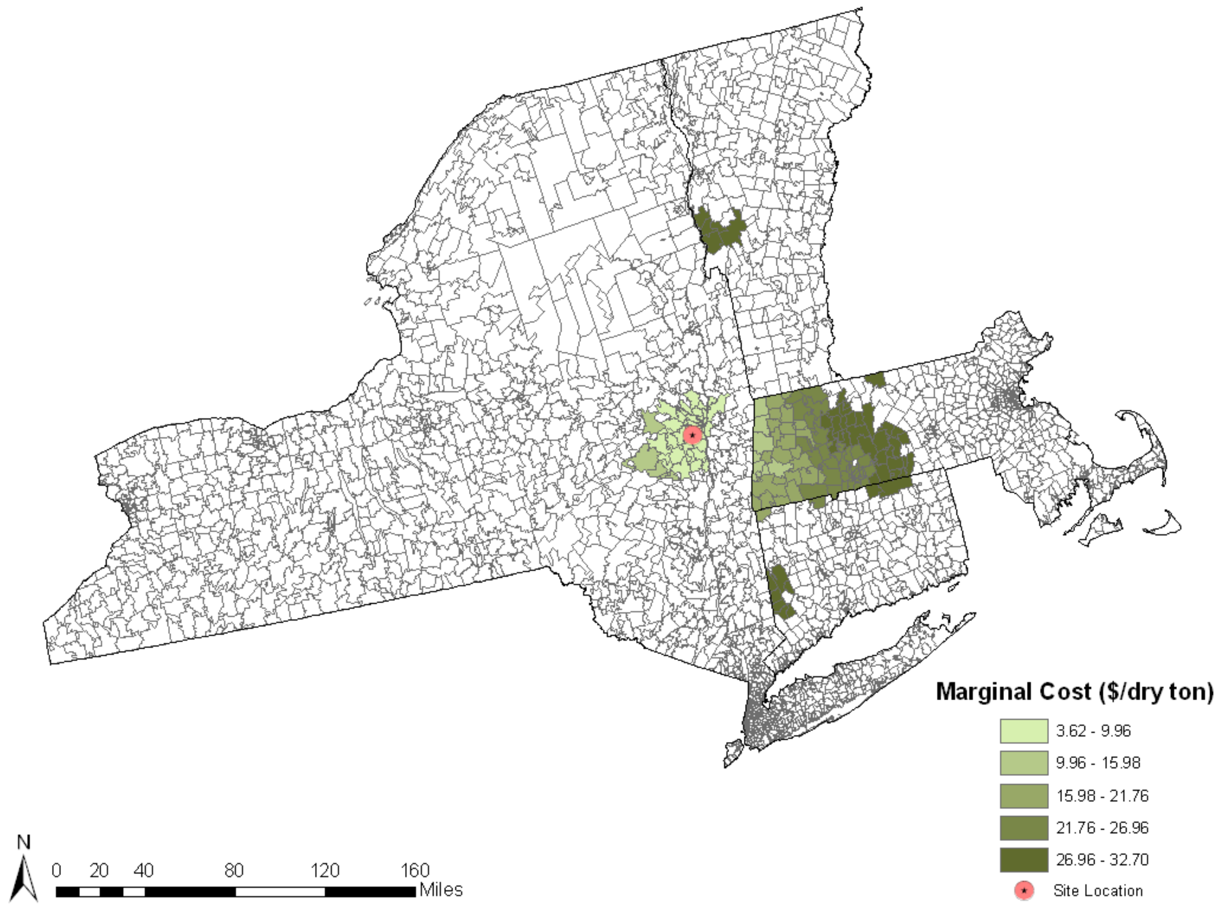

Figure E11. MC by ZCTA of hardwood mill residues for the 12161 zip code (12054 ZCTA) bio-basin.

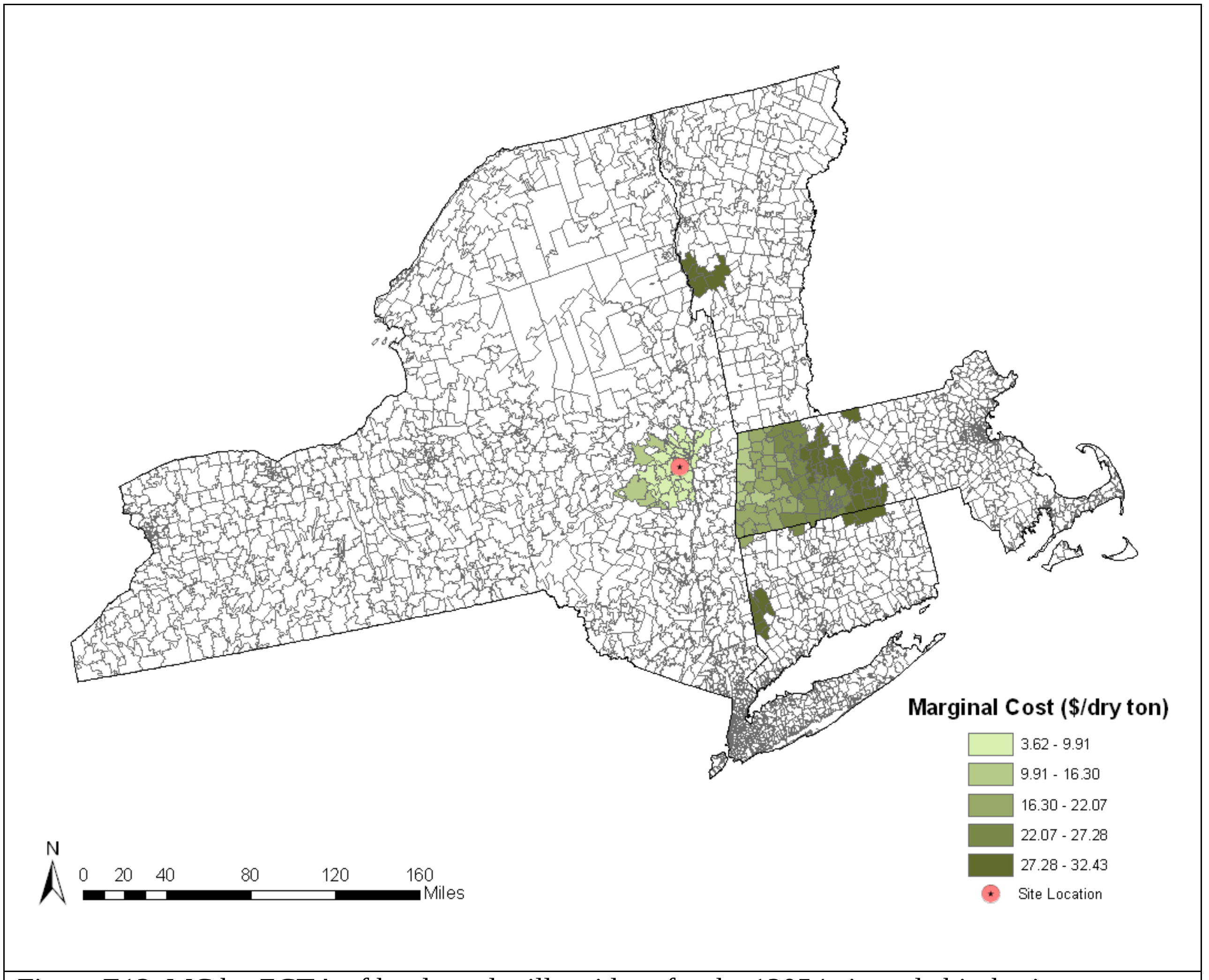

Figure E12. MC by ZCTA of hardwood mill residues for the 12054 zip code bio-basin.

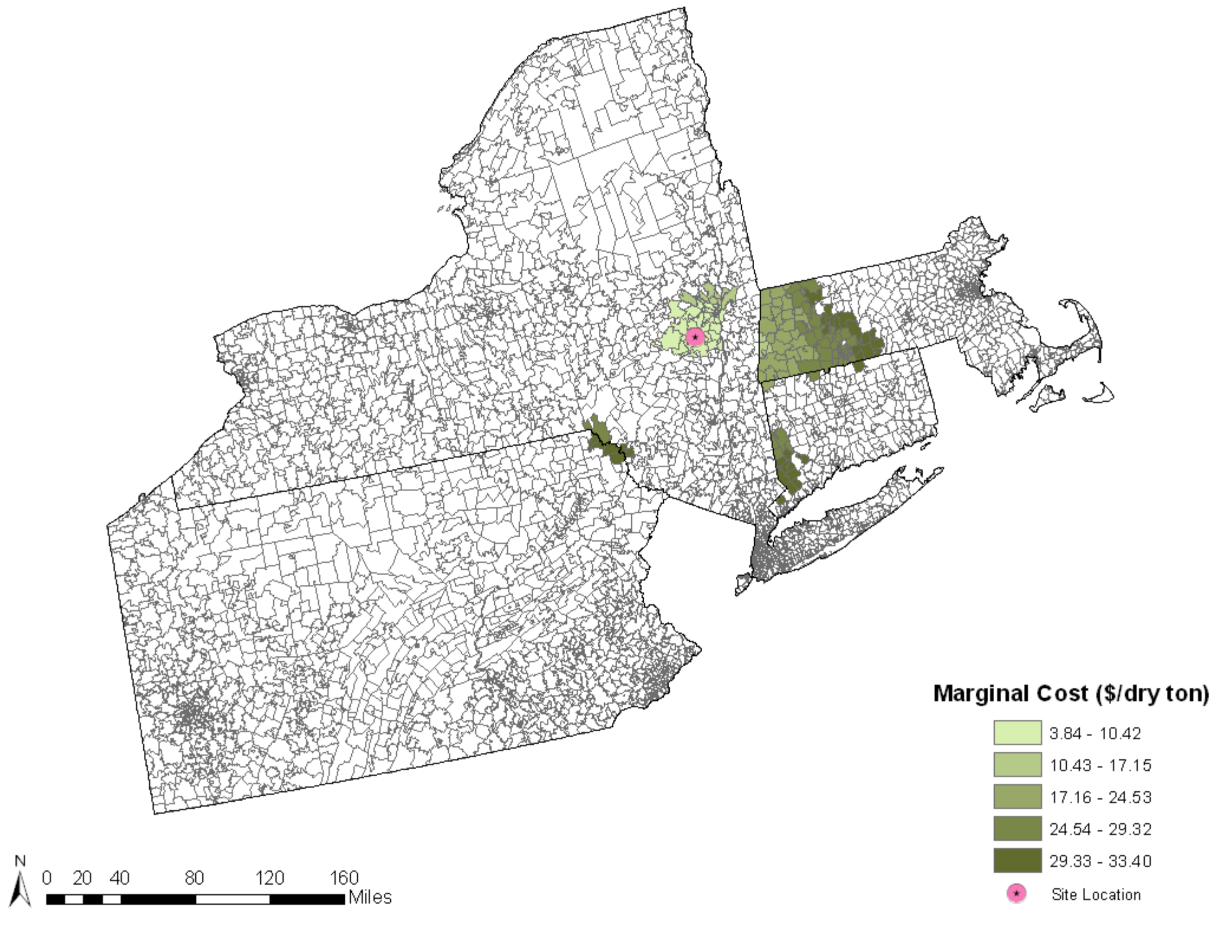

Figure E13. MC by ZCTA of hardwood mill residues for the 12055 zip code (12193 ZCTA) bio-basin.

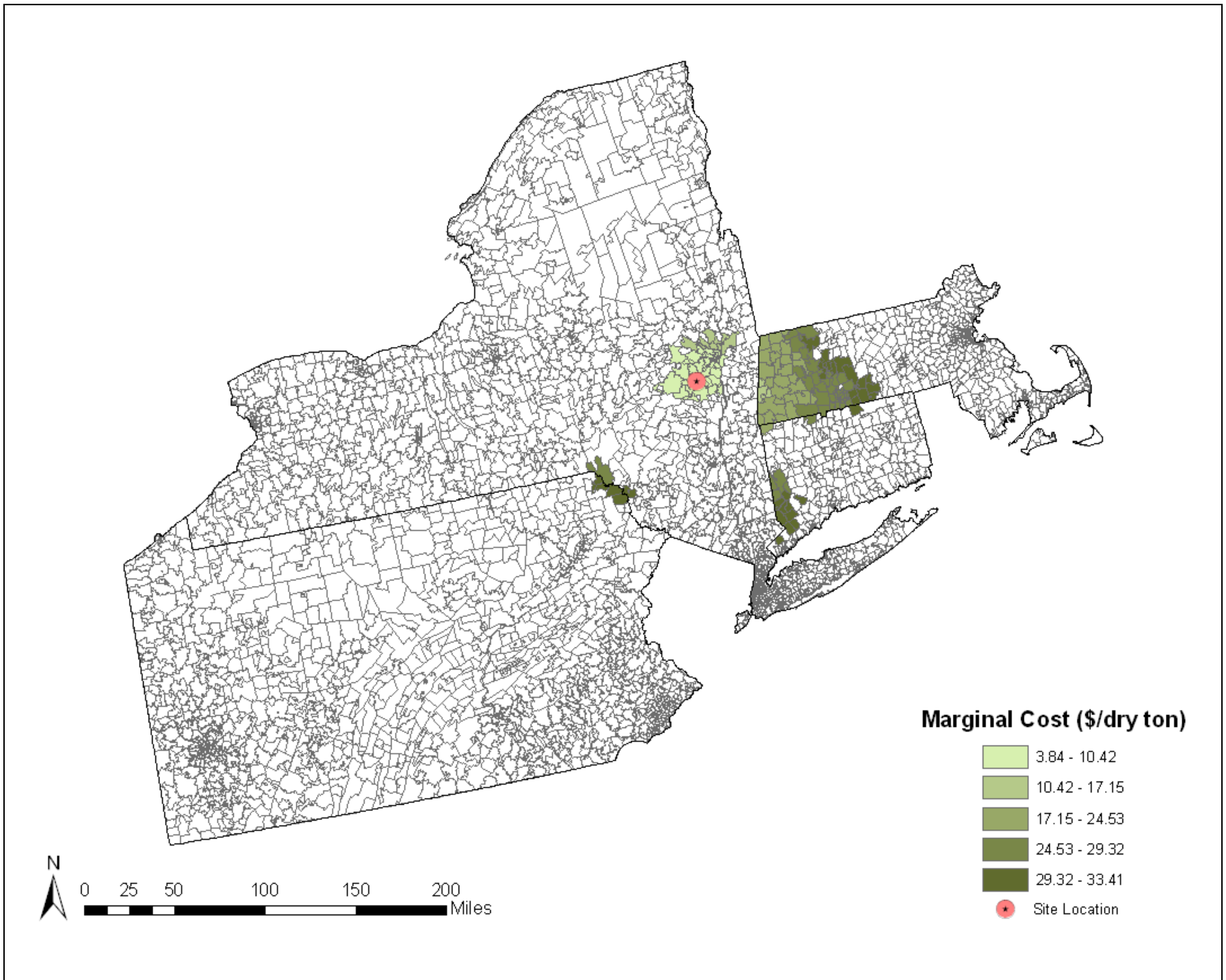

Figure E14. MC by ZCTA of hardwood mill residues for the 12193 zip code bio-basin.

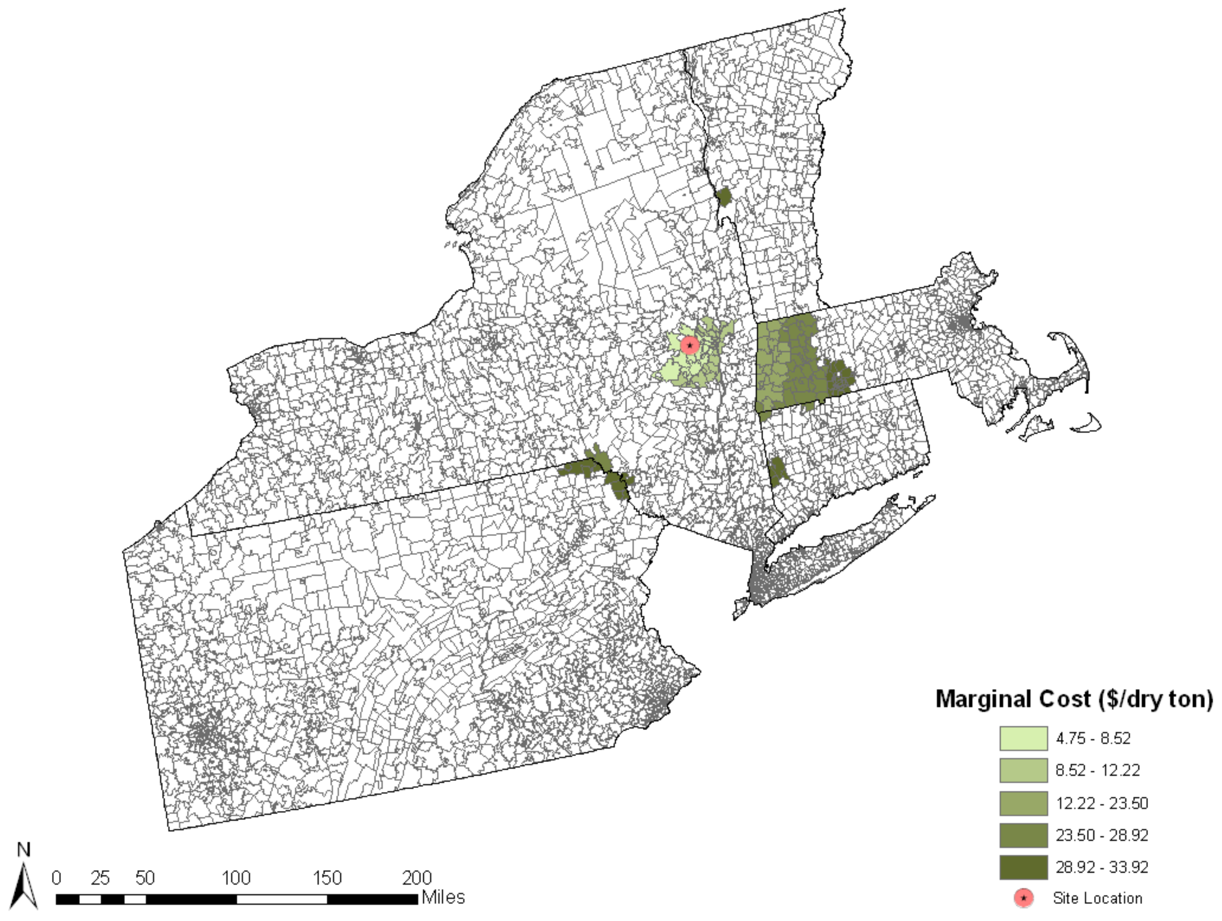

Figure E15. MC by ZCTA of hardwood mill residues for the 12107 zip code (12009 ZCTA) bio-basin.

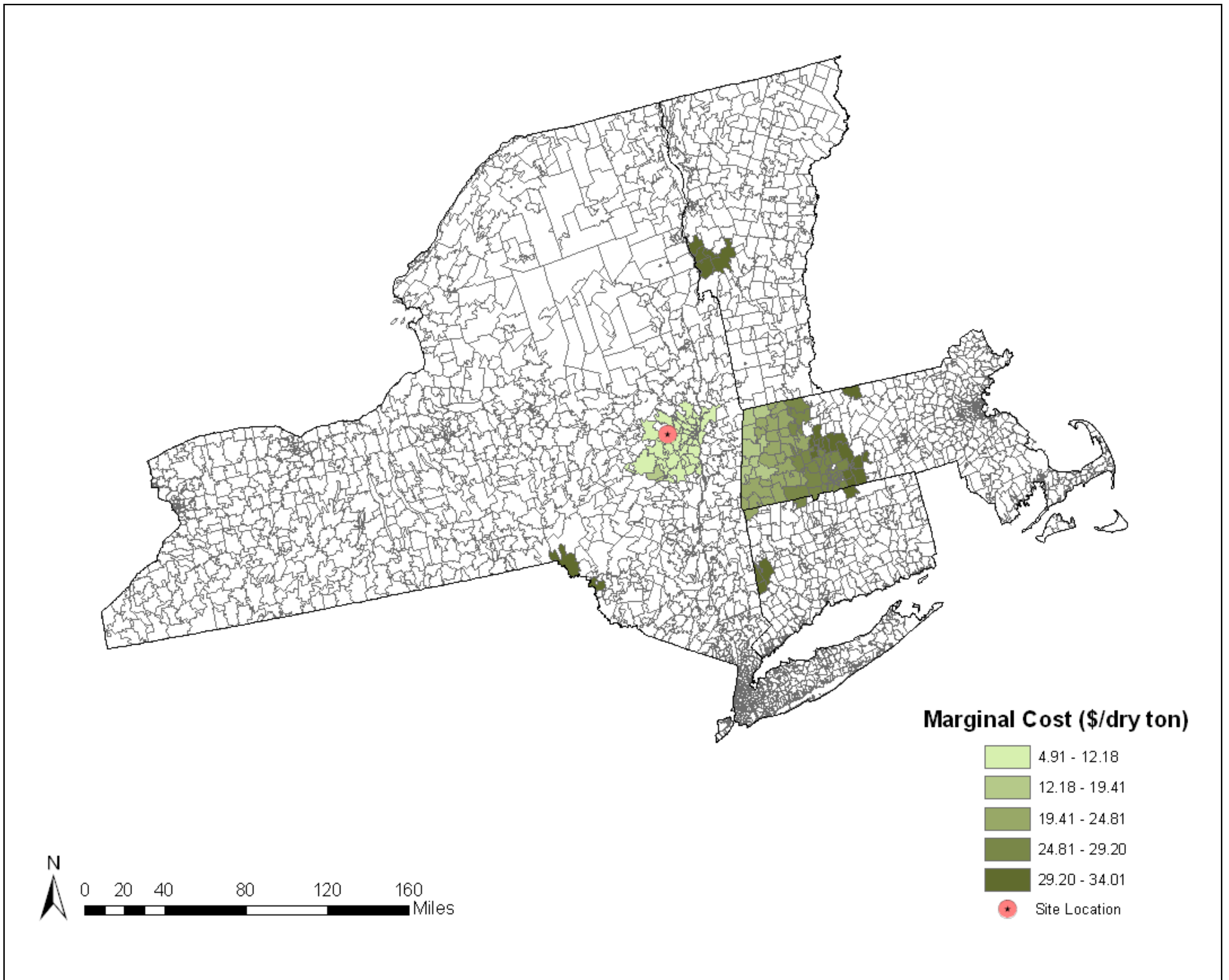

Figure E16. MC by ZCTA of hardwood mill residues for the 12085 zip code (12009 ZCTA) bio-basin.

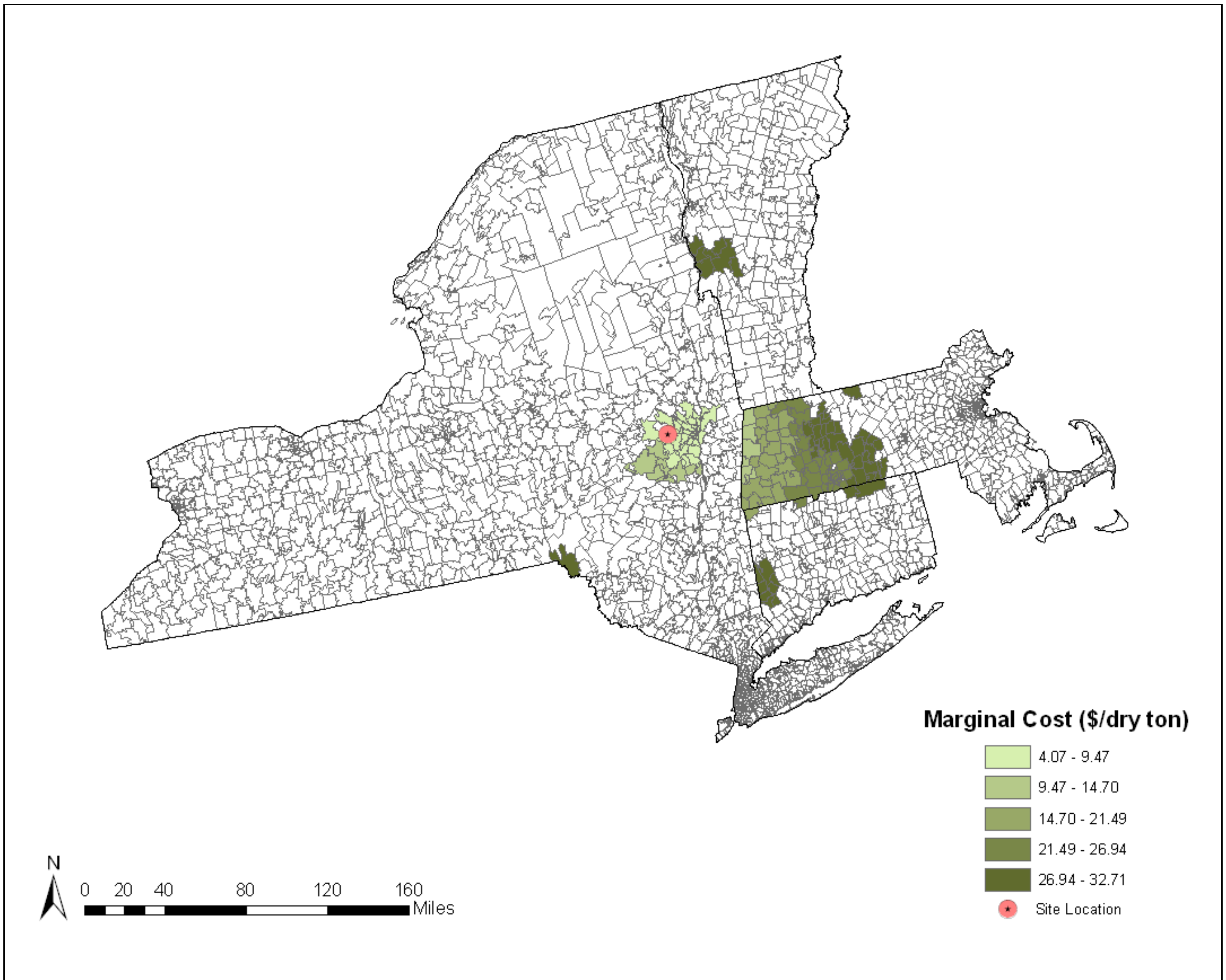

Figure E17. MC by ZCTA of hardwood mill residues for the 12232 zip code (12009 ZCTA) bio-basin.

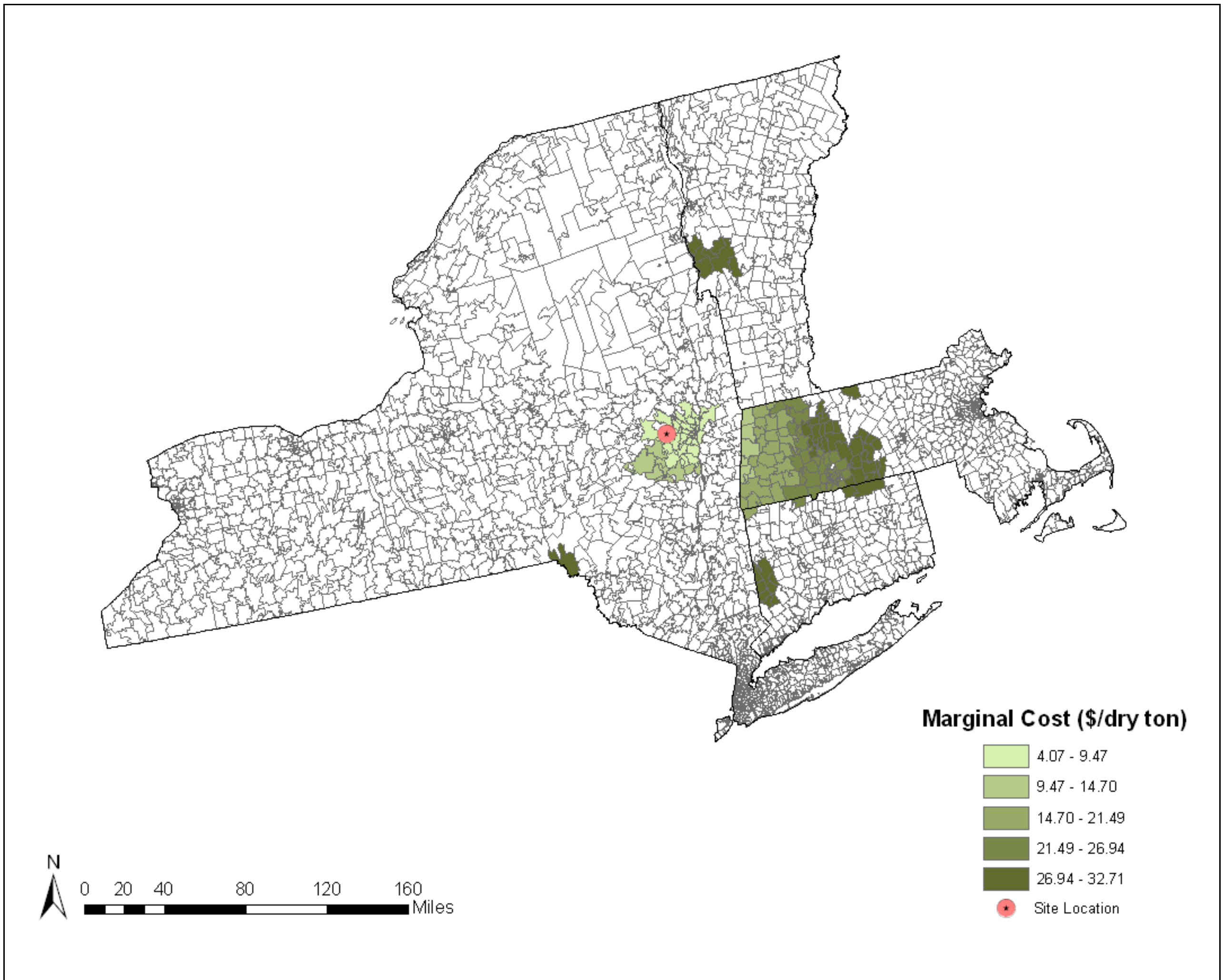

Figure E18. MC by ZCTA of hardwood mill residues for the 12226 zip code (12009 ZCTA) bio-basin.

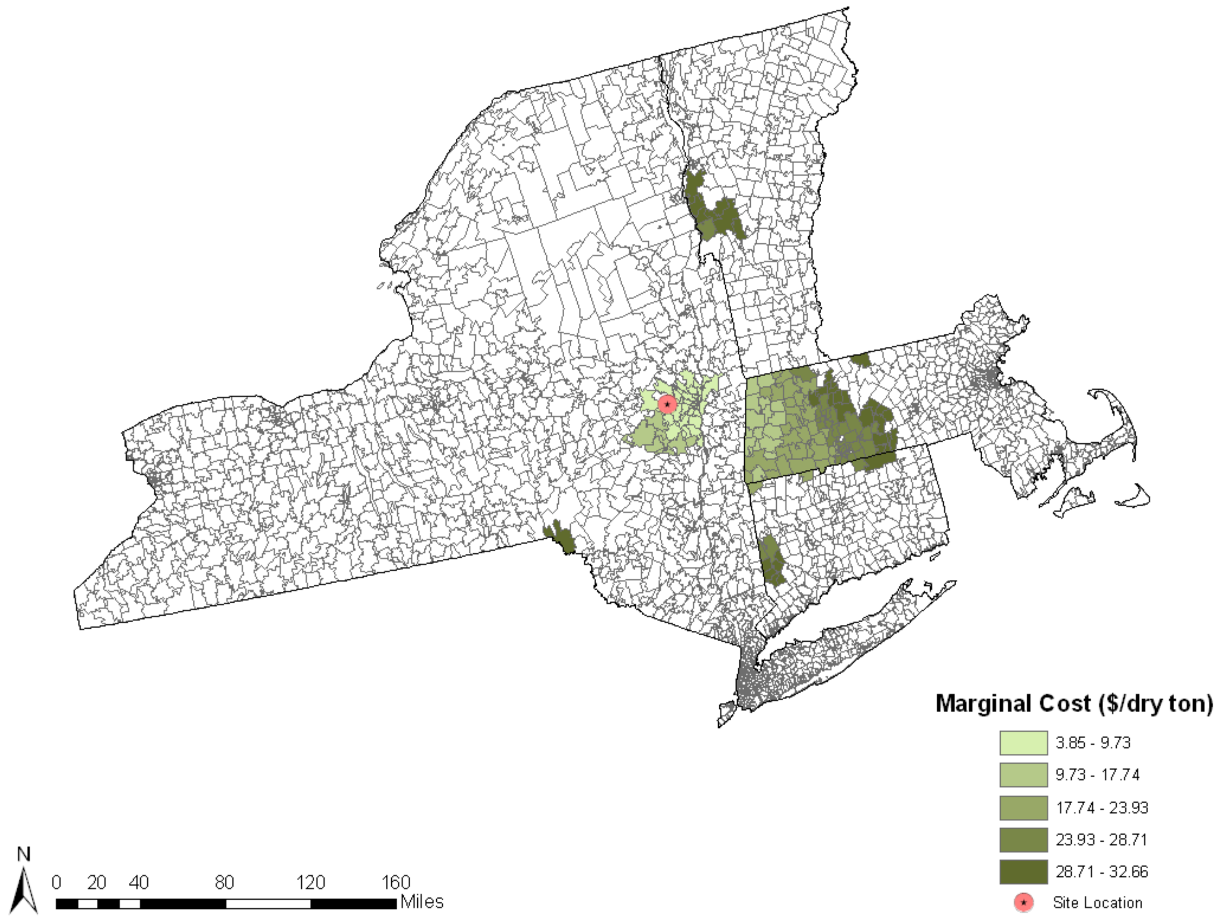

Figure E19. MC by ZCTA of hardwood mill residues for the 12222 zip code (12009 ZCTA) bio-basin.

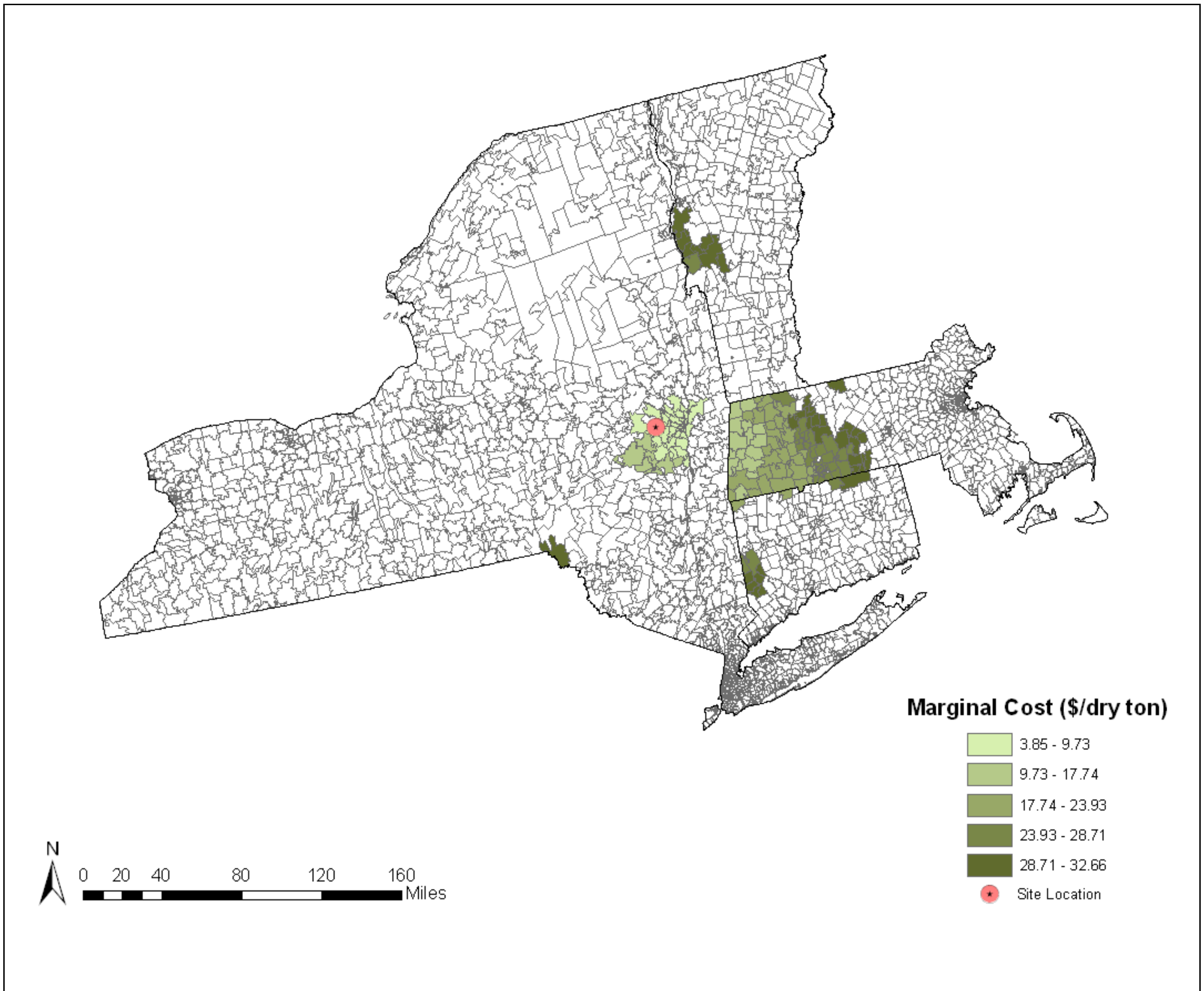

Figure E20. MC by ZCTA of hardwood mill residues for the 12220 zip code (12009 ZCTA) bio-basin.

Appendix F

Bio-basin ZCTA maps for the top ten sites for logging residues for northern region with MCs.

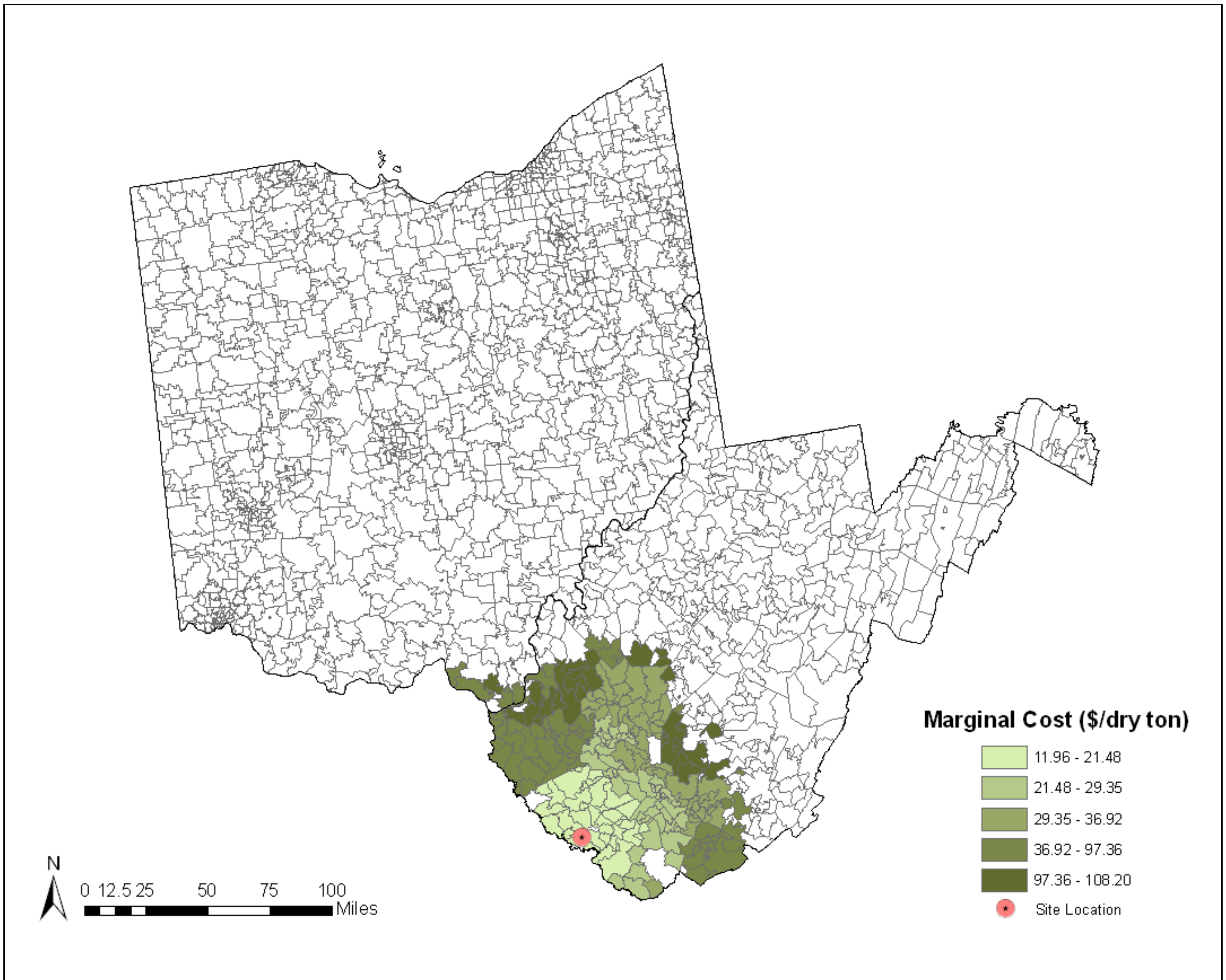

Figure F1. MC by ZCTA of total logging residues for the 25682 zip code biobasin.

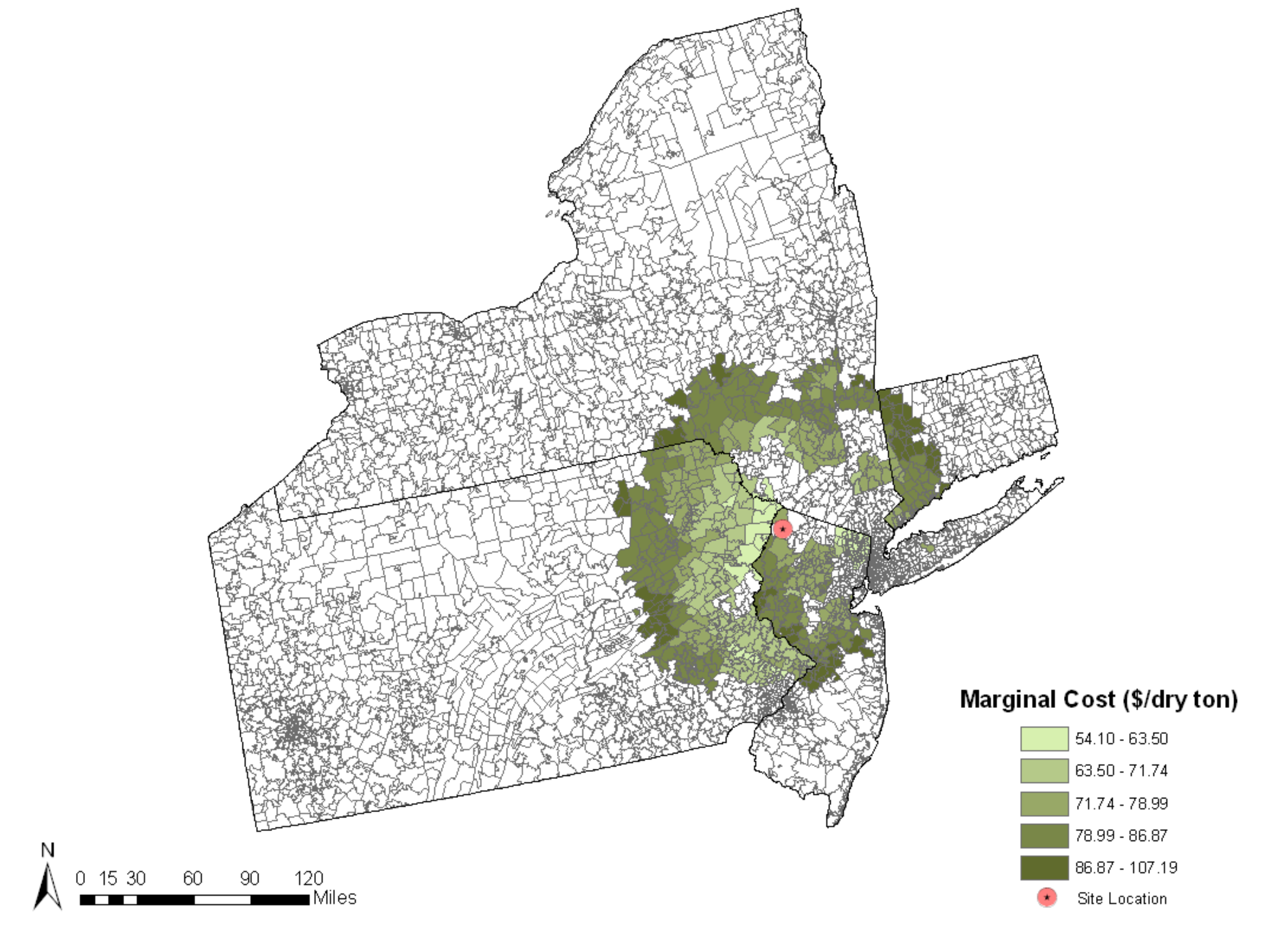

Figure F2. MC by ZCTA of total logging residues for the 07890 zip code (07826 ZCTA) biobasin.

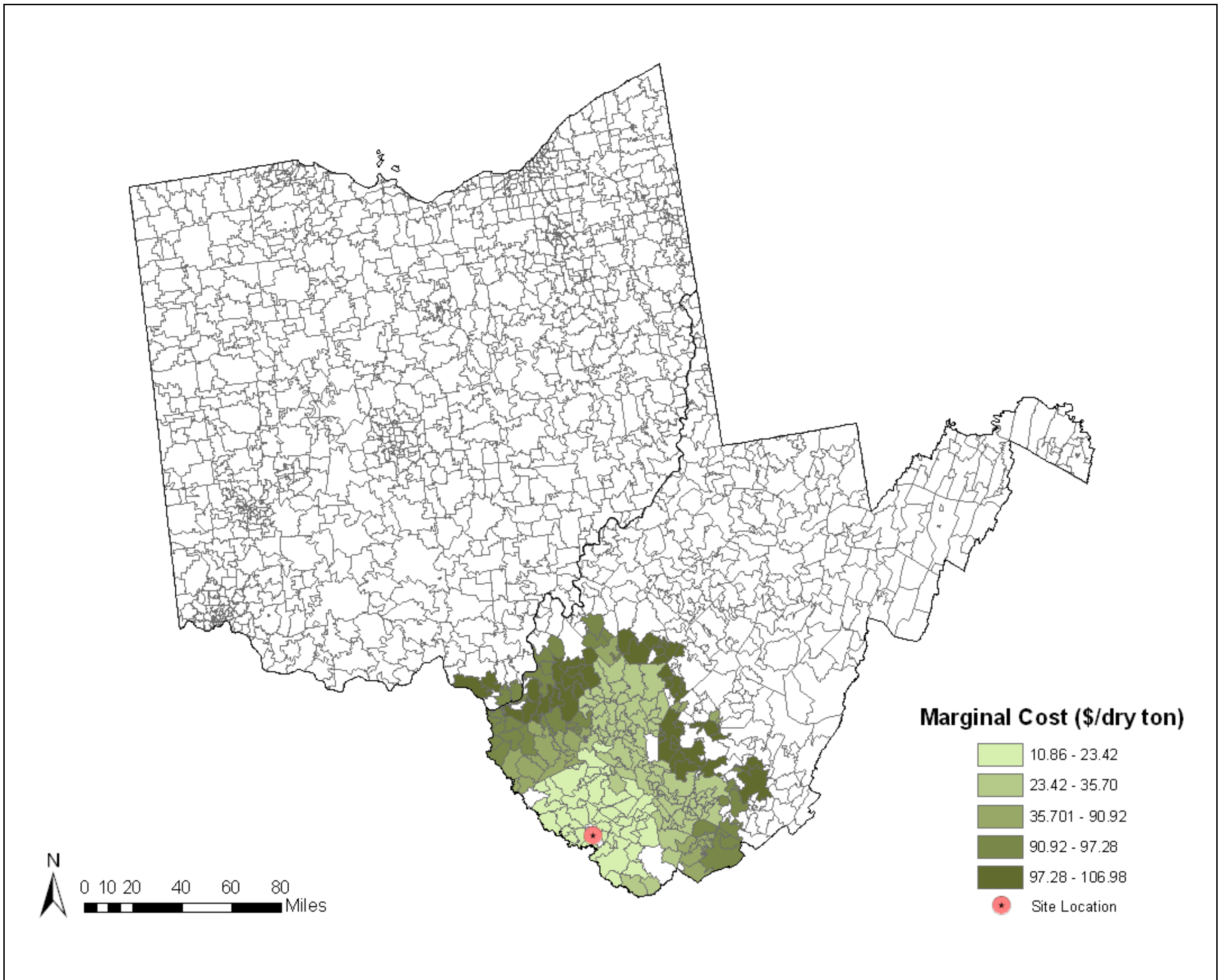

Figure F3. MC by ZCTA of total logging residues for the 25608 zip code biobasin.

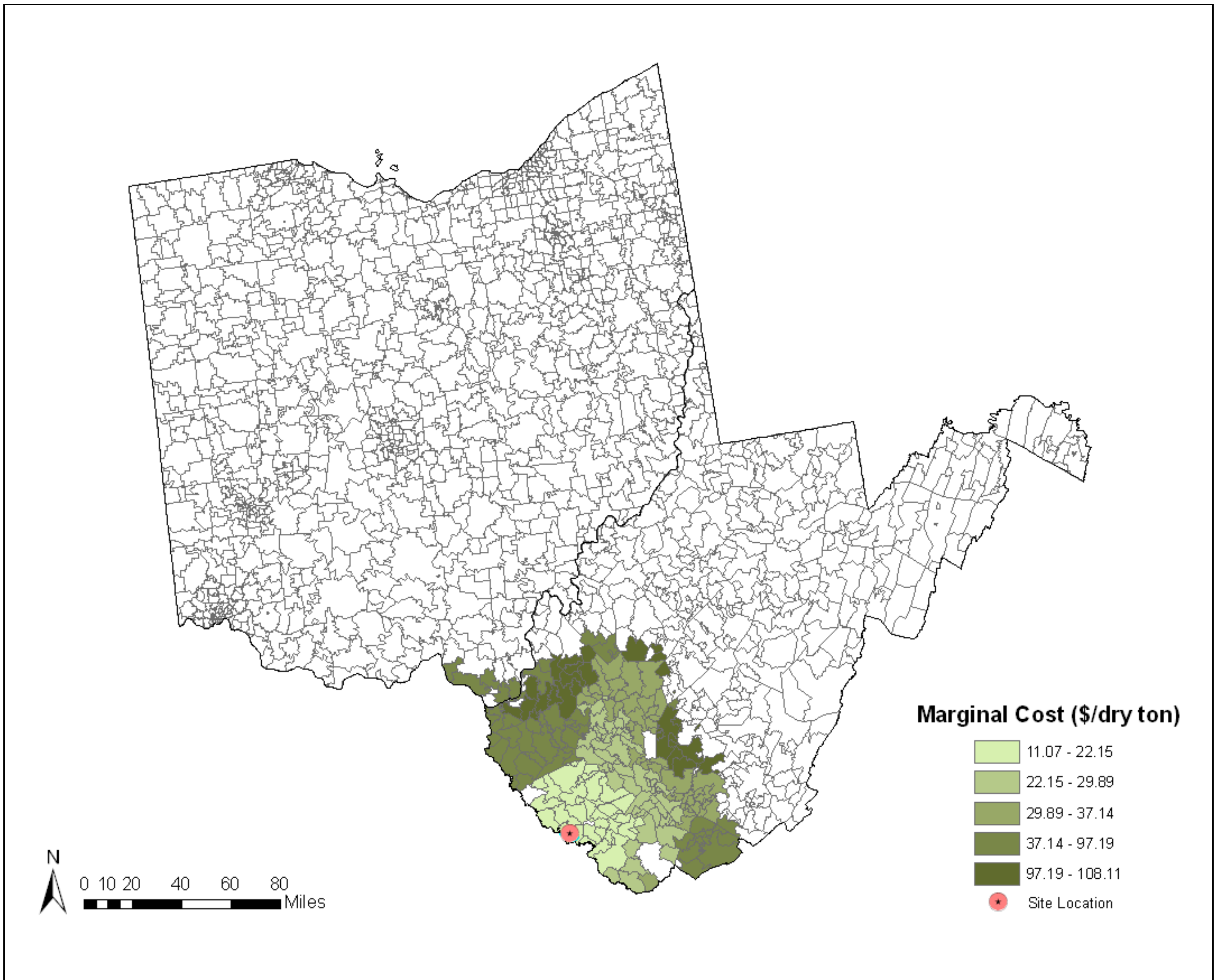

Figure F4. MC by ZCTA of total logging residues for the 25672 zip code (25694 ZCTA) biobasin.

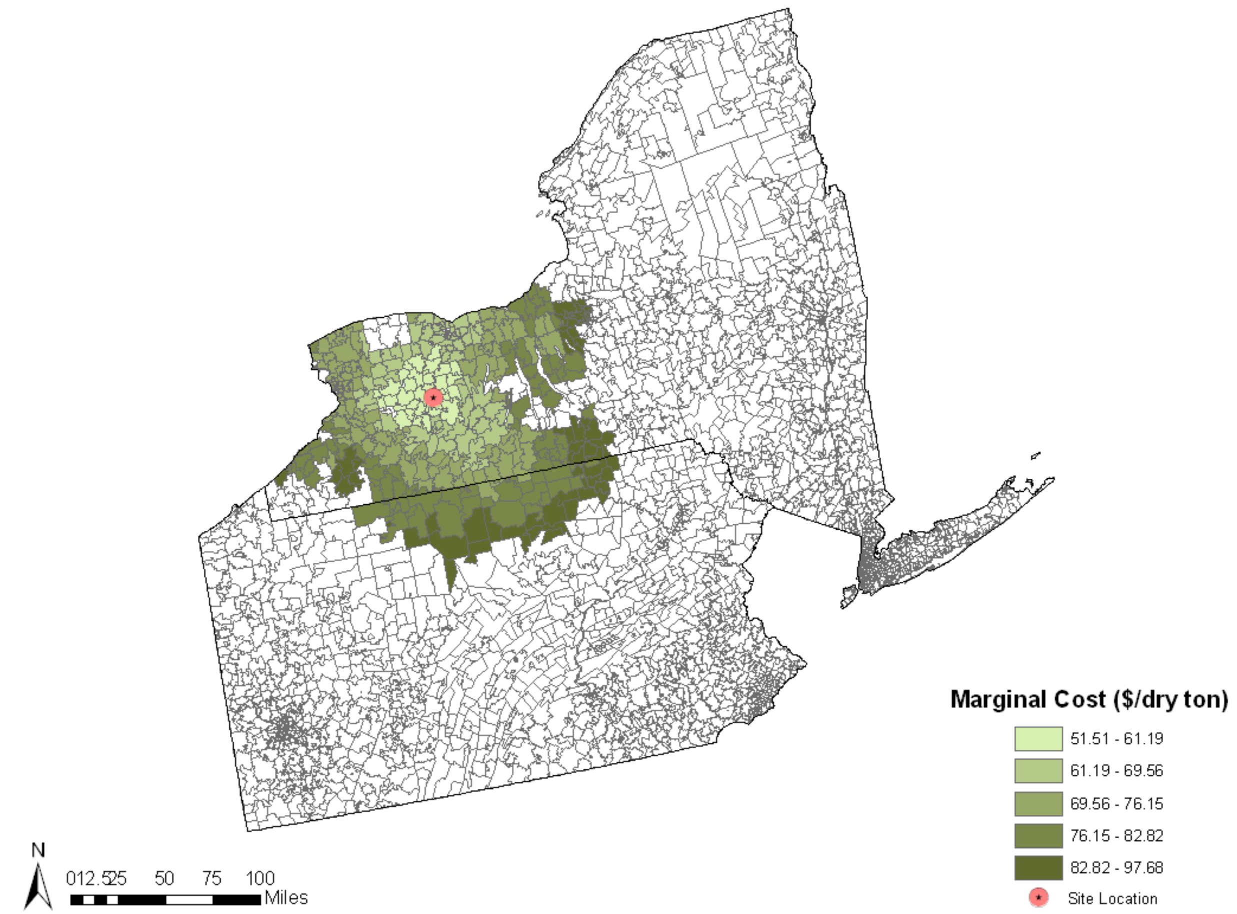

Figure F5. MC by ZCTA of total logging residues for the 14556 zip code (14510 ZCTA) biobasin.

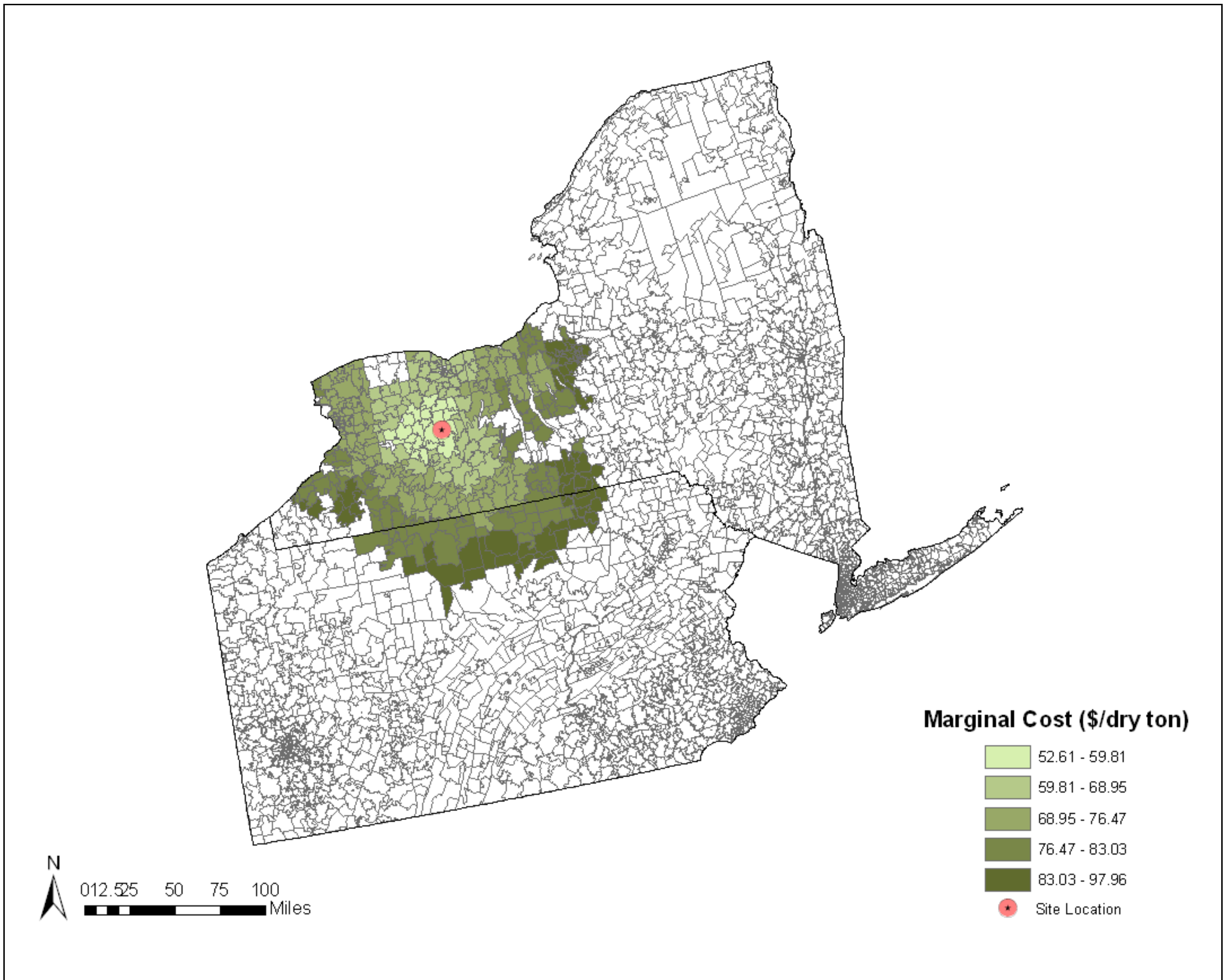

Figure F6. MC by ZCTA of total logging residues for the 14462 zip code biobasin.

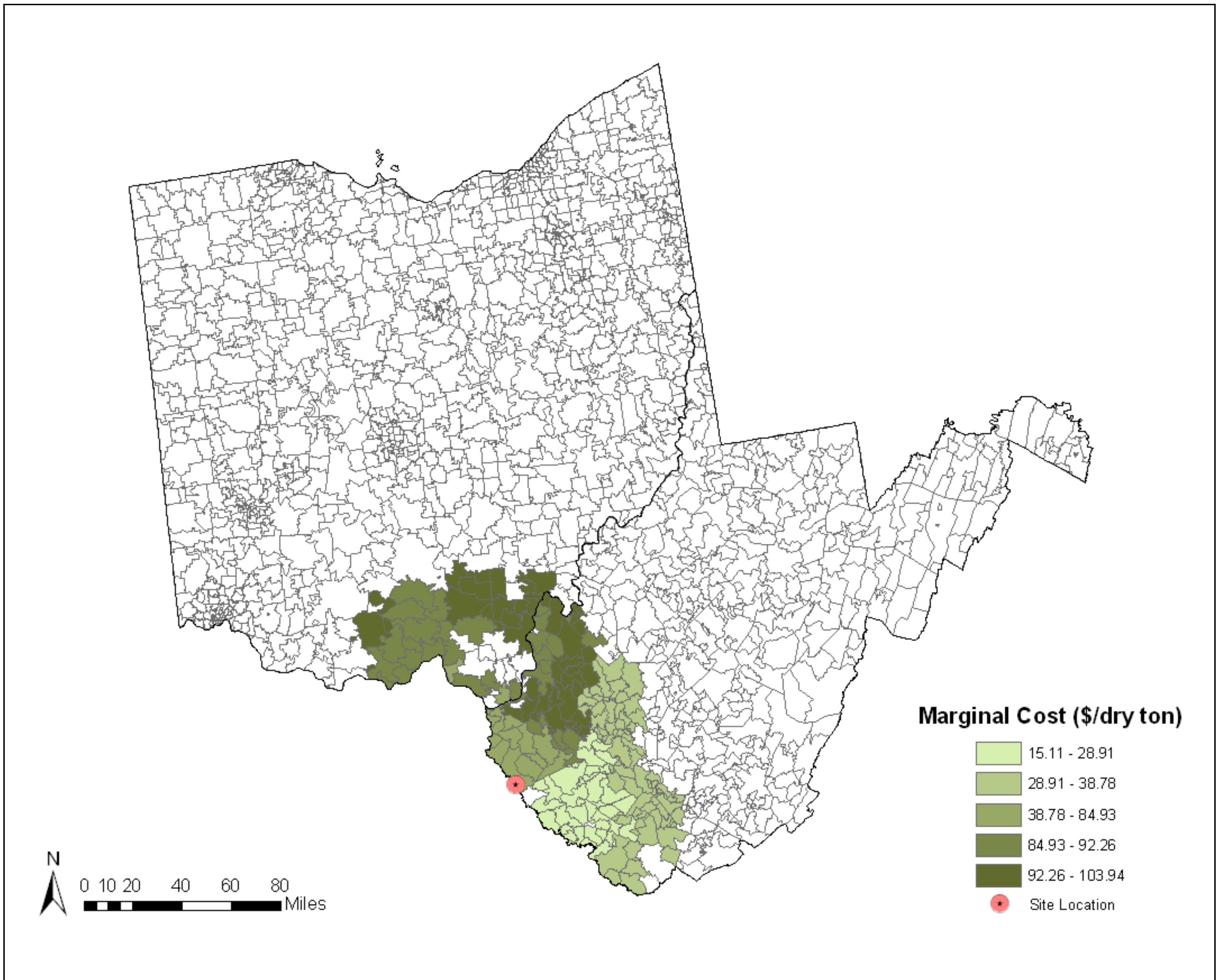

Figure F7. MC by ZCTA of total logging residues for the 25669 zip code biobasin.

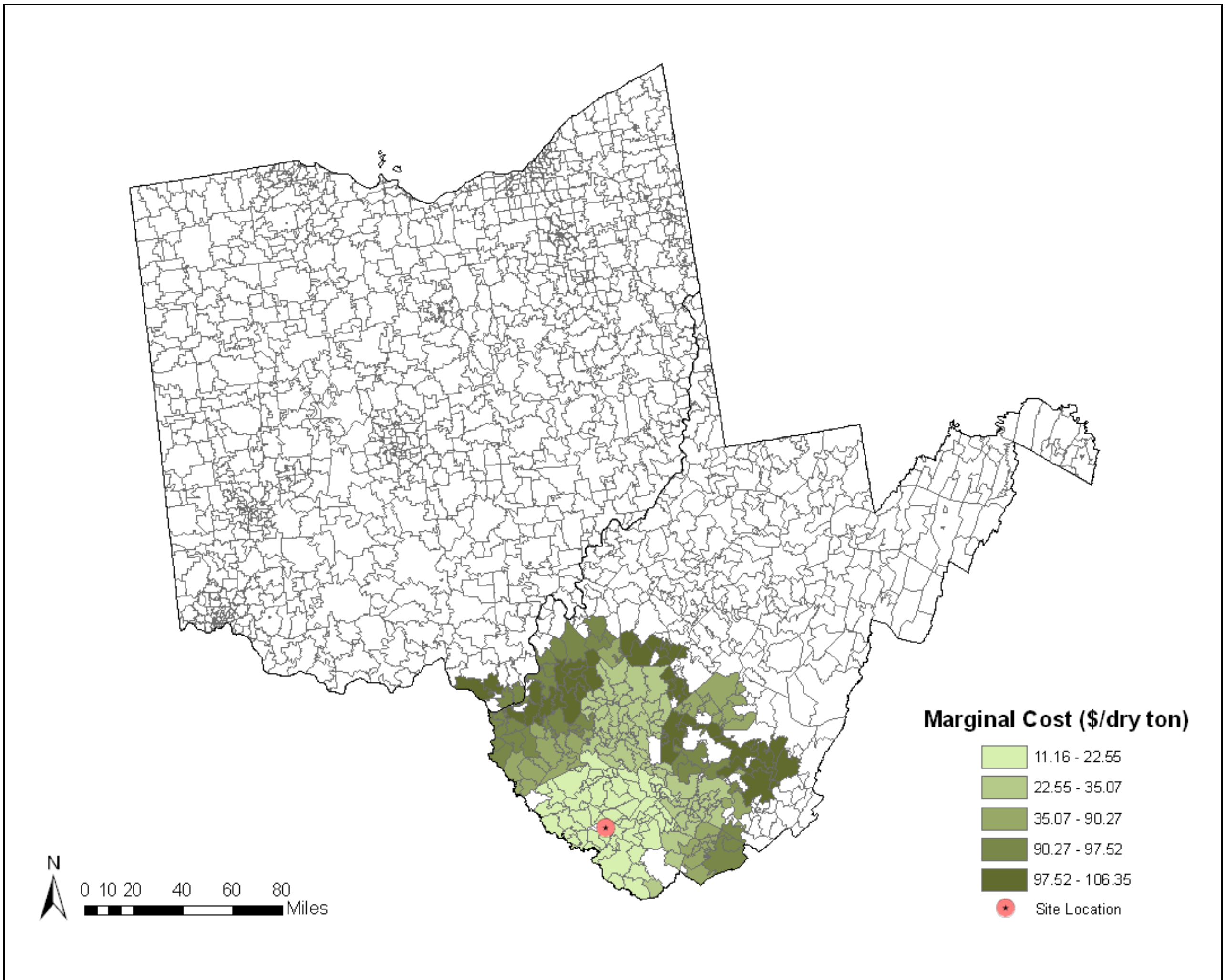

Figure F8. MC by ZCTA of total logging residues for the 25650 zip code biobasin.

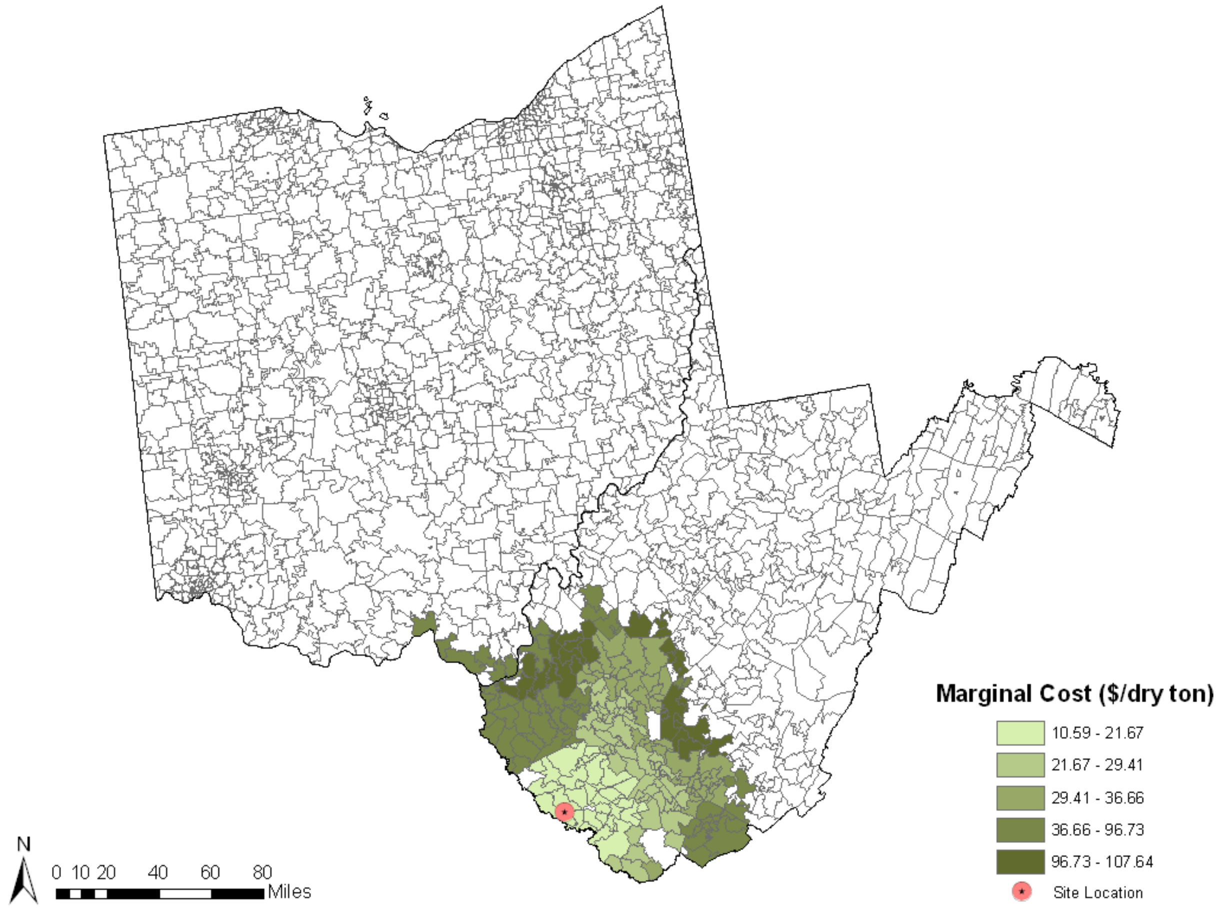

Figure F9. MC by ZCTA of total logging residues for the 25688 zip code (25678 ZCTA) biobasin.

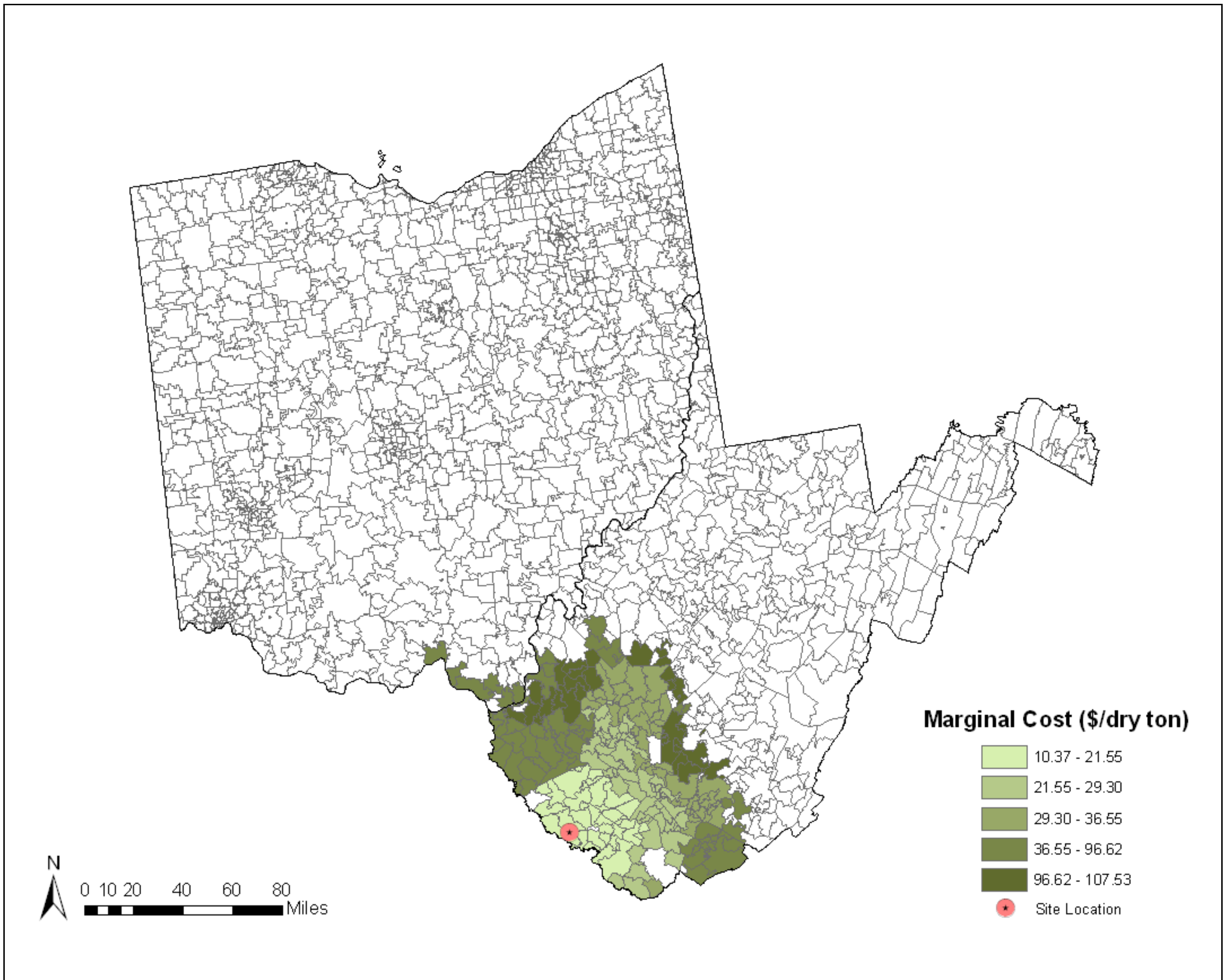

Figure F10. MC by ZCTA of total logging residues for the 25678 zip code biobasin.

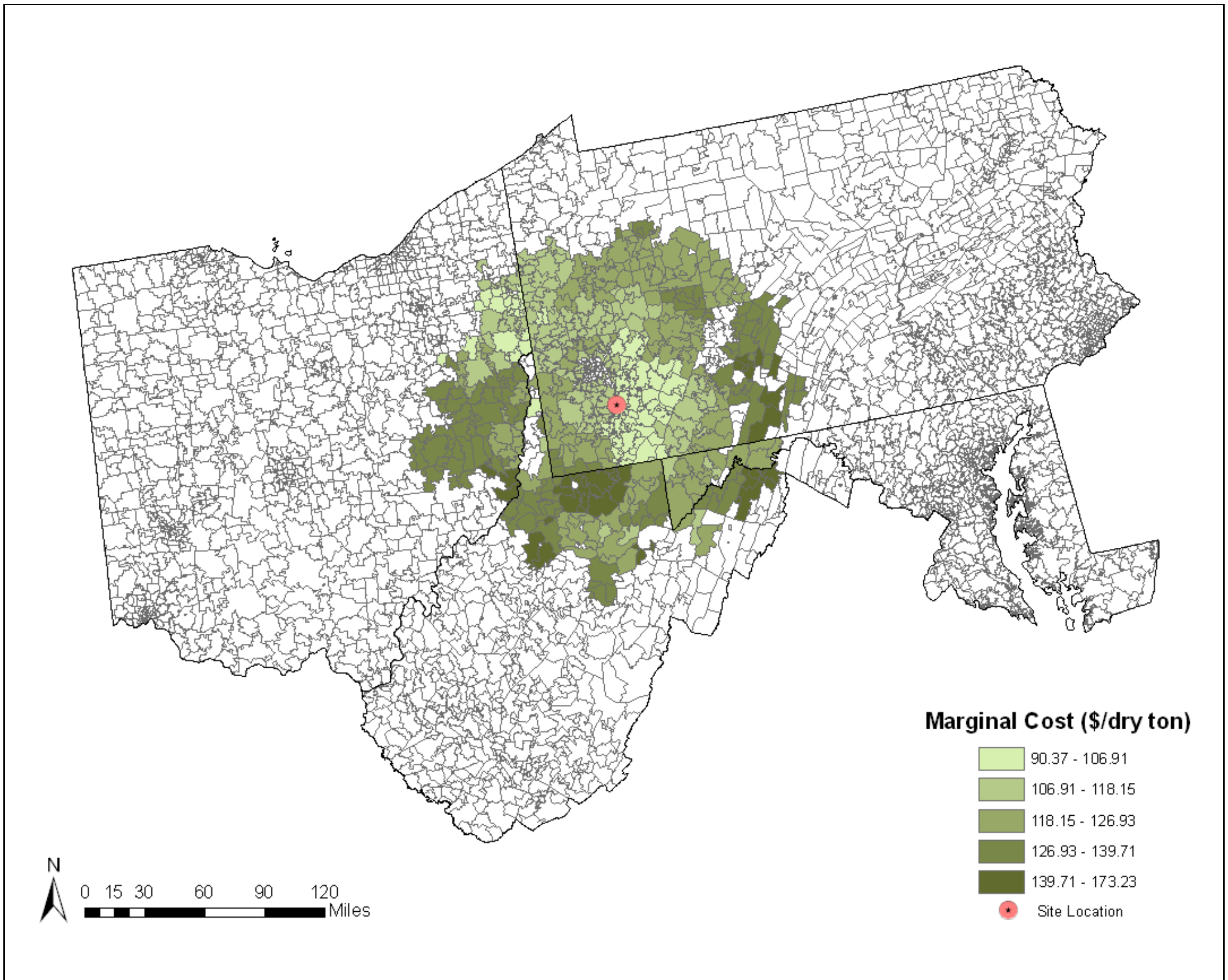

Figure F11. MC by ZCTA of in-woods logging residues for the 15072 zip code (15012 ZCTA) biobasin.

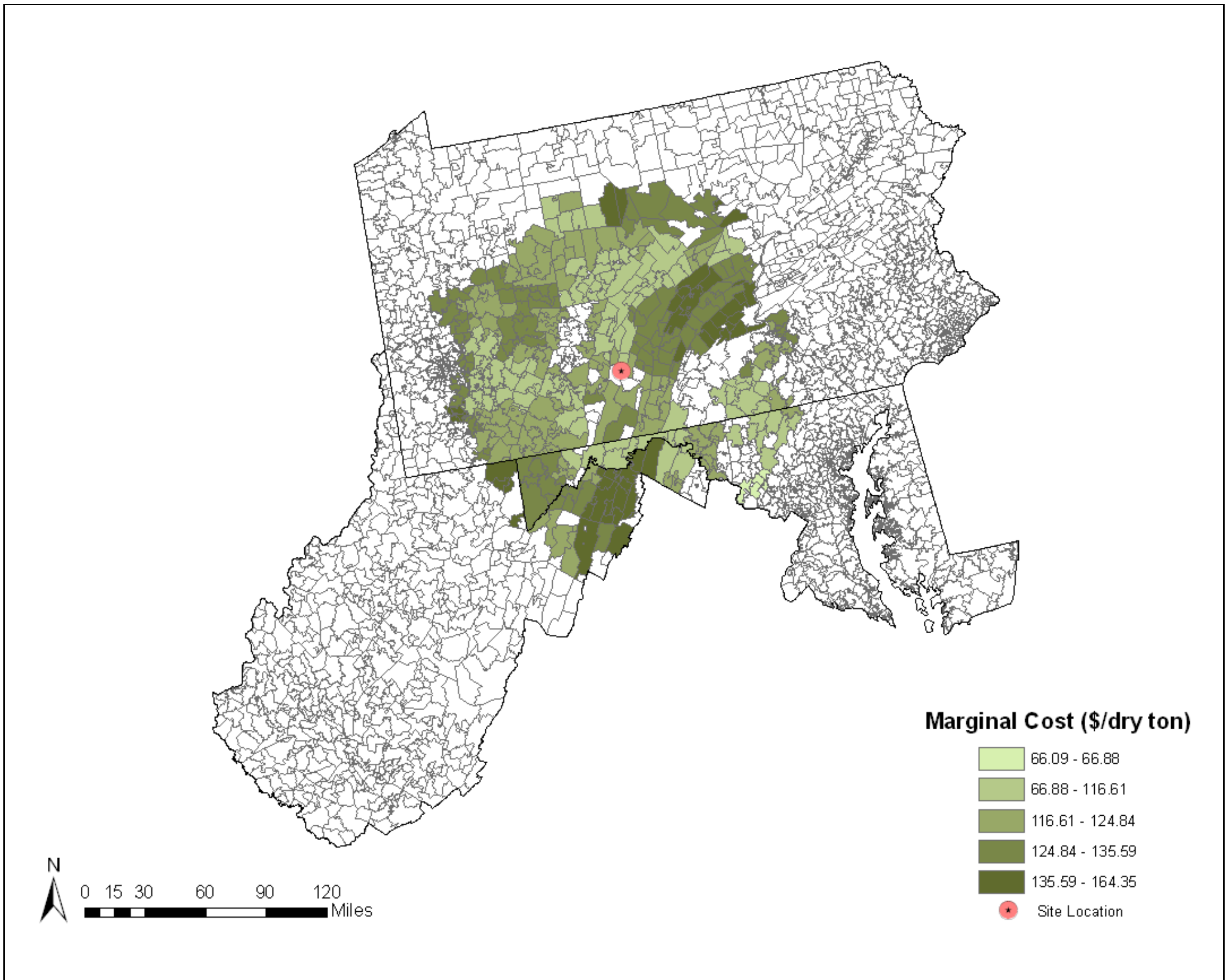

Figure F12. MC by ZCTA of in-woods logging residues for the 16695 zip code biobasin.

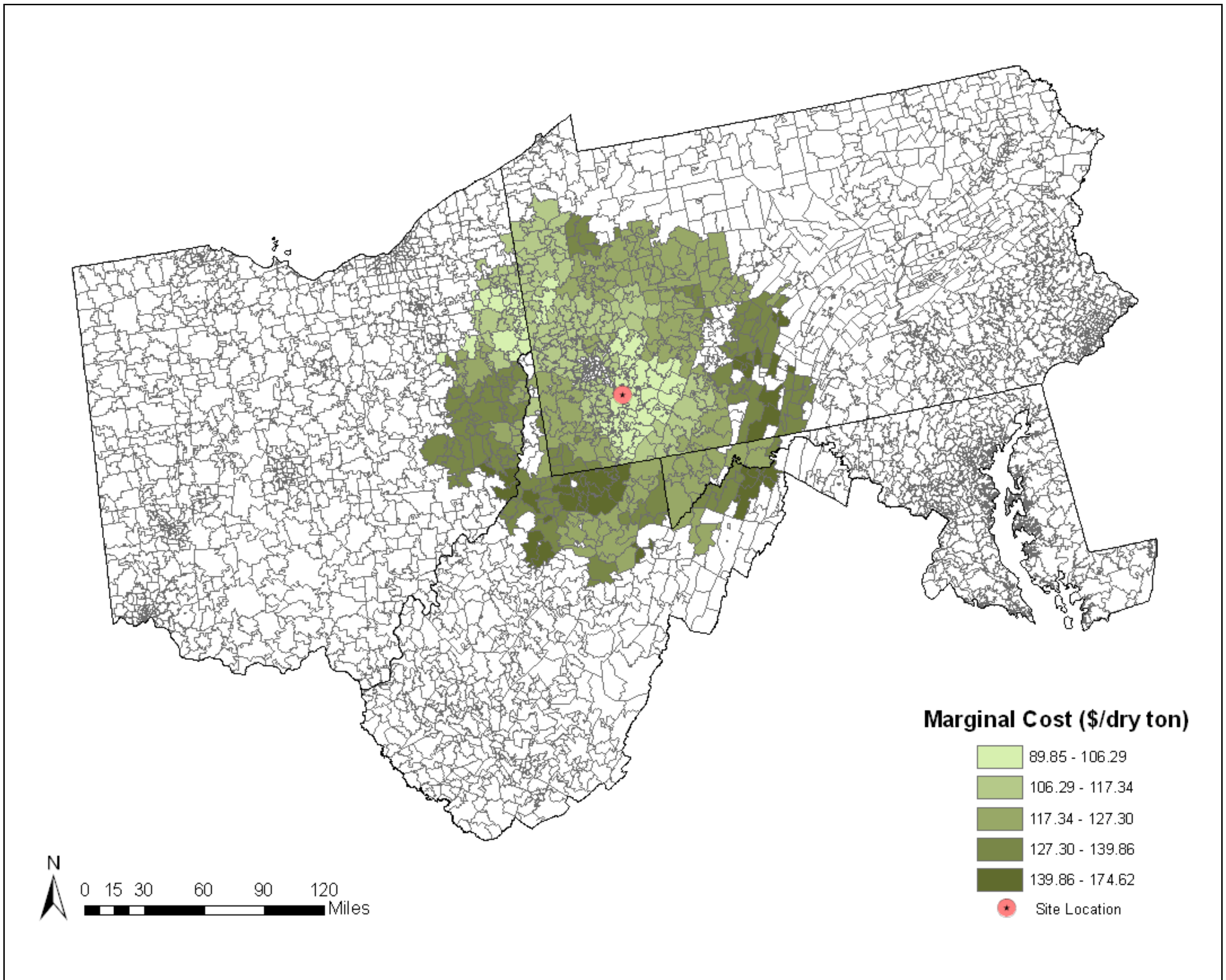

Figure F13. MC by ZCTA of in-woods logging residues for the 15695 zip code (15089 ZCTA) biobasin.

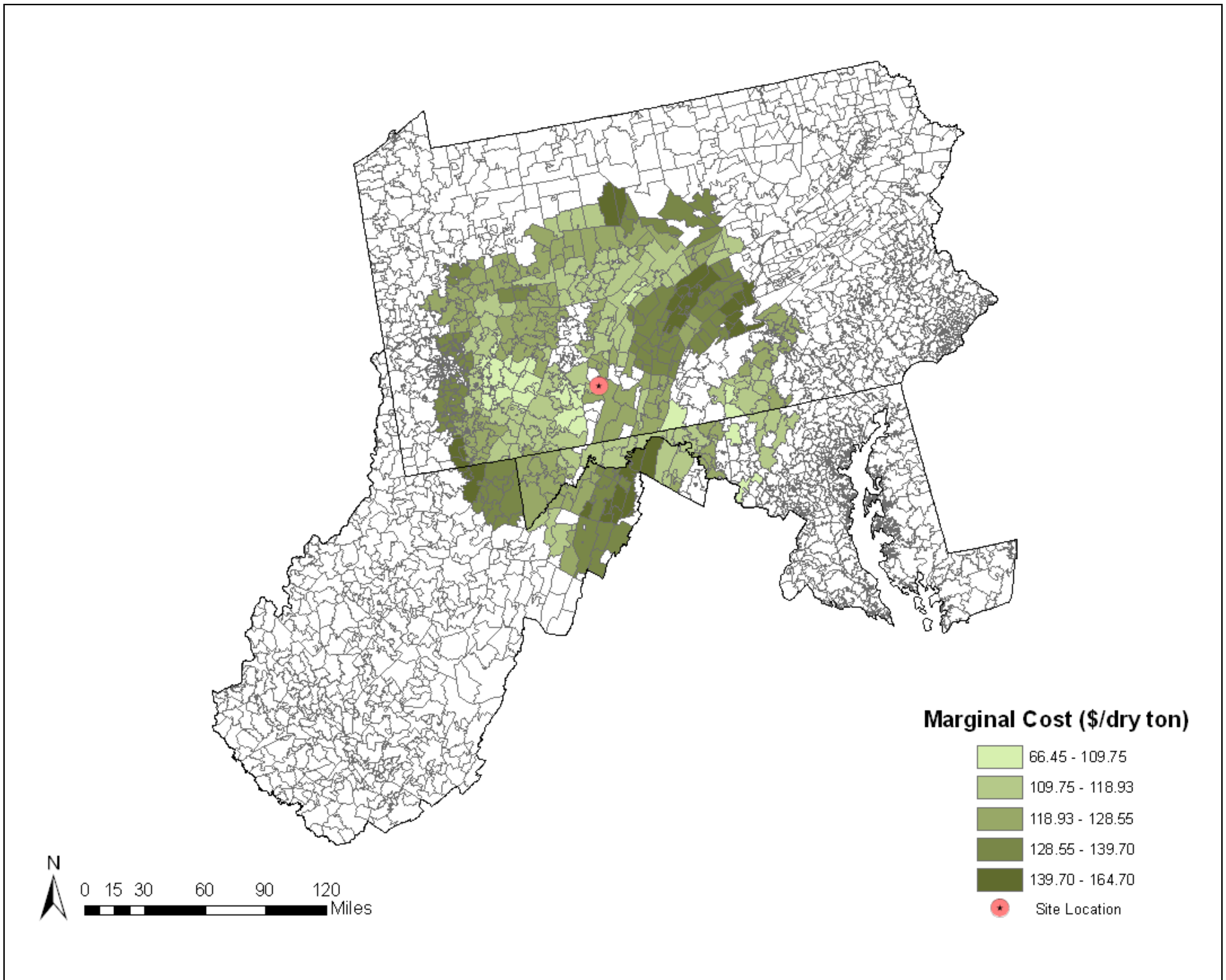

Figure F14. MC by ZCTA of in-woods logging residues for the 15539 zip code biobasin.

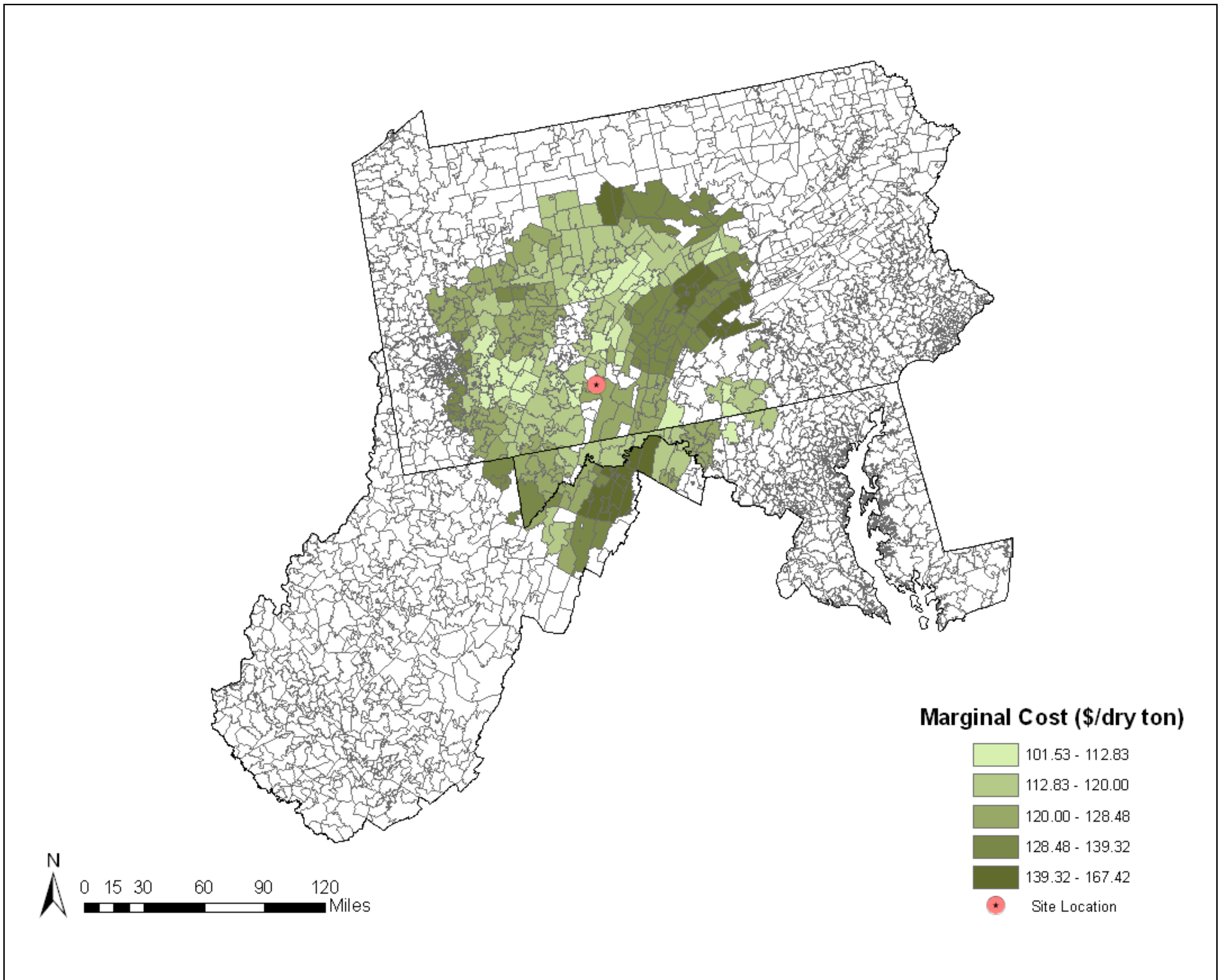

Figure F15. MC by ZCTA of in-woods logging residues for the 16670 zip code (16655 ZCTA) biobasin.

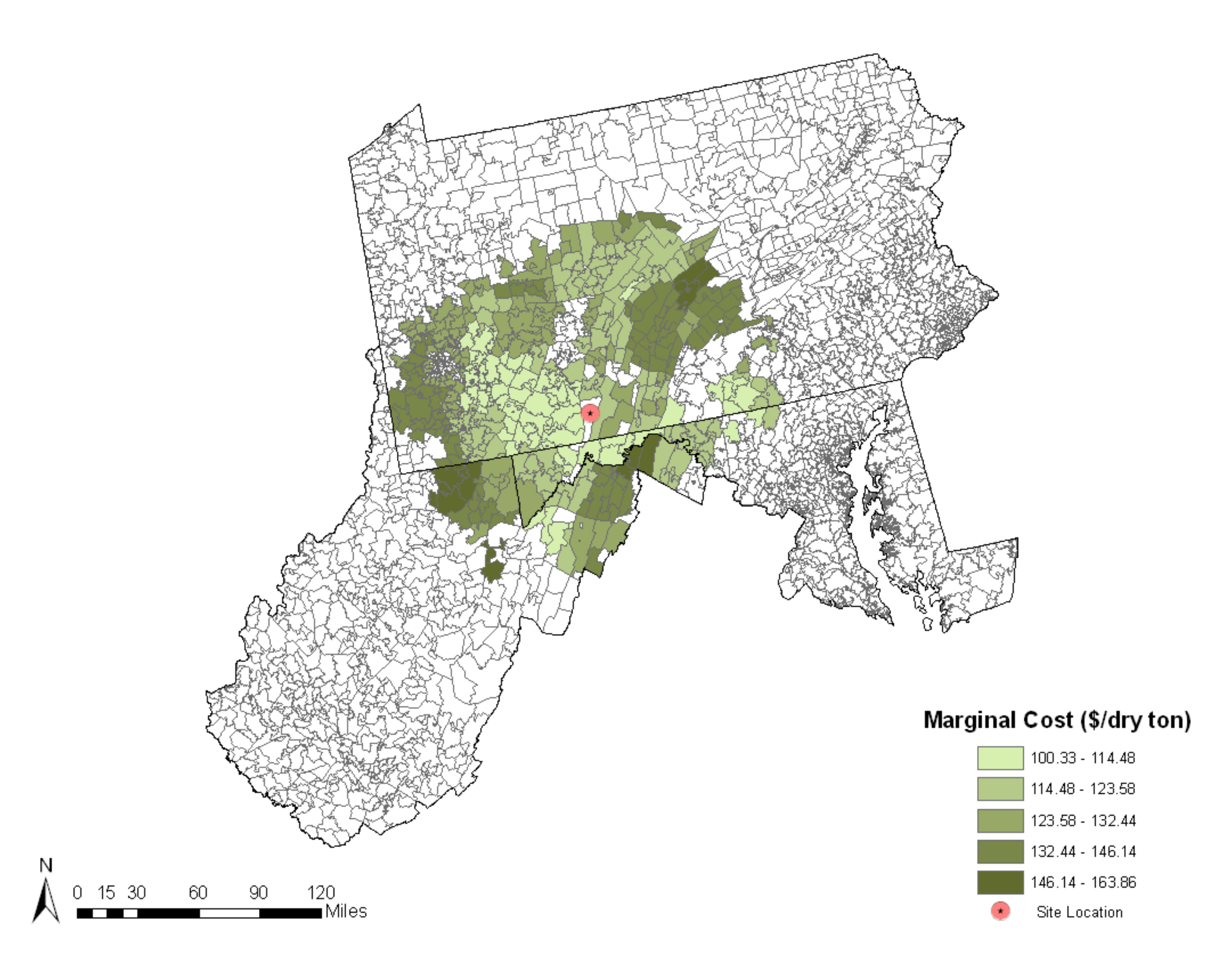

Figure F16. MC by ZCTA of in-woods logging residues for the 15534 zip code biobasin.

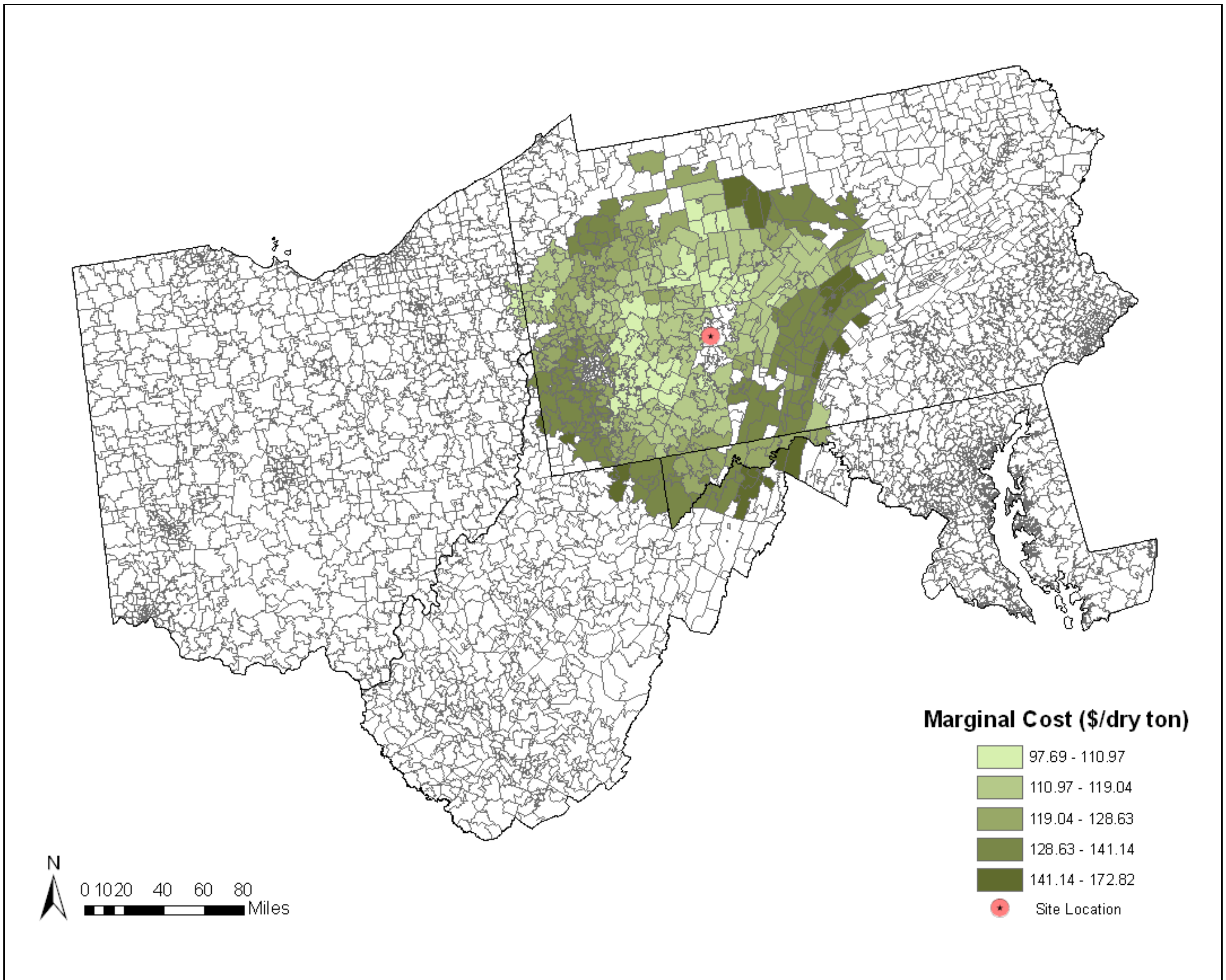

Figure F17. MC by ZCTA of in-woods logging residues for the 15927 zip code biobasin.

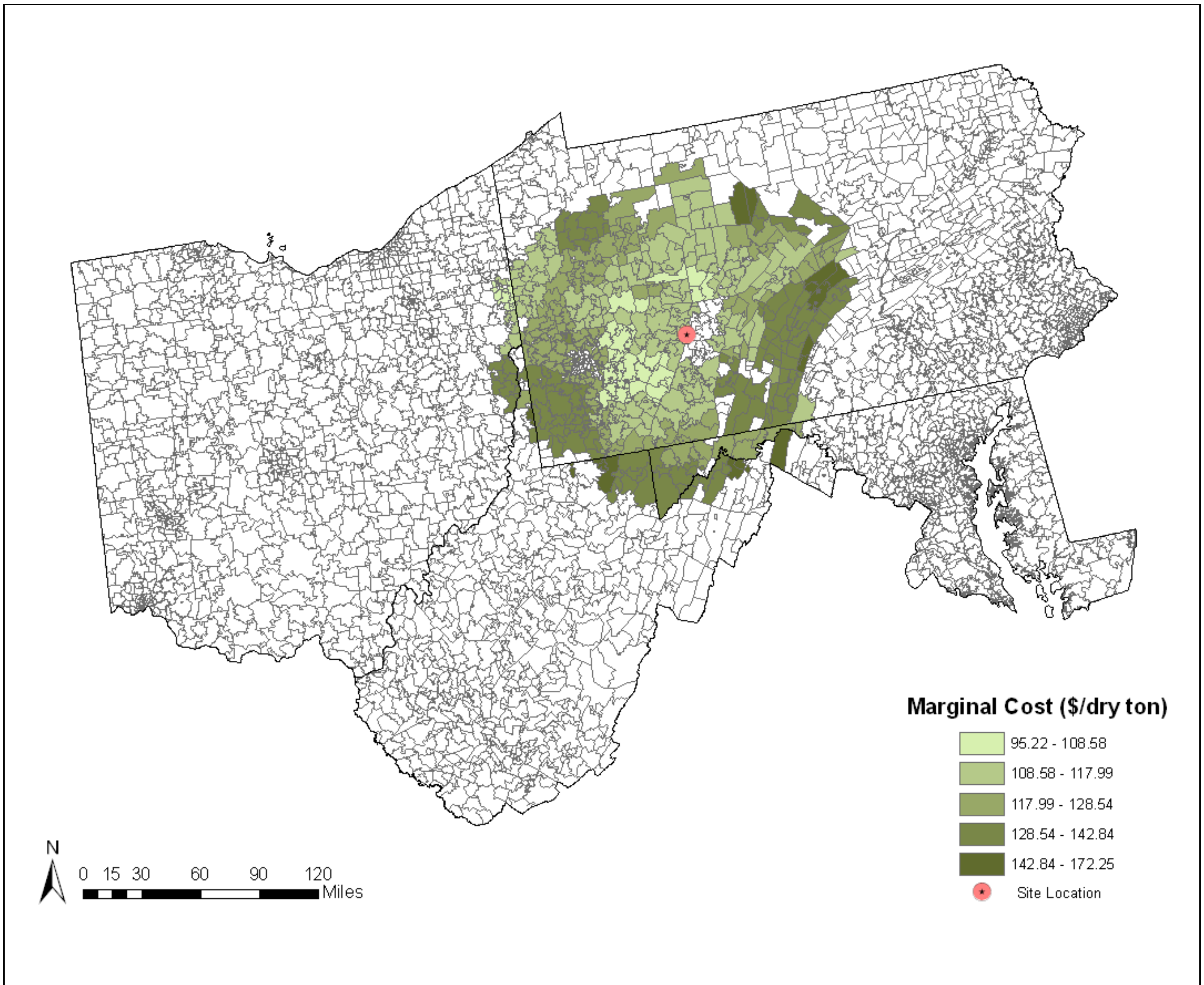

Figure F18. MC by ZCTA of in-woods logging residues for the 15960 zip code biobasin.

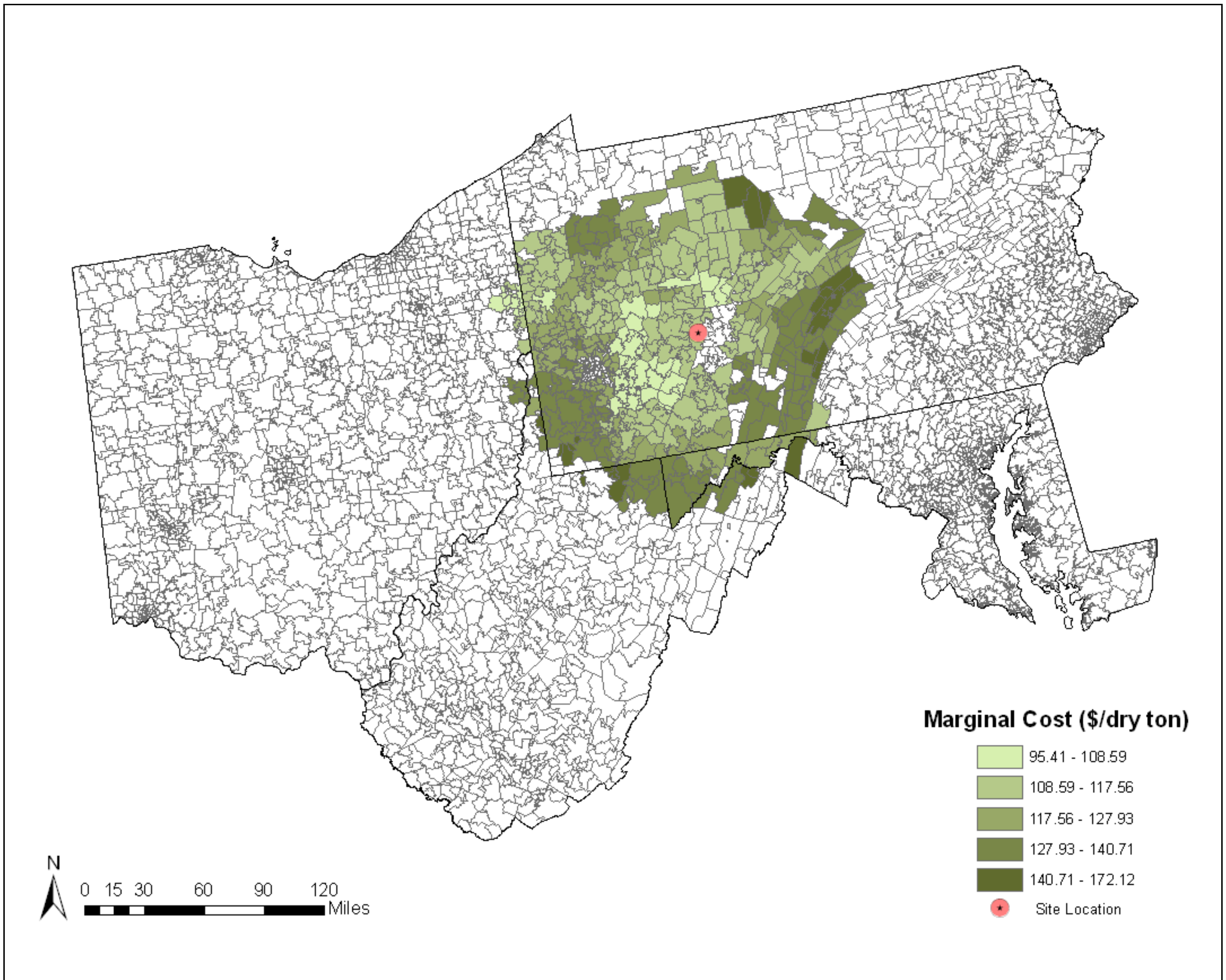

Figure F19. MC by ZCTA of in-woods logging residues for the 15957 zip code biobasin.

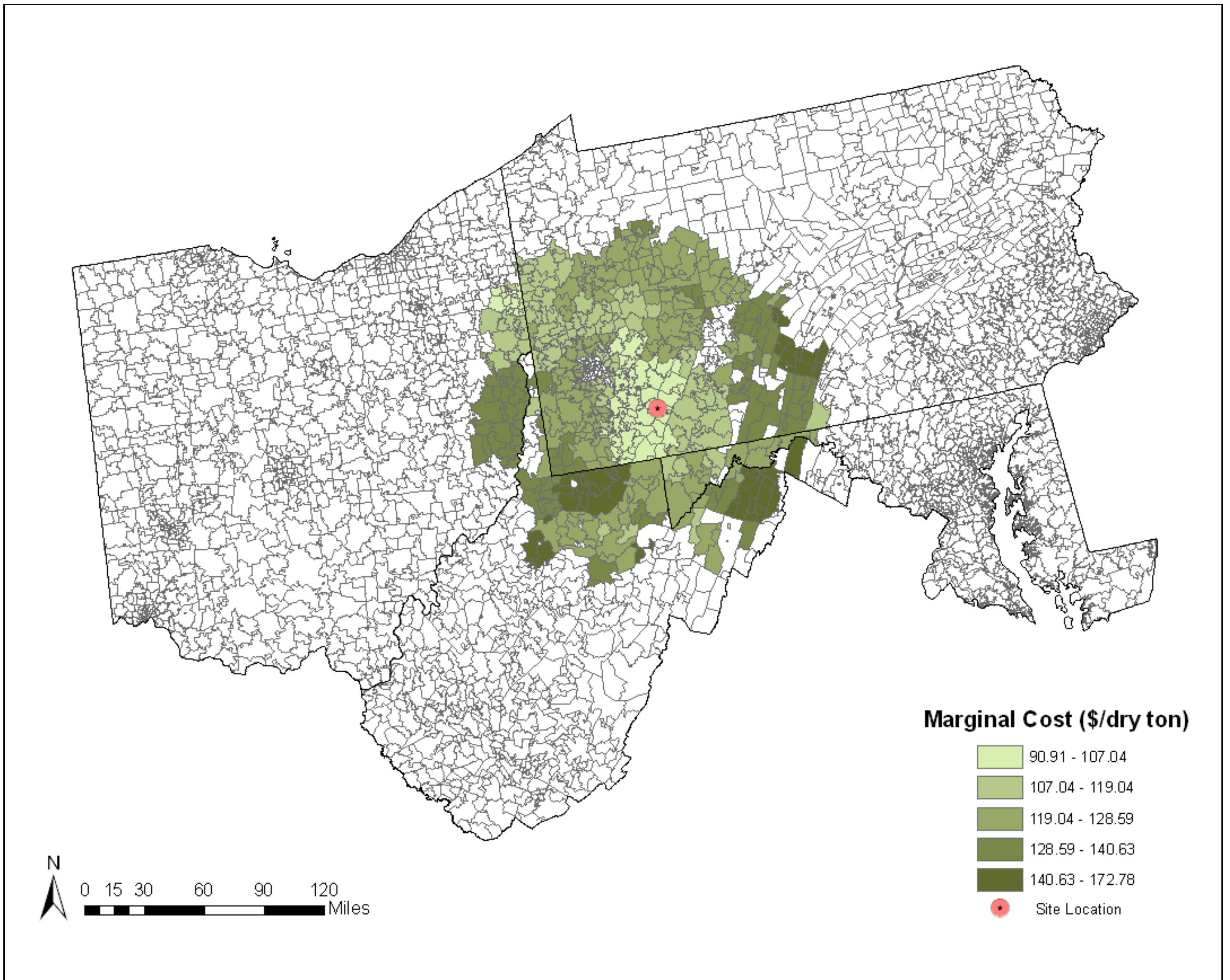

Figure F20. MC by ZCTA of in-woods logging residues for the 15490 zip code biobasin.

Appendix G

Bio-basin ZCTA

maps for the top ten sites for agricultural residues (corn stover and wheat straw) for northern region categorized by MC.

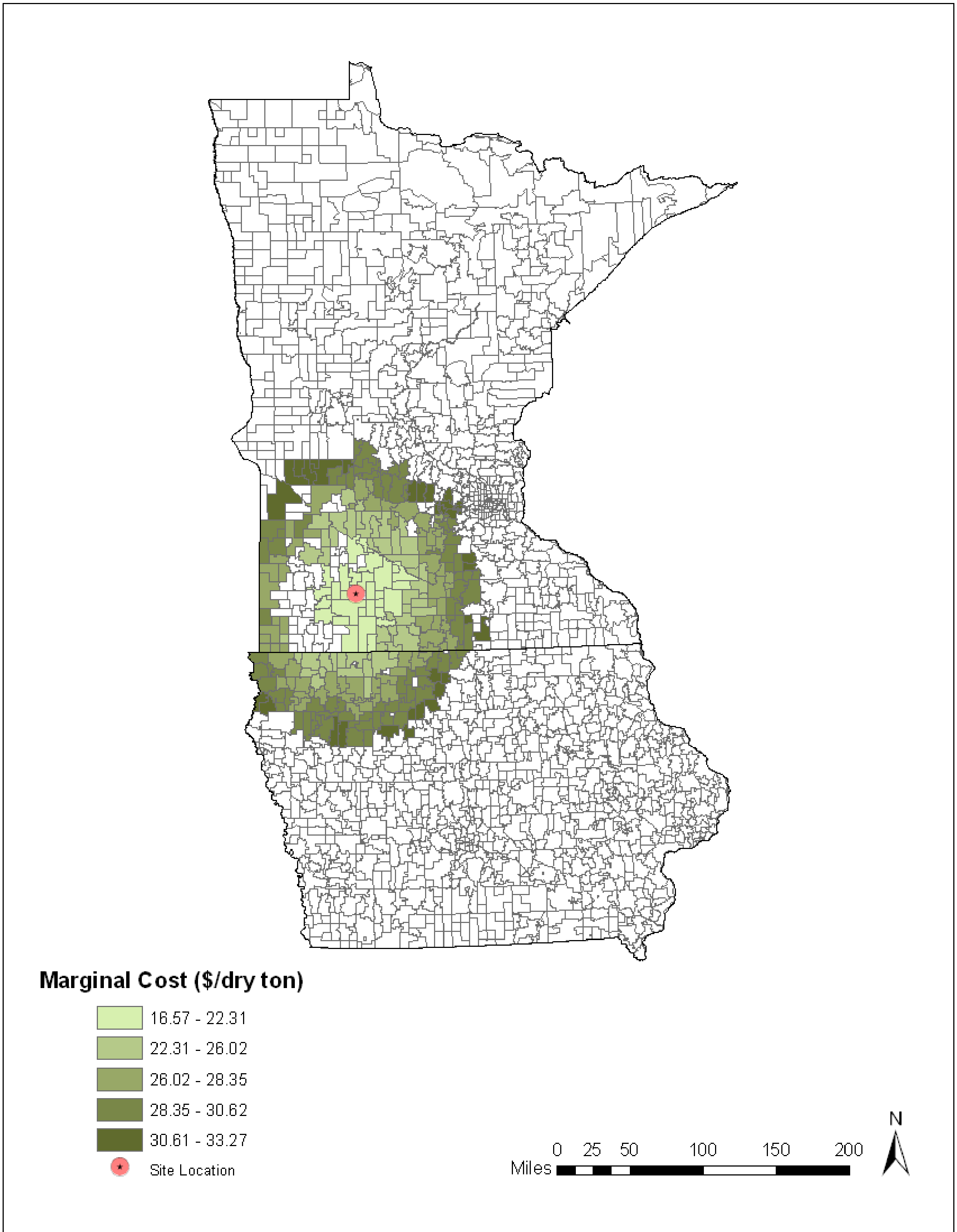

Figure G1. MC by ZCTA of corn stover for the 56145 zip code biobasin.

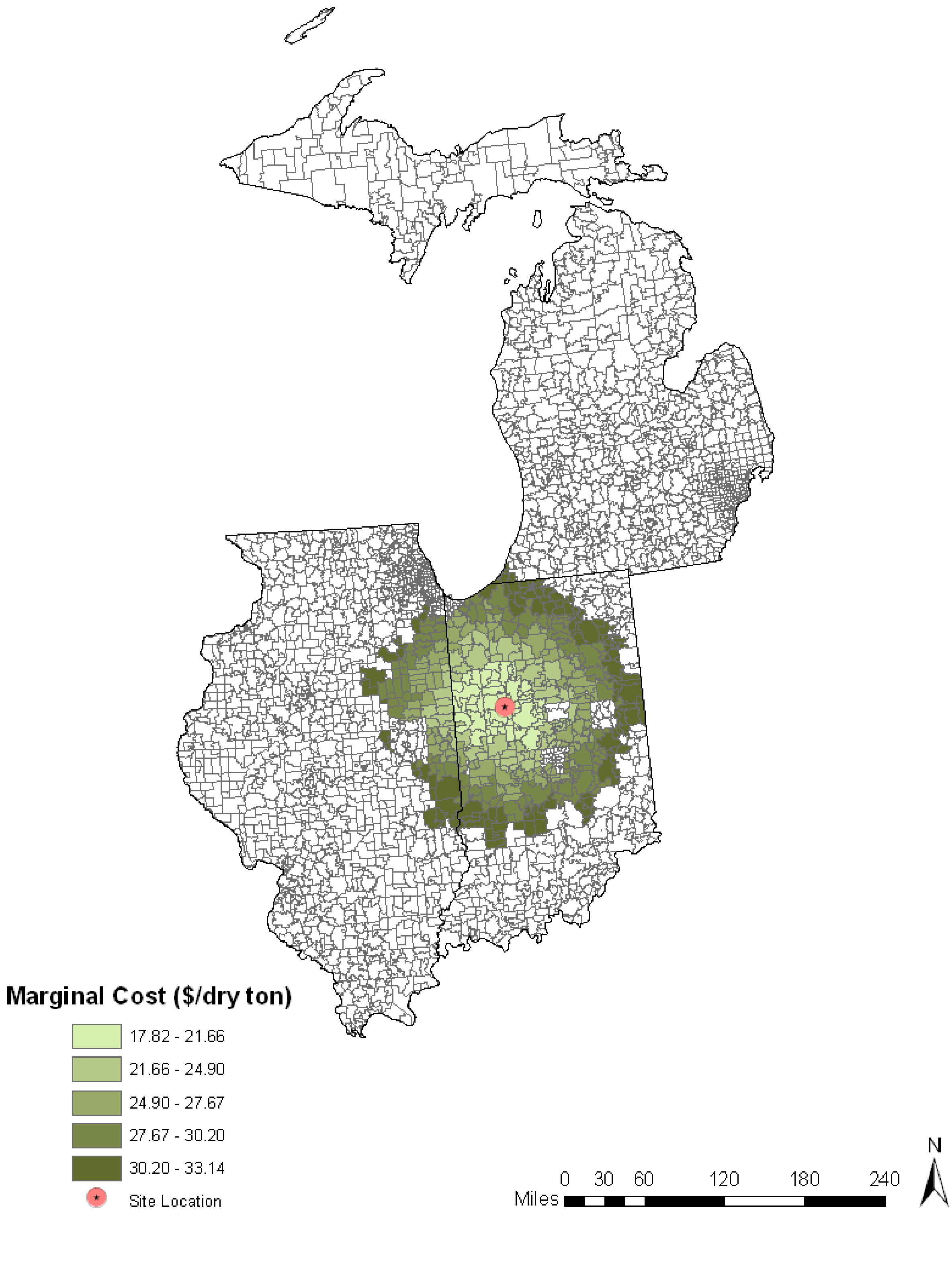

Figure G2. MC by ZCTA of corn stover for the 47902 zip code (47905 ZCTA) biobasin.

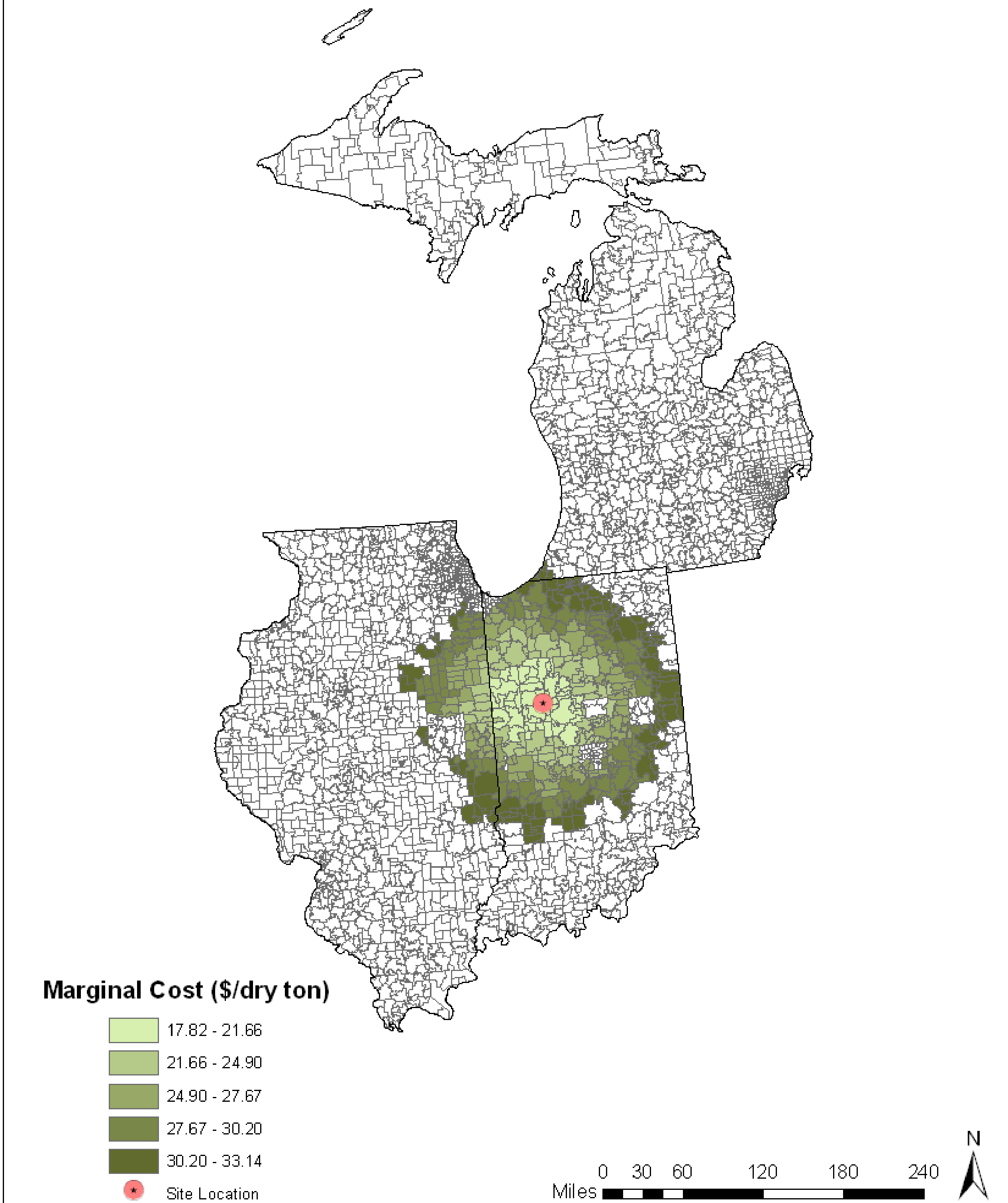

Figure G3. MC by ZCTA of corn stover for the 47903 zip code (47905 ZCTA) biobasin.

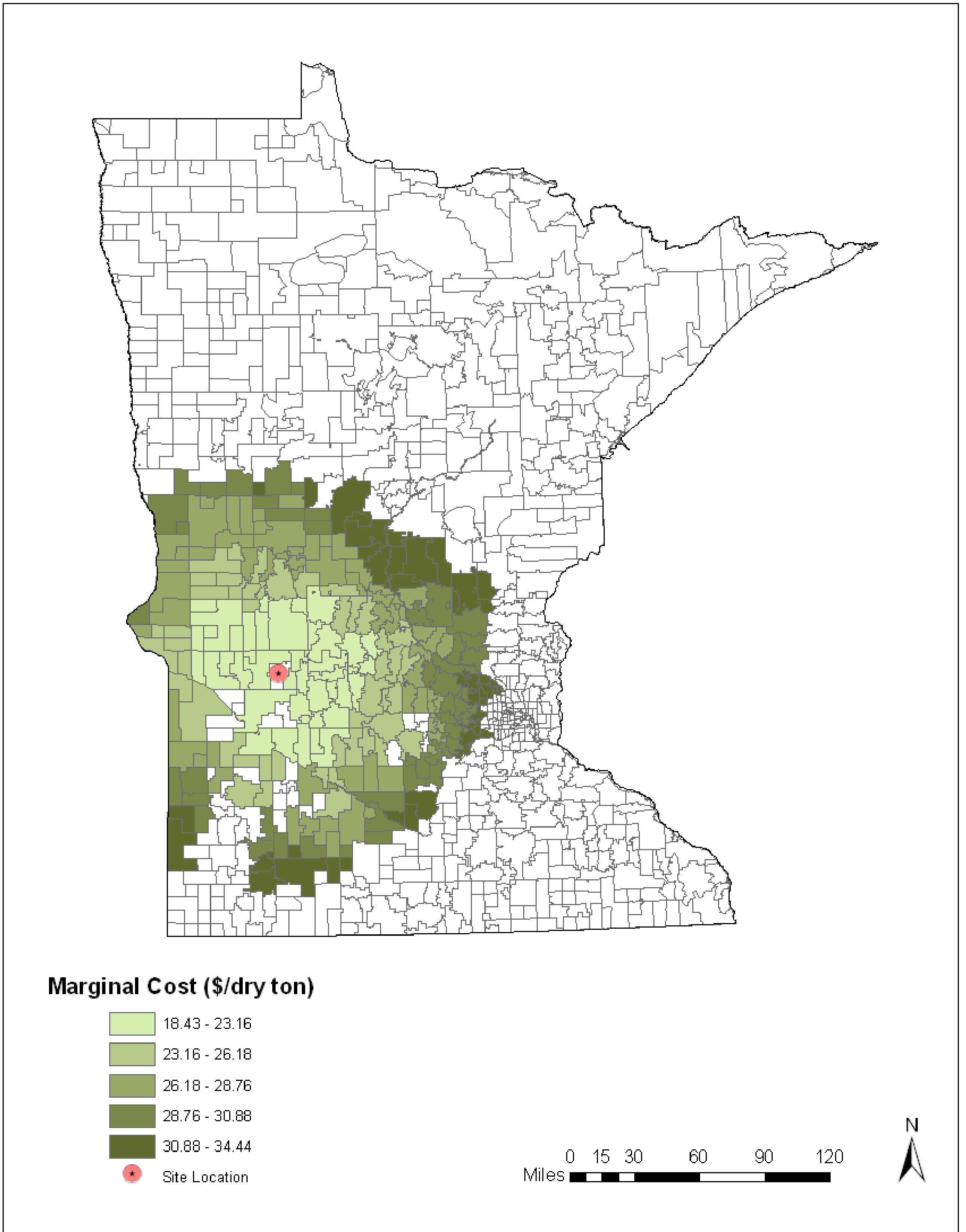

Figure G4. MC by ZCTA of corn stover for the 56271 zip code biobasin.

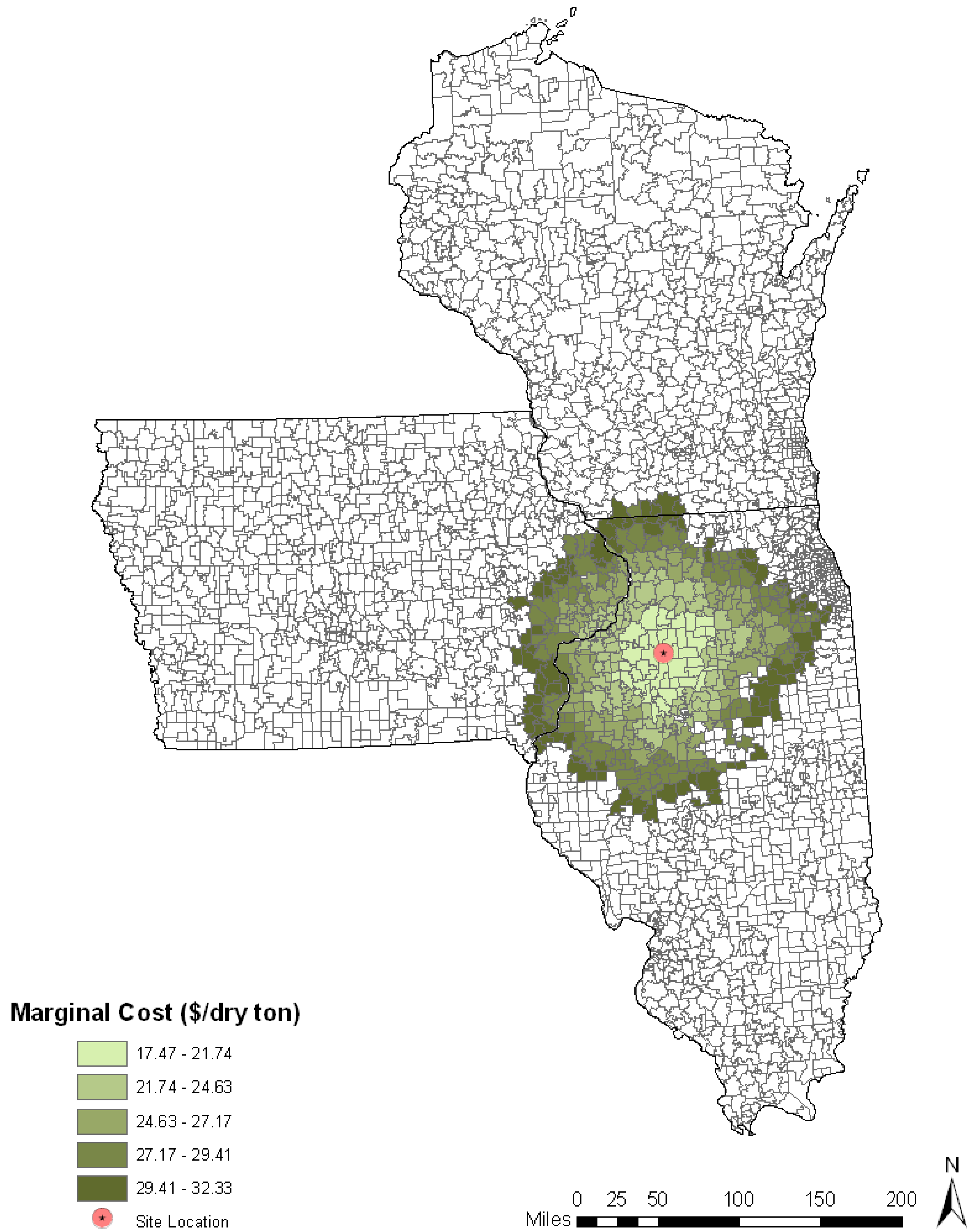

Figure G5. MC by ZCTA of corn stover for the 61345 zip code biobasin.

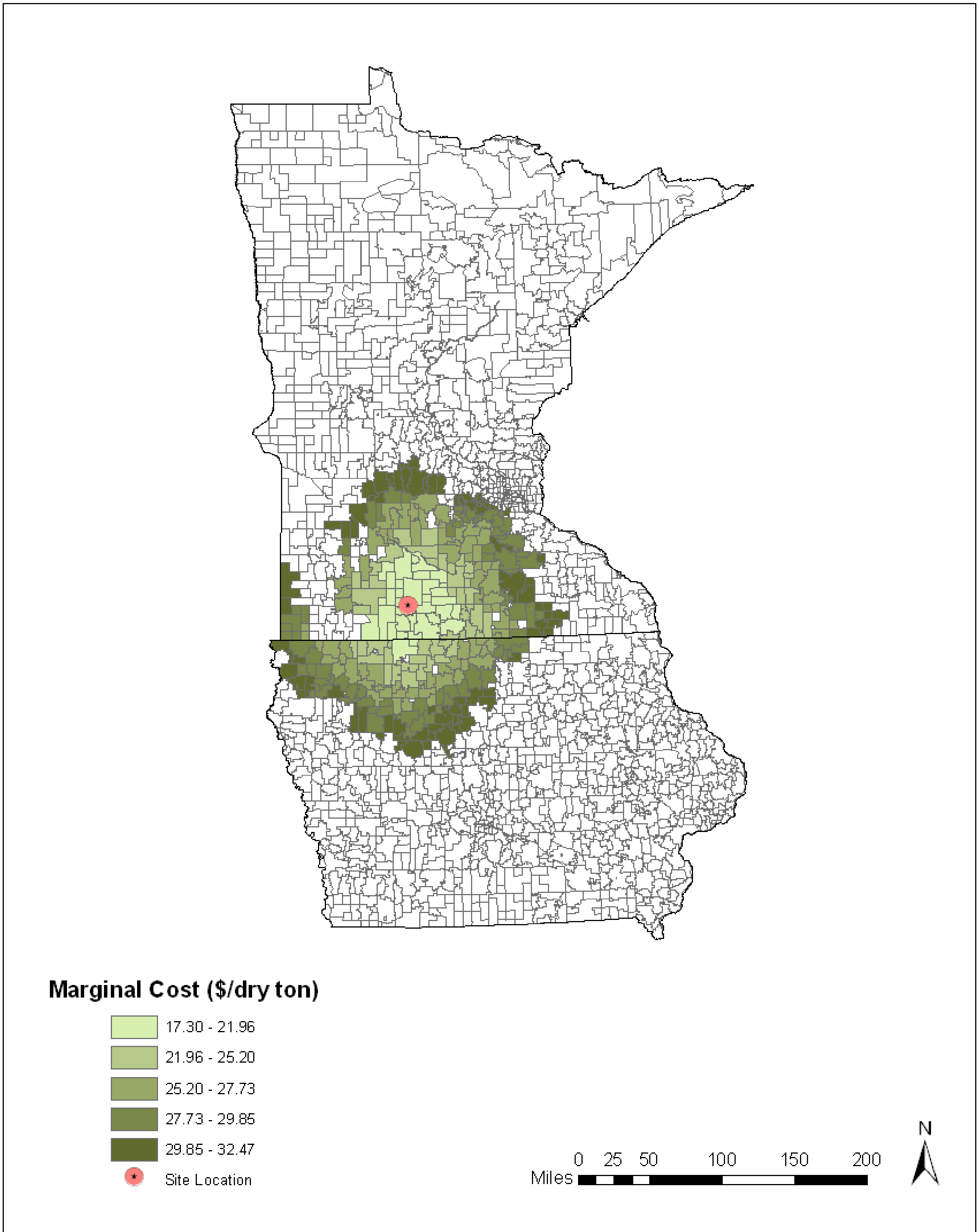

Figure G6. MC by ZCTA of corn stover for the 56162 zip code biobasin.

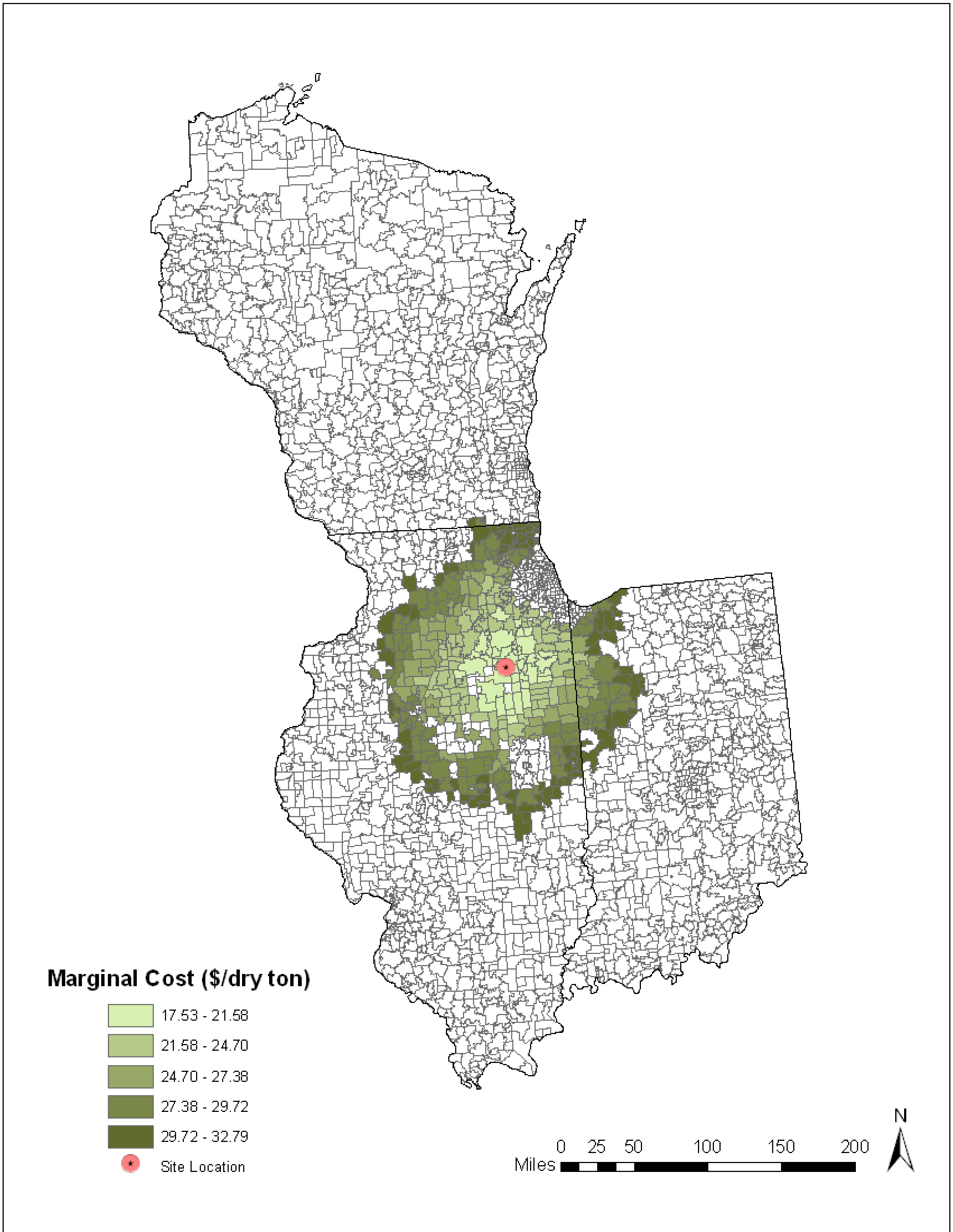

Figure G7. MC by ZCTA of corn stover for the 60420 zip code biobasin.

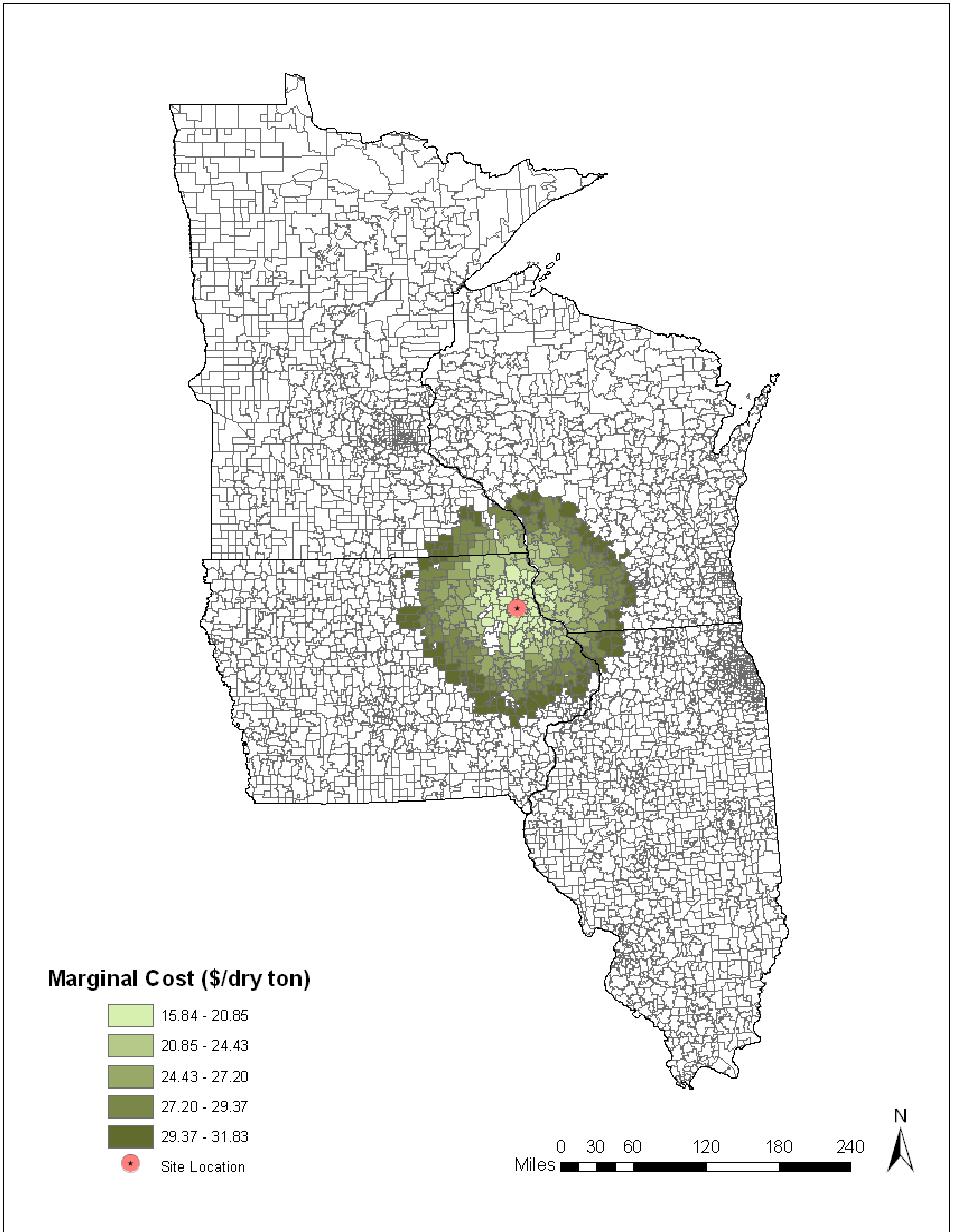

Figure G8. MC by ZCTA of corn stover for the 52043 zip code biobasin.

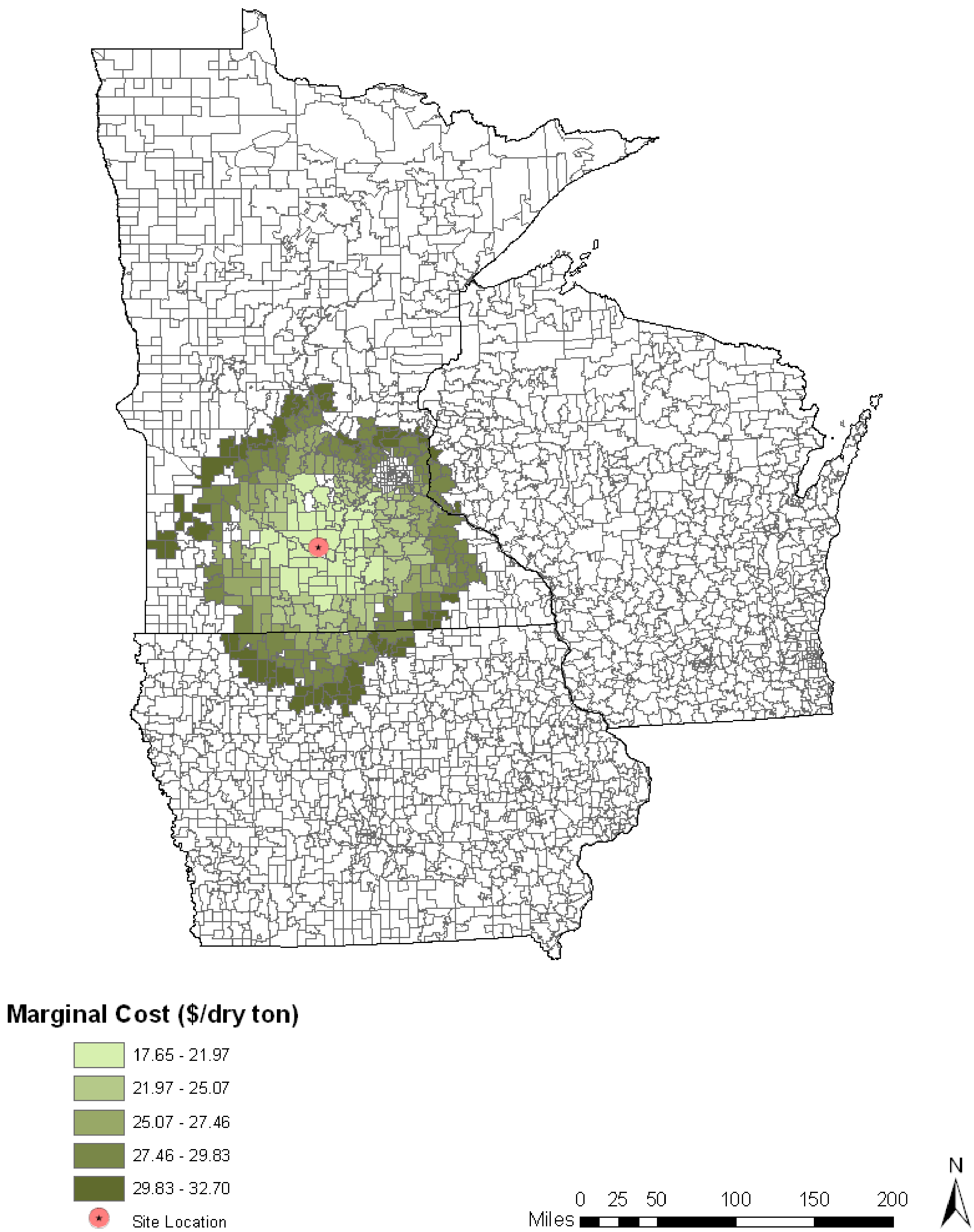

Figure G9. MC by ZCTA of corn stover for the 56074 zip code biobasin.

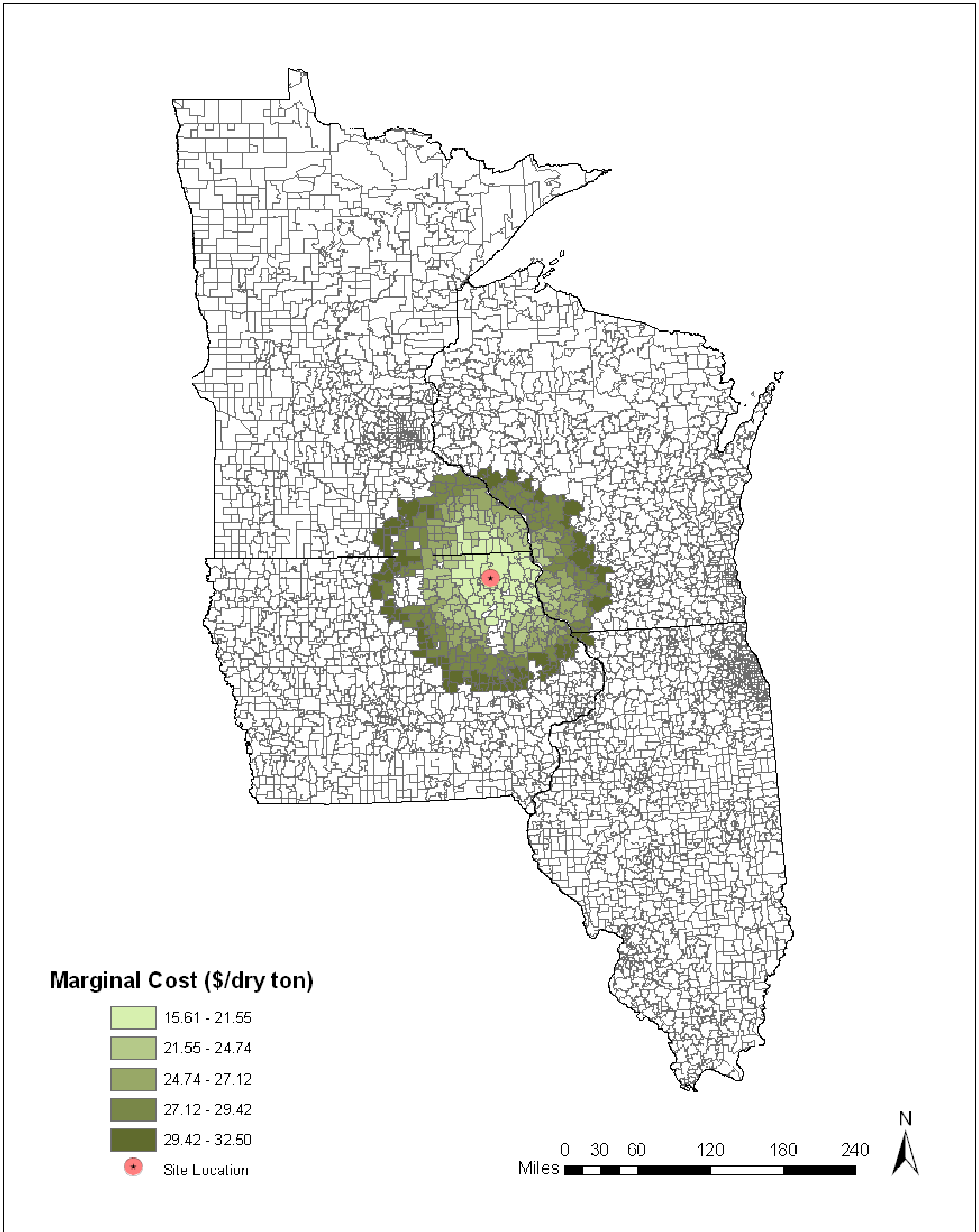

Figure G10. MC by ZCTA of corn stover for the 52168 zip code (52132 ZCTA) biobasin.

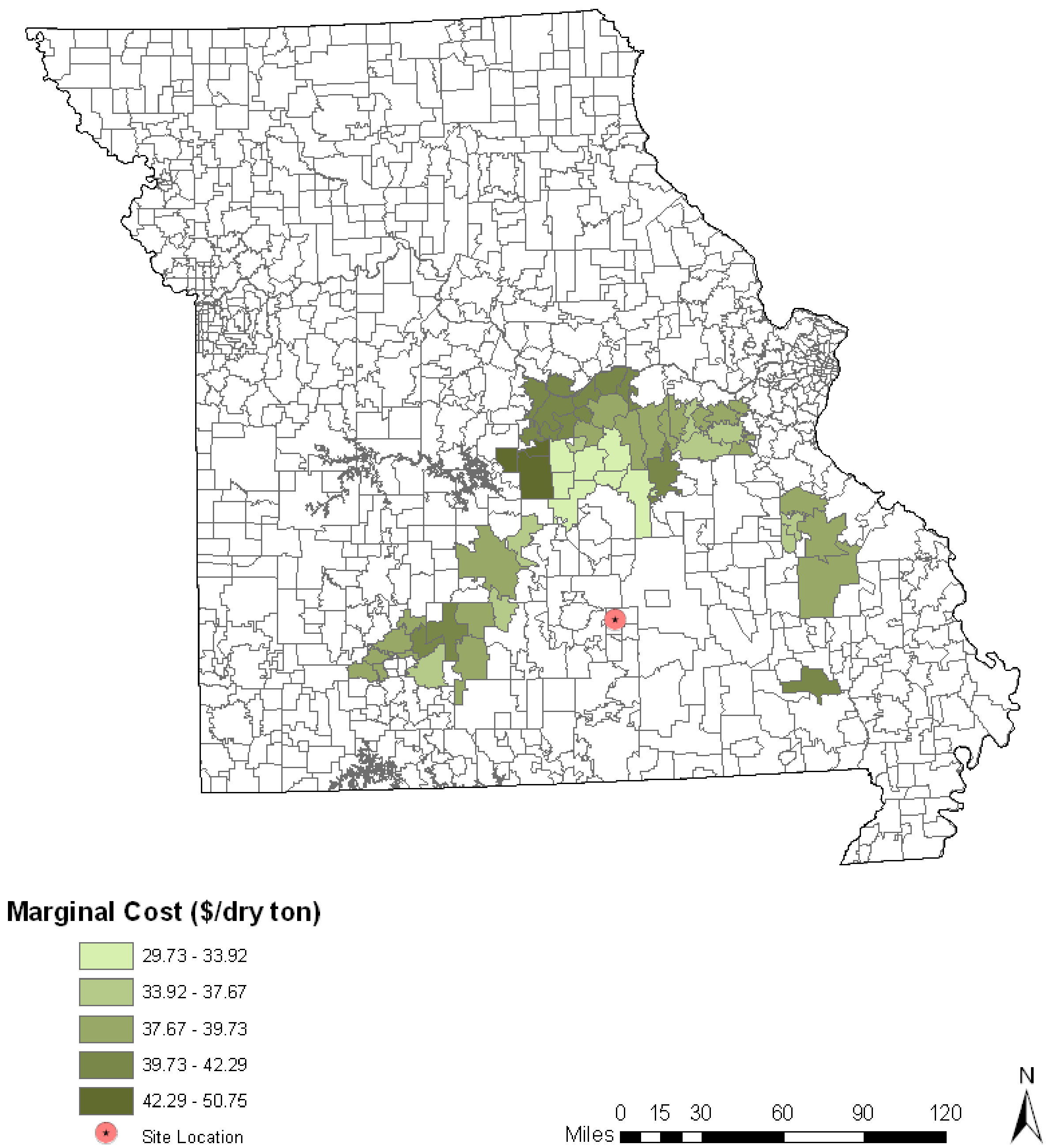

Figure G11. MC by ZCTA of wheat straw for the 65555 zip code biobasin.

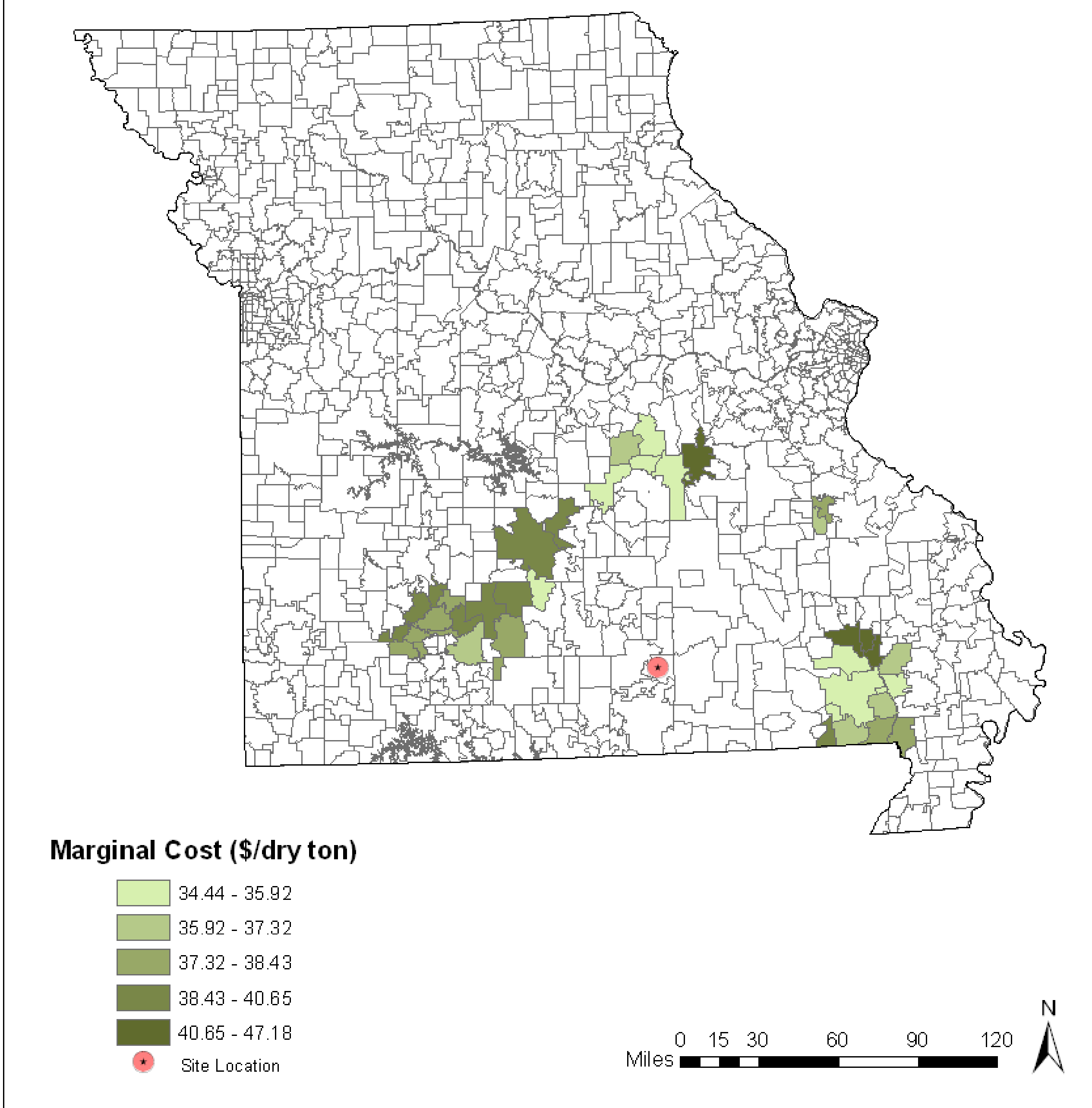

Figure G12. MC by ZCTA of wheat straw for the 65548 zip code biobasin.

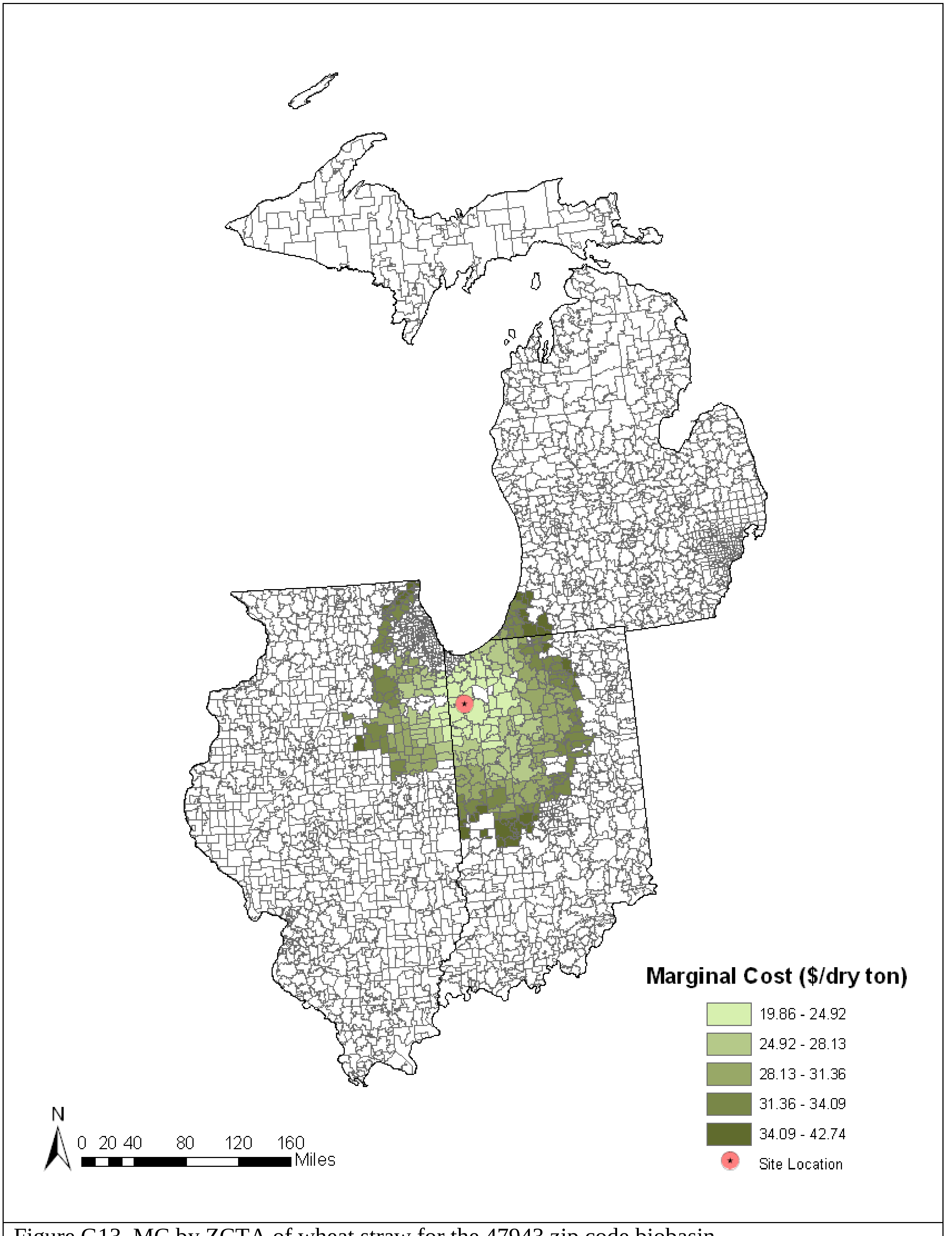

Figure G13. MC by ZCTA of wheat straw for the 47943 zip code biobasin.

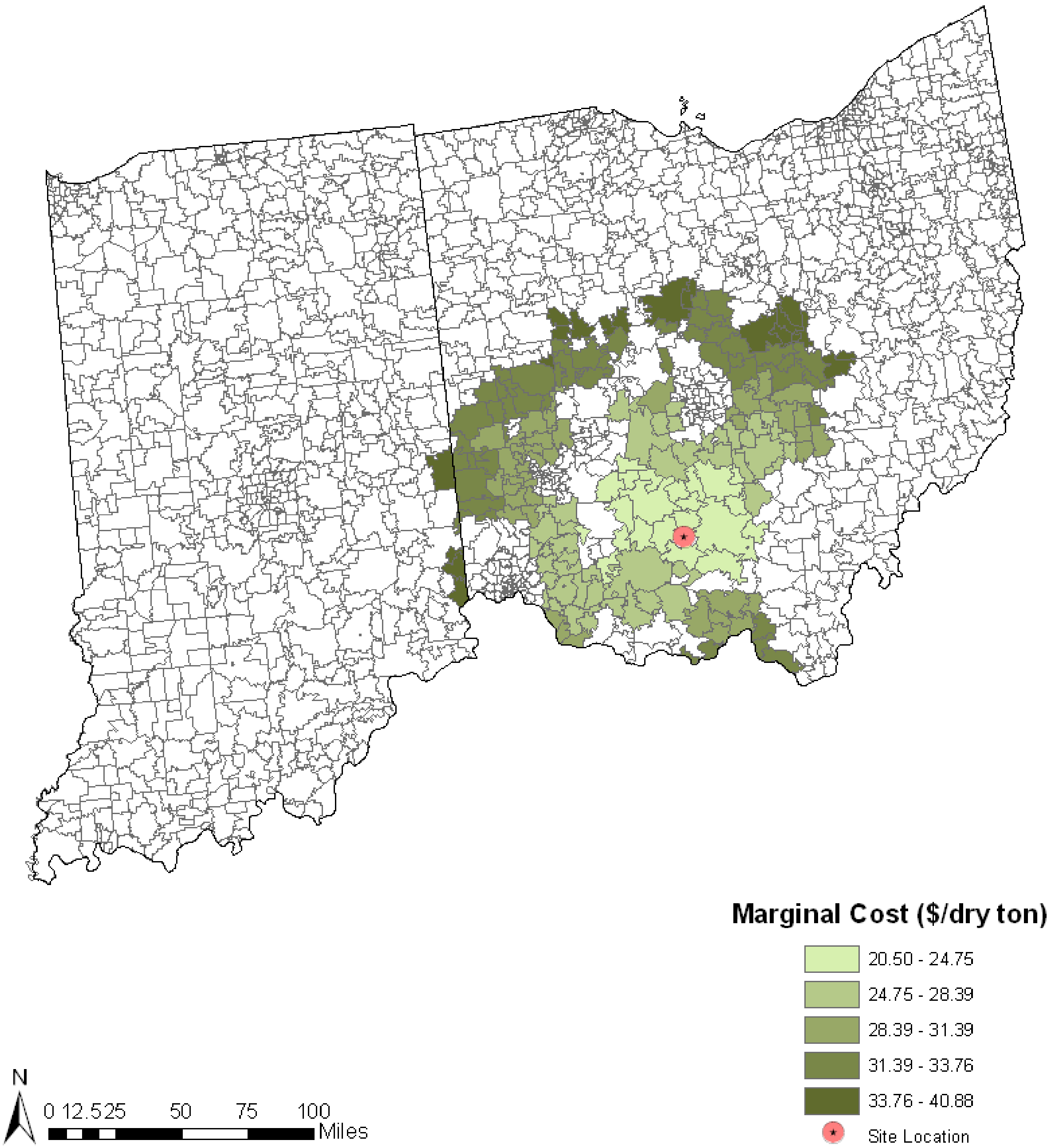

Figure G14. MC by ZCTA of wheat straw for the 45681 zip code biobasin.

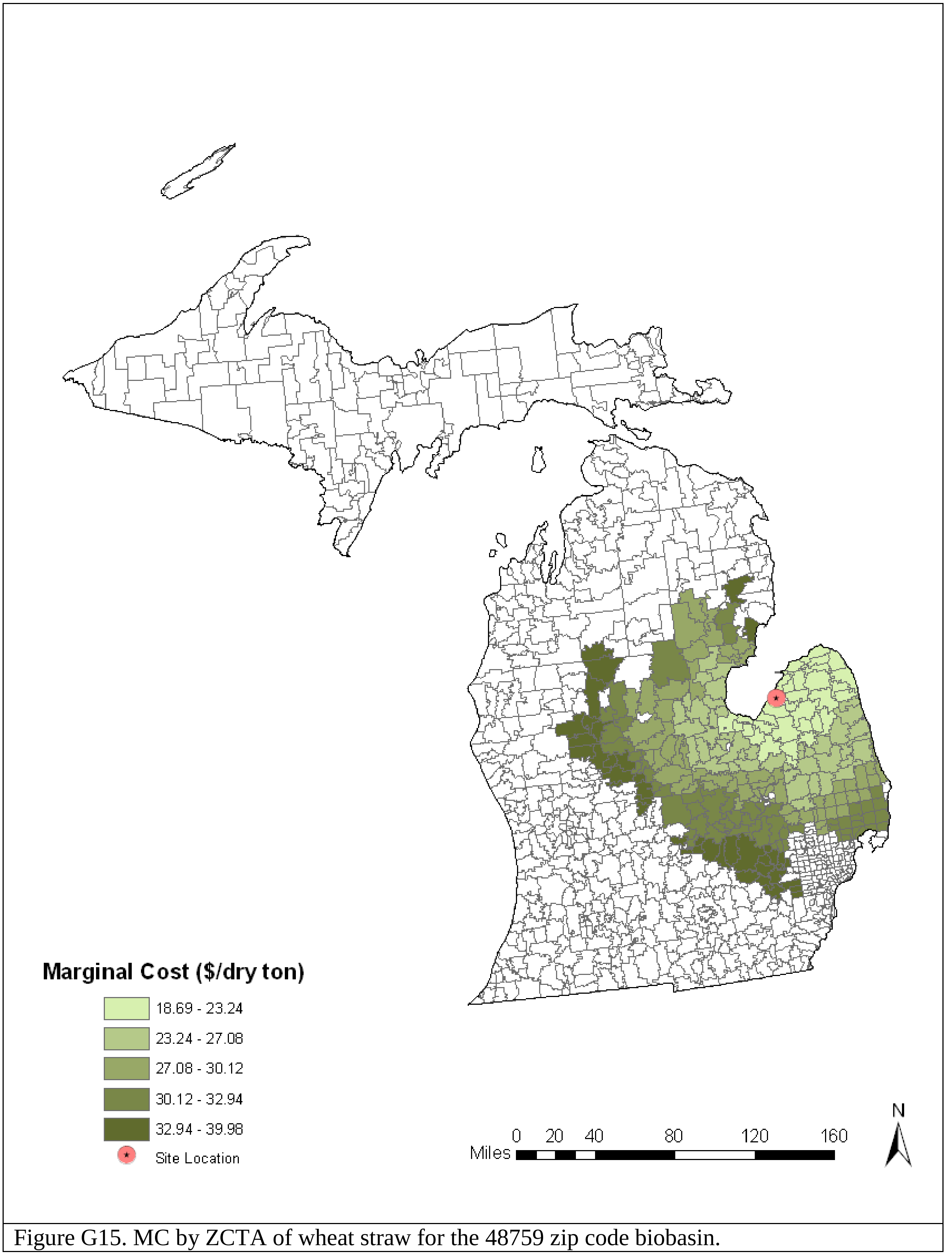

Figure G15. MC by ZCTA of wheat straw for the 48759 zip code biobasin.

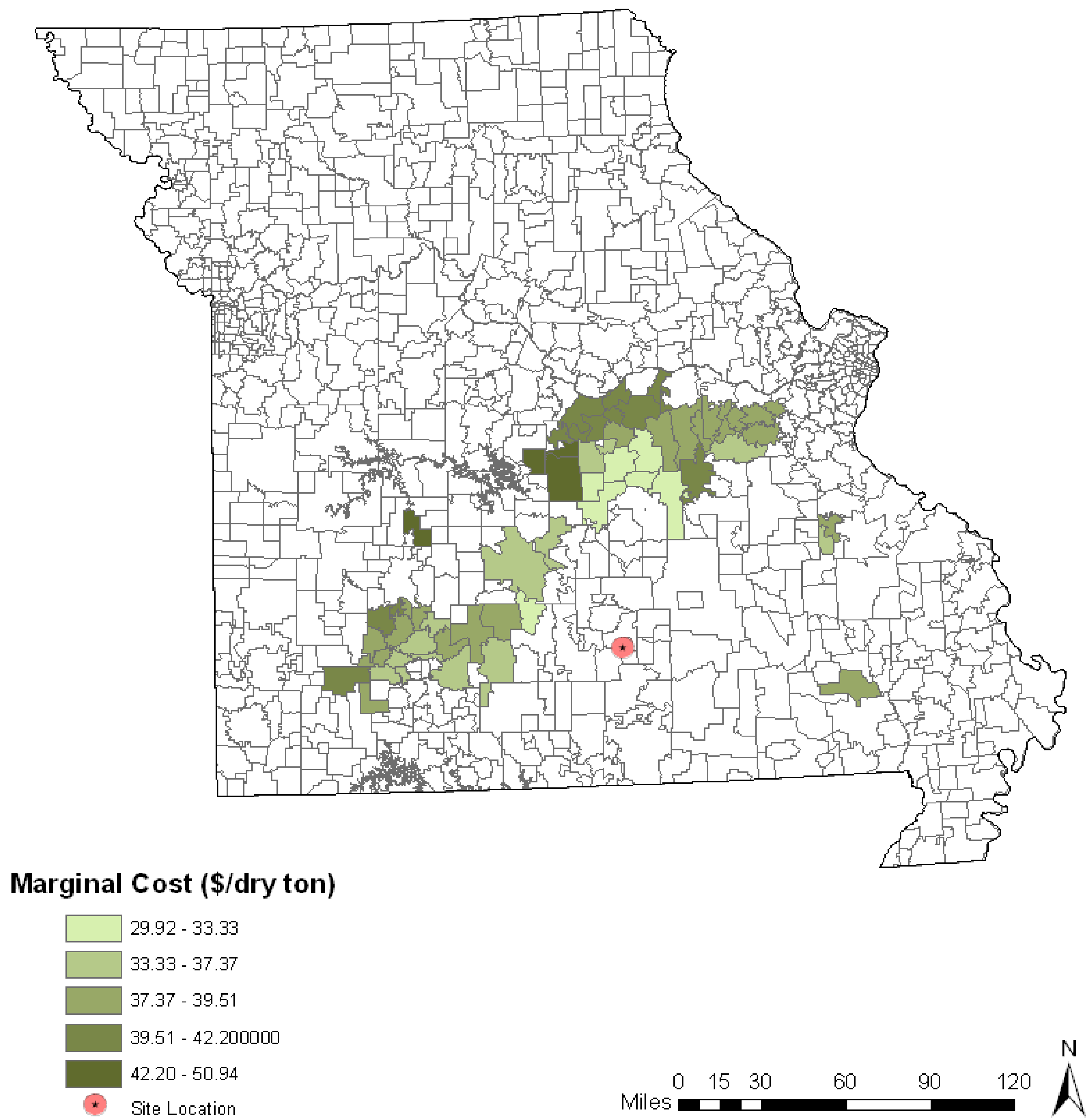

Figure G16. MC by ZCTA of wheat straw for the 65564 zip code biobasin.

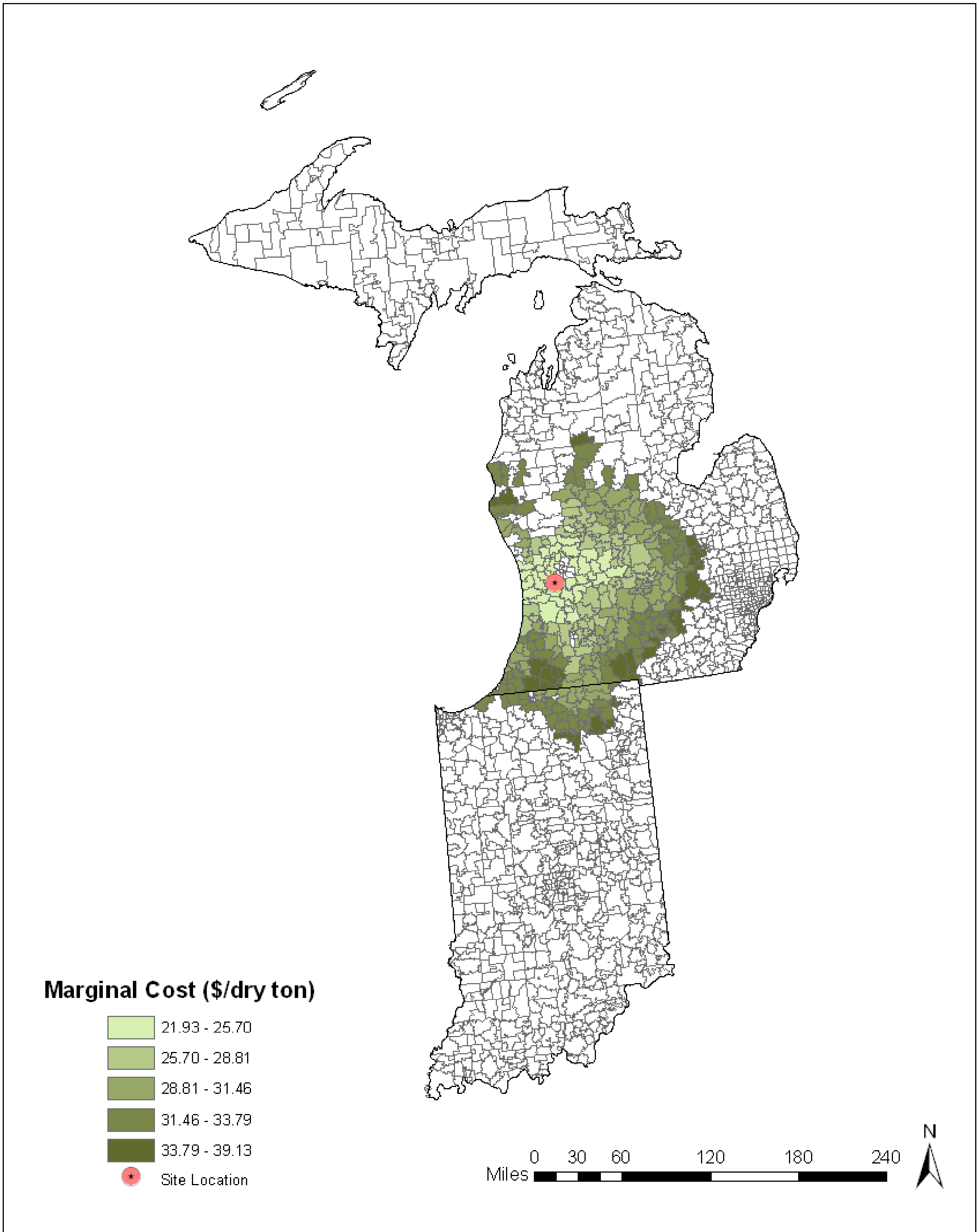

Figure G17. MC by ZCTA of wheat straw for the 49315 zip code biobasin.

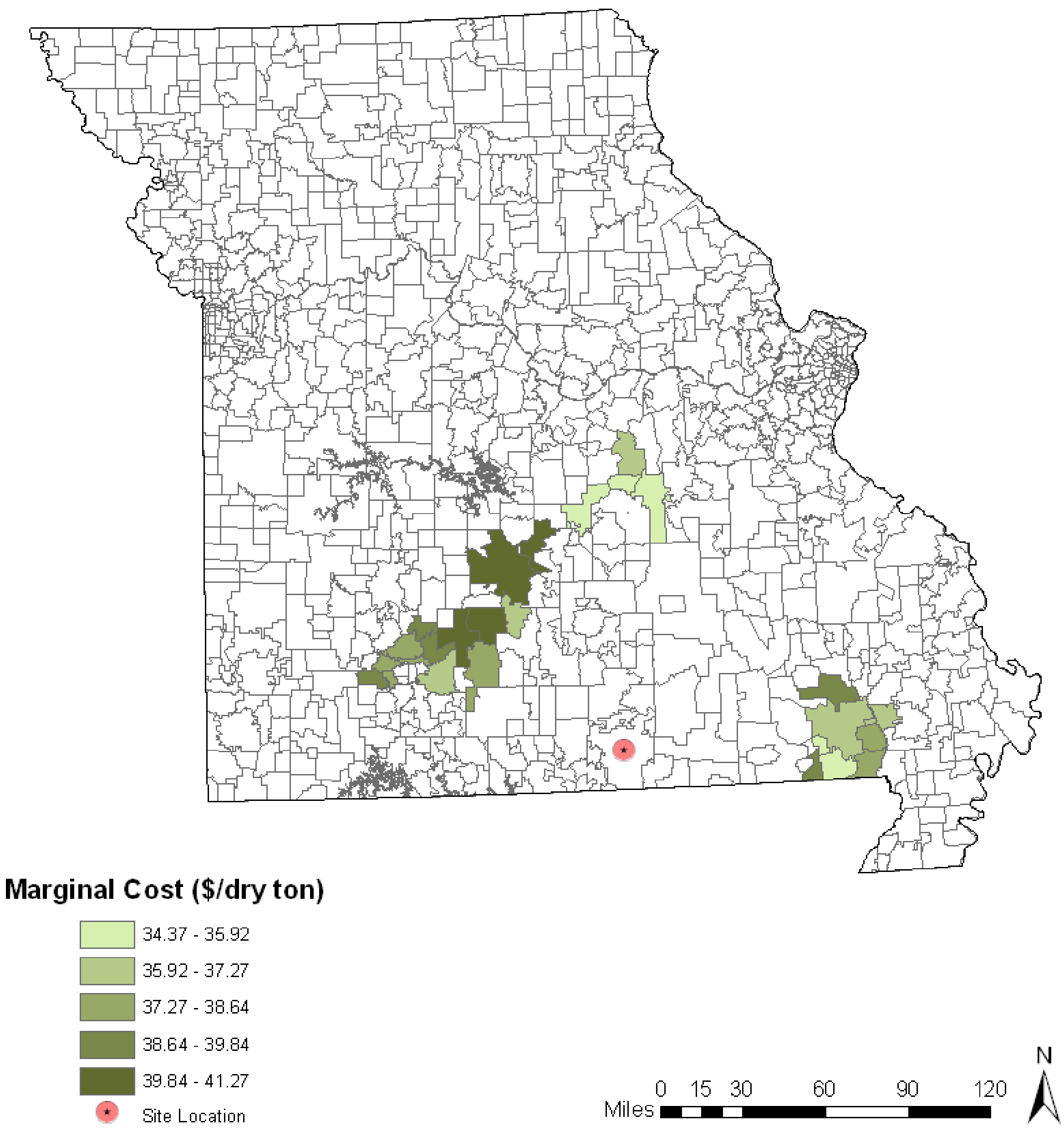

Figure G18. MC by ZCTA of wheat straw for the 65775 zip code biobasin.

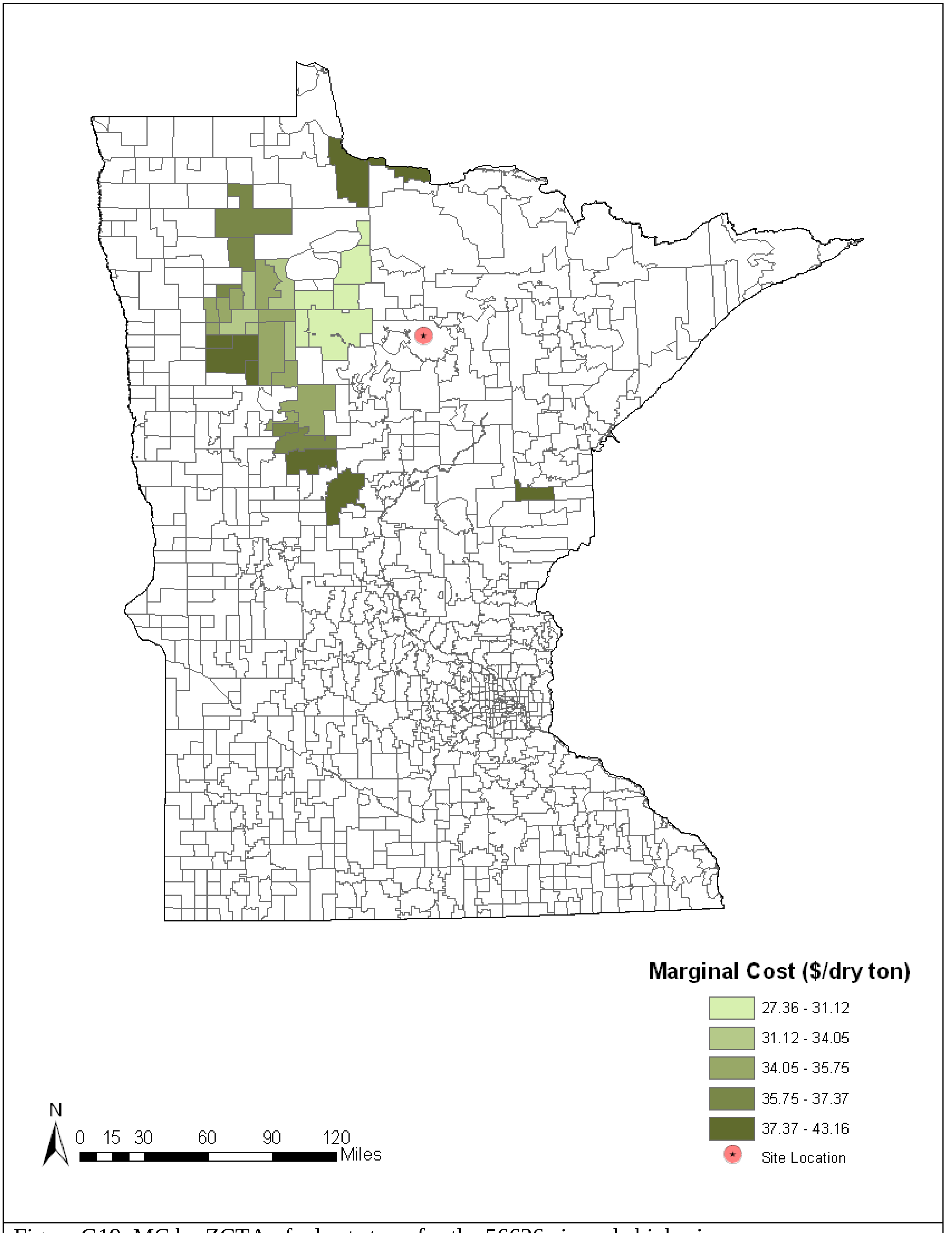

Figure G19. MC by ZCTA of wheat straw for the 56636 zip code biobasin.

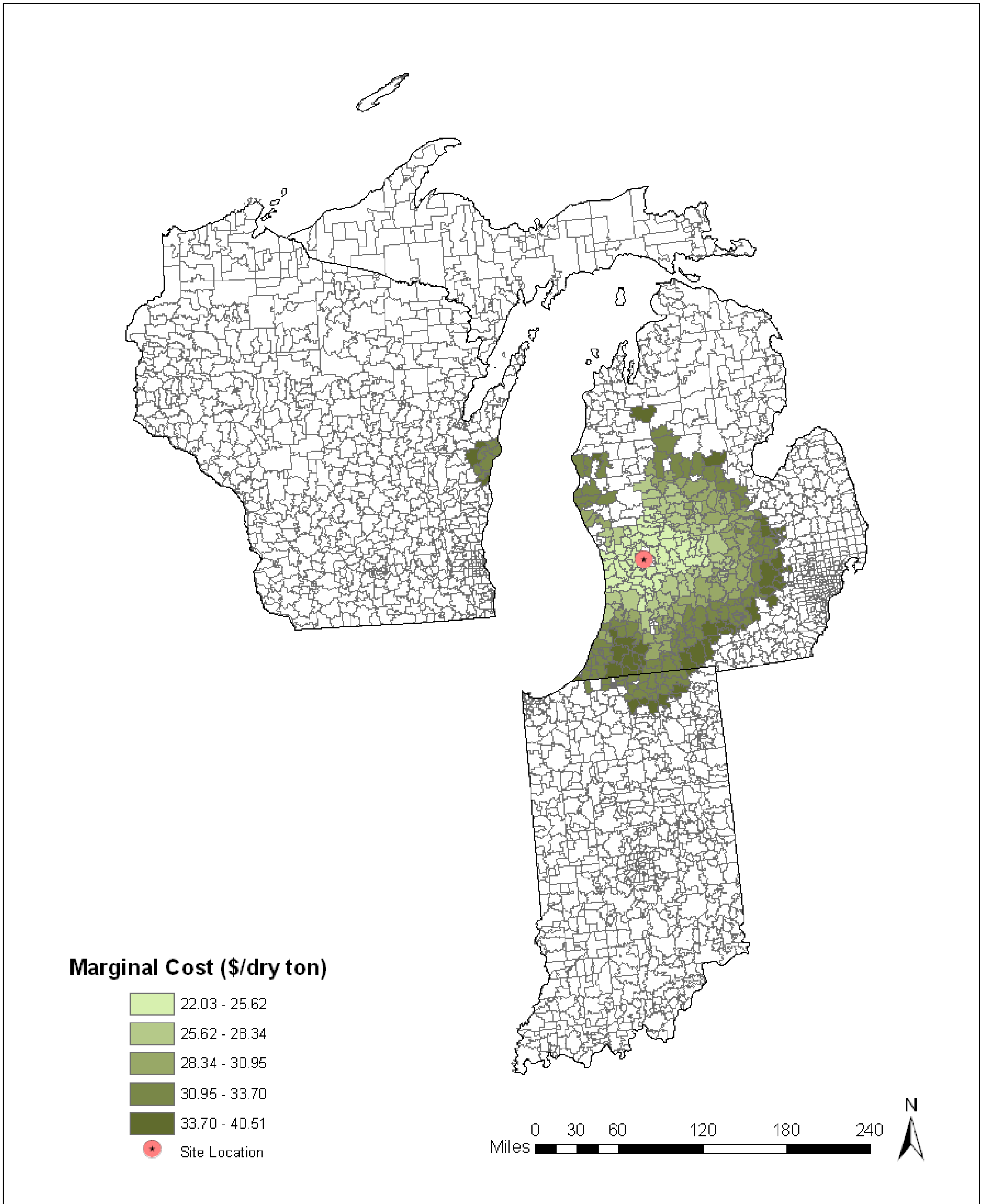

Figure G20. MC by ZCTA of wheat straw for the 49516 zip code (49506 ZCTA) biobasin.