

To Kathryn Louise Rutledge Bereitschaft

*tui vires est mihi vires*

APPROVAL PAGE

This dissertation has been approved by the following committee of the Faculty of  
The Graduate School at the University of North Carolina at Greensboro.

Committee Chair Dr. Keith Debbage

Committee Members Dr. Zhi-Jun Liu

Dr. Jay Lennartson

Dr. Anna Marshall-Baker

March 2, 2011  
Date of Acceptance by Committee

March 2, 2011  
Date of Final Oral Examination

## ACKNOWLEDGEMENTS

I would foremost like to thank my advisor, Dr. Keith Debbage, and committee members Dr. Jay Lennartson, Dr. Zhi-Jun Liu and Dr. Anna Marshall-Baker for their invaluable guidance, insight and support throughout this project. I would also like to thank my fellow graduate students, and the faculty of the Department of Geography, for providing the stimulating, collegial environment essential to my development as an academic.

This work would not have come to fruition without the additional support of friends and family. Dr. Eliza Nelson was instrumental in providing both intellectual and emotional support, particularly during the final stages when it was needed most. I am infinitely thankful for my parents, Frank and Kathy Bereitschaft, for their unconditional love and unwavering belief that I “will be anything and all [I] strive to be.” To my mother, who lost her battle with cancer a year before completion, this is for you.

## TABLE OF CONTENTS

	Page
LIST OF TABLES .....	viii
LIST OF FIGURES .....	xvi
CHAPTER	
I. INTRODUCTION .....	1
II. LITERATURE REVIEW .....	7
Effects of Air Pollution .....	8
Air Pollutant Properties and Trends .....	9
Ozone (O <sub>3</sub> ) .....	10
Particulate Matter (PM <sub>2.5</sub> and PM <sub>10</sub> ) .....	14
Carbon Dioxide (CO <sub>2</sub> ) .....	16
An Overview of Urban Form .....	17
A Brief History of Urban Form in the United States .....	18
Models of Urban Form .....	26
Measuring Urban Form .....	33
Sprawl Indices .....	34
Spatial Metrics .....	43
Urban Form and Air Quality .....	48
Energy Consumption .....	49
Meteorology and the UHI .....	52
Directly Linking Urban Form and Air Quality .....	54
III. METHODOLOGY .....	58
Research Hypotheses .....	58
Study Area .....	62
Air Quality Data .....	64
Urban Form Data .....	66
Sprawl Indices .....	66
Spatial Metrics: An Overview .....	68
Calculating Spatial Metrics .....	76
Urban Form Factors .....	79
Control Variables .....	81
Regression Models .....	85
Metropolitan Scale .....	85
Urban Form Factor Models .....	85

Urban Sprawl Index Models .....	89
Megapolitan Scale.....	94
Study Limitations and Considerations .....	94
IV. RESULTS AND DISCUSSION .....	98
Geographic Overview: Air Quality.....	98
Non-Point Source Emissions .....	98
Point vs. Non-Point Source Emissions .....	100
Ambient Concentrations .....	102
Geographic Overview: Urban Form .....	106
Urban Sprawl Indices.....	106
Spatial Metrics .....	108
Urban Form Factors .....	121
Correlation Analysis .....	131
Air Pollution vs. Urban Sprawl Indices .....	131
Air Pollution vs. Spatial Metrics.....	136
Air Pollution vs. Urban Form Factors .....	139
Air Pollution vs. Control Variables .....	141
Evaluating Collinearity .....	144
Spatial Metrics: High vs. Low Threshold .....	147
Summary of Correlations.....	148
Regression Analysis: Metropolitan Scale .....	150
Regression Model Set 1 .....	150
Regression Model Set 2 .....	153
Regression Model Set 3 .....	157
Regression Model Set 4 .....	164
Regression Model Set 5 .....	168
Regression Model Set 6 .....	172
Metropolitan Scale Summary .....	175
Regression Analysis: Megapolitan Scale.....	179
Regression Model Set 1 .....	179
Regression Model Set 2 .....	181
Megapolitan Scale Summary .....	182
Case Studies .....	184
Los Angeles and the Inland Empire .....	184
California's Central Valley .....	188
Giants of the South: Atlanta, GA and Houston, TX .....	191
The Northeast Megalopolis.....	194
The Southeast "Sprawl Belt" .....	198
Cascadia .....	202
V. CONCLUSION .....	210

Summary of Major Findings .....	210
Future Research .....	217
REFERENCES .....	224
APPENDIX A. TABLES AND FIGURES .....	240

## LIST OF TABLES

		Page
Table 1.	Pearson correlations among spatial metrics calculated at the high urban threshold .....	241
Table 2.	Pearson correlations among spatial metrics calculated at the low urban threshold.....	242
Table 3.	Pearson correlations among spatial metrics with the high and low urban threshold values averaged .....	243
Table 4.	Pearson correlations among spatial metrics calculated at the high and low urban threshold.....	244
Table 5.	Principal component analysis of spatial metrics calculated at the metropolitan scale, high urban threshold .....	245
Table 6.	Principal component analysis of spatial metrics calculated at the metropolitan scale, low urban threshold .....	245
Table 7.	Principal component analysis of spatial metrics calculated at the megapolitan scale, high urban threshold.....	246
Table 8.	Principal component analysis of spatial metrics calculated at the megapolitan scale, low urban threshold.....	246
Table 9.	Principal component analysis of meteorological/climatic variables at the metropolitan scale yielded two climate factors: “temperature” and “moisture” .....	247
Table 10.	Principal component analysis of meteorological/climatic variables at the megapolitan scale yielded two climate factors: “temperature” and “moisture” .....	247
Table 11.	Descriptive statistics for control variables at the metropolitan scale (Metro.) and megapolitan scale (Mega.).....	248
Table 12.	Descriptive statistics for air pollutants calculated at the metropolitan scale (Metro.) and megapolitan scale (Mega.).....	249

Table 13.	Top 10 MSAs and CSAs with the highest ambient concentrations of O <sub>3</sub> , PM <sub>2.5</sub> and PM <sub>10</sub> .....	250
Table 14.	Top 10 MSAs and CSAs with the lowest ambient concentrations of O <sub>3</sub> , PM <sub>2.5</sub> and PM <sub>10</sub> .....	251
Table 15.	Top 10 most sprawling MSAs and CSAs by sprawl index*.....	252
Table 16.	Top 10 least sprawling MSAs and CSAs by sprawl index*.....	254
Table 17.	Descriptive statistics for sprawl indices and Ewing et al. (2003) sprawl index components.....	256
Table 18.	Descriptive statistics for spatial metrics calculated at the high and low urban threshold at the metropolitan scale.....	257
Table 19.	Descriptive statistics for spatial metrics calculated at the high and low urban threshold at the megapolitan scale.....	258
Table 20.	Paired t-test of spatial metrics for 86 metropolitan-scale areas calculated and the high and low urban threshold.....	259
Table 21.	Paired t-test of spatial metrics for 19 megapolitan-scale areas calculated and the high and low urban threshold.....	259
Table 22.	Independent samples t-test indicating difference in spatial metrics calculated at the metropolitan vs. megapolitan scale.....	260
Table 23.	ANOVA of spatial metrics calculated at the metropolitan scale between four U.S. regions: Northeast, Midwest, South, and West.....	261
Table 24.	Top 10 MSAs and CSAs by the urban form factors urban “continuity” and urban “shape complexity” at the high urban threshold.....	262
Table 25.	Top 10 MSAs and CSAs by the urban form factors urban “continuity” and urban “shape complexity” at the low urban threshold.....	264
Table 26.	Nineteen megapolitan areas ranked (from high to low) in terms of the urban form factors urban “continuity” calculated at a high and low urban threshold.....	266

Table 27. Nineteen megapolitan areas ranked (from high to low) in terms of the urban form factor urban “shape complexity” calculated at a high and low urban threshold.....	267
Table 28. ANOVA of the urban form factors urban “continuity” and urban “shape complexity” calculated at the metropolitan scale between four U.S. regions: Northeast, Midwest, South, and West .....	268
Table 29a. Pearson correlations between air pollutant concentrations and urban sprawl indices .....	269
Table 29b. Pearson correlations between air pollutant non-point source emissions and urban sprawl indices .....	270
Table 30a. Pearson correlations between air pollutant concentrations and spatial metrics calculated at the metropolitan scale, high urban threshold.....	271
Table 30b. Pearson correlations between air pollutant non-point source emissions and spatial metrics calculated at the metropolitan scale using a high urban threshold .....	272
Table 31. Pearson correlations between air pollutants and control variables at the metropolitan scale .....	273
Table 32a. Pearson correlations between the urban form factors urban “continuity” and urban “shape complexity” calculated at the metropolitan scale, and control variables.....	274
Table 32b. Pearson correlations between the urban form factors urban “continuity” and urban “shape complexity” calculated at the megapolitan scale, and control variables .....	275
Table 33a. Pearson correlations between air pollutant concentrations and spatial metrics at the metropolitan scale using a low urban threshold.....	276
Table 33b. Pearson correlations between air pollutants and spatial metrics at the metropolitan scale using a low urban threshold.....	277
Table 34a. Pearson correlations between air pollutant concentrations and the urban form factors urban “continuity” and urban “shape complexity” calculated at the metropolitan scale .....	278

Table 34b. Pearson correlations between air pollutant non-point source emissions and the urban form factors urban “continuity” and urban “shape complexity” calculated at the metropolitan scale.....	279
Table 35a. Pearson correlations between air pollutant concentrations and the urban form factors urban “continuity” and urban “shape complexity” calculated at the megapolitan scale .....	280
Table 35b. Pearson correlations between air pollutant non-point source emissions and the urban form factors urban “continuity” and urban “shape complexity” calculated at the megapolitan scale.....	281
Table 36. Pearson correlations between air pollutants and control variables at the metropolitan scale .....	282
Table 37. Pearson correlations among urban sprawl indices and the four Ewing sprawl components .....	283
Table 38. Multiple linear regression of the urban form factors urban “continuity” and urban “shape complexity” versus the concentration of ozone (O <sub>3</sub> ), fine particulate matter (PM <sub>2.5</sub> ) and coarse particulate matter (PM <sub>10</sub> ) (Regression model set 1, metropolitan scale).....	284
Table 39. Multiple linear regression of the urban form factors urban “continuity” and urban “shape complexity” versus the concentration of ozone (O <sub>3</sub> ), fine particulate matter (PM <sub>2.5</sub> ) and coarse particulate matter (PM <sub>10</sub> ) (Regression model set 1, metropolitan scale).....	285
Table 40. Multiple linear regression of the urban form factors urban “continuity” and urban “shape complexity” versus the non-point source emission of the ozone (O <sub>3</sub> ) precursors volatile organic compounds (VOCs) and nitrogen oxides (NO <sub>x</sub> ), fine particulate matter (PM <sub>2.5</sub> ), coarse particulate matter (PM <sub>10</sub> ) and carbon dioxide (CO <sub>2</sub> ) from on-road sources (Regression model set 2, metropolitan scale) .....	286

Table 41. Multiple linear regression of the urban form factors urban “continuity” and urban “shape complexity” versus the non-point source emission of the ozone (O <sub>3</sub> ) precursors volatile organic compounds (VOCs) and nitrogen oxides (NO <sub>x</sub> ), fine particulate matter (PM <sub>2.5</sub> ), coarse particulate matter (PM <sub>10</sub> ) and carbon dioxide (CO <sub>2</sub> ) from on-road sources (Regression model set 2, metropolitan scale) .....	287
Table 42. Multiple linear regression of the Ewing et al. (2003) urban sprawl index versus the concentration of ozone (O <sub>3</sub> ), fine particulate matter (PM <sub>2.5</sub> ) and coarse particulate matter (PM <sub>10</sub> ) (Regression model set 3, metropolitan scale) .....	288
Table 43. Multiple linear regression of the Sutton (2003) urban sprawl index (high threshold) versus the concentration of ozone (O <sub>3</sub> ), fine particulate matter (PM <sub>2.5</sub> ) and coarse particulate matter (PM <sub>10</sub> ) (Regression model set 3, metropolitan scale) .....	289
Table 44. Multiple linear regression of the Sutton (2003) urban sprawl index (low threshold) versus the concentration of ozone (O <sub>3</sub> ), fine particulate matter (PM <sub>2.5</sub> ) and coarse particulate matter (PM <sub>10</sub> ) (Regression model set 3, metropolitan scale) .....	290
Table 45. Multiple linear regression of the Lopez and Hynes (2003) urban sprawl index versus the concentration of ozone (O <sub>3</sub> ), fine particulate matter (PM <sub>2.5</sub> ) and coarse particulate matter (PM <sub>10</sub> ) (Regression model set 3, metropolitan scale) .....	291
Table 46. Multiple linear regression of the Nasser and Overberg (USA Today) (2001) urban sprawl index versus the concentration of ozone (O <sub>3</sub> ), fine particulate matter (PM <sub>2.5</sub> ) and coarse particulate matter (PM <sub>10</sub> ) (Regression model set 3, metropolitan scale).....	292
Table 47. Multiple linear regression of the Burchfield et al. (2006) urban sprawl index versus the concentration of ozone (O <sub>3</sub> ), fine particulate matter (PM <sub>2.5</sub> ) and coarse particulate matter (PM <sub>10</sub> ) (Regression model set 3, metropolitan scale) .....	293
Table 48. Multiple linear regression of the Ewing (2003) urban sprawl index components street connectivity, centeredness, mixed use, and residential density versus the concentration of ozone (O <sub>3</sub> ), fine particulate matter (PM <sub>2.5</sub> ) and coarse particulate matter (PM <sub>10</sub> ) (Regression model set 4, metropolitan scale) .....	294

Table 49. Multiple linear regression of the Ewing (2003) urban sprawl index versus the non-point source emission of the ozone (O <sub>3</sub> ) precursors volatile organic compounds (VOCs) and nitrogen oxides (NO <sub>x</sub> ), fine particulate matter (PM <sub>2.5</sub> ), coarse particulate matter (PM <sub>10</sub> ) and carbon dioxide (CO <sub>2</sub> ) from on-road sources (Regression model set 5, metropolitan scale) .....	295
Table 50. Multiple linear regression of the Sutton (2003) urban sprawl index (high threshold) versus the non-point source emission of the ozone (O <sub>3</sub> ) precursors volatile organic compounds (VOCs) and nitrogen oxides (NO <sub>x</sub> ), fine particulate matter (PM <sub>2.5</sub> ), coarse particulate matter (PM <sub>10</sub> ) and carbon dioxide (CO <sub>2</sub> ) from on-road sources (Regression model set 5, metropolitan scale).....	296
Table 51. Multiple linear regression of the Sutton (2003) urban sprawl index (low threshold) versus the non-point source emission of the ozone (O <sub>3</sub> ) precursors volatile organic compounds (VOCs) and nitrogen oxides (NO <sub>x</sub> ), fine particulate matter (PM <sub>2.5</sub> ), coarse particulate matter (PM <sub>10</sub> ) and carbon dioxide (CO <sub>2</sub> ) from on-road sources (Regression model set 5, metropolitan scale).....	297
Table 52. Multiple linear regression of the Lopez and Hynes (2003) urban sprawl index (high threshold) versus the non-point source emission of the ozone (O <sub>3</sub> ) precursors volatile organic compounds (VOCs) and nitrogen oxides (NO <sub>x</sub> ), fine particulate matter (PM <sub>2.5</sub> ), coarse particulate matter (PM <sub>10</sub> ) and carbon dioxide (CO <sub>2</sub> ) from on-road sources (Regression model set 5, metropolitan scale).....	298
Table 53. Multiple linear regression of the Nasser and Overberg (2001) (USA Today) urban sprawl index versus the non-point source emission of the ozone (O <sub>3</sub> ) precursors volatile organic compounds (VOCs) and nitrogen oxides (NO <sub>x</sub> ), fine particulate matter (PM <sub>2.5</sub> ), coarse particulate matter (PM <sub>10</sub> ) and carbon dioxide (CO <sub>2</sub> ) from on-road sources (Regression model set 5, metropolitan scale).....	299
Table 54. Multiple linear regression of the Burchfield (2006) urban sprawl index versus the non-point source emission of the ozone (O <sub>3</sub> ) precursors volatile organic compounds (VOCs) and nitrogen oxides (NO <sub>x</sub> ), fine particulate matter (PM <sub>2.5</sub> ), coarse particulate matter (PM <sub>10</sub> ) and carbon dioxide (CO <sub>2</sub> ) from on-road sources (Regression model set 5, metropolitan scale) .....	300

Table 55. Multiple linear regression of the Ewing (2003) urban sprawl index components street connectivity, centeredness, mixed use, and residential density versus the non-point source emission of the ozone (O <sub>3</sub> ) precursors volatile organic compounds (VOCs) and nitrogen oxides (NO <sub>x</sub> ), fine particulate matter (PM <sub>2.5</sub> ), coarse particulate matter (PM <sub>10</sub> ) and carbon dioxide (CO <sub>2</sub> ) from on-road sources (Regression model set 6, metropolitan scale).....	301
Table 56. Multiple linear regression of the urban form factors urban “continuity” and urban “shape complexity” versus the concentration of ozone (O <sub>3</sub> ), fine particulate matter (PM <sub>2.5</sub> ) and coarse particulate matter (PM <sub>10</sub> ) (Regression model set 1, megapolitan scale) .....	302
Table 57. Multiple linear regression of the urban form factors urban “continuity” and urban “shape complexity” versus the concentration of ozone (O <sub>3</sub> ), fine particulate matter (PM <sub>2.5</sub> ) and coarse particulate matter (PM <sub>10</sub> ) (Regression model set 1, megapolitan scale) .....	303
Table 58. Multiple linear regression of the urban form factors urban “continuity” and urban “shape complexity” versus the non-point source emission of the ozone (O <sub>3</sub> ) precursors volatile organic compounds (VOCs) and nitrogen oxides (NO <sub>x</sub> ), fine particulate matter (PM <sub>2.5</sub> ), coarse particulate matter (PM <sub>10</sub> ) and carbon dioxide (CO <sub>2</sub> ) from on-road sources (Regression model set 2, megapolitan scale) .....	304
Table 59. Multiple linear regression of the urban form factors urban “continuity” and urban “shape complexity” versus the non-point source emission of the ozone (O <sub>3</sub> ) precursors volatile organic compounds (VOCs) and nitrogen oxides (NO <sub>x</sub> ), fine particulate matter (PM <sub>2.5</sub> ), coarse particulate matter (PM <sub>10</sub> ) and carbon dioxide (CO <sub>2</sub> ) from on-road sources (Regression model set 2, megapolitan scale) .....	305
Table 60. Exurban area and population among selected large metropolitan areas. Source: Sutton (2006) .....	306
Table 61. Nineteen megapolitan areas ranked (from high to low) in terms of O <sub>3</sub> concentration and number of O <sub>3</sub> exceedances (1998 – 2002).....	307

Table 62. Nineteen megapolitan areas ranked (from high to low) in terms of PM <sub>2.5</sub> and PM <sub>10</sub> concentration (1998 – 2002).....	308
-------------------------------------------------------------------------------------------------------------------------------------------------------	-----

## LIST OF FIGURES

		Page
Figure 1.	The metropolitan-scale analysis included 23 metropolitan statistical areas (MSAs) and 63 combined statistical areas (CSAs).....	309
Figure 2.	Nineteen megapolitan areas as described by Lang (2006) .....	310
Figure 3.	Intensity of city lights at night in the United States. ....	311
Figure 4.	High and low urban thresholds in the Greensboro—Winston-Salem— High Point CSA based on intensity of city lights at night.....	312
Figure 5.	Urban landcover within the high and low urban thresholds in Greensboro—Winston-Salem—High Point CSA.....	313
Figure 6.	Non-point emission of volatile organic compounds (VOCs) and nitrogen oxides (NOx) by county in 2000.....	314
Figure 7.	Non-point emission of PM <sub>2.5</sub> by county in 2000.....	315
Figure 8.	Non-point emission of PM <sub>10</sub> by county in 2000.....	316
Figure 9.	On-road emission of CO <sub>2</sub> by county in 2002 .....	317
Figure 10.	Non-point emission density of volatile organic compounds (VOCs) and nitrogen oxides (NOx) by county in 2000.....	318
Figure 11.	Non-point emission density of PM <sub>2.5</sub> by county in 2000.....	319
Figure 12.	Non-point emission density of PM <sub>10</sub> by county in 2000 .....	320
Figure 13.	Non-point emission density of on-road CO <sub>2</sub> by county in 2000.....	321
Figure 14.	Per capita non-point emission of volatile organic compounds (VOCs) and nitrogen oxides (NOx) by county in 2000.....	322
Figure 15.	Per capita non-point emission of PM <sub>2.5</sub> by county in 2000 .....	323
Figure 16.	Per capita non-point emission of PM <sub>10</sub> by county in 2000 .....	324

Figure 17. Per capita non-point emission of on-road CO <sub>2</sub> by county in 2000 .....	325
Figure 18. Major U.S. regions .....	326
Figure 19. Annual average fourth maximum 8-hour ozone concentration (ppm) 1998 to 2002.....	327
Figure 20. Kriging-based model of annual average fourth maximum 8-hour ozone concentration (ppm) between 1998 and 2002 .....	328
Figure 21. Annual average PM <sub>25</sub> concentration (µg/m <sup>3</sup> ) 1998 to 2002.....	329
Figure 22. Kriging-based model of annual average PM <sub>25</sub> concentration (µg/m <sup>3</sup> ) between 1998 and 2002.....	330
Figure 23. Annual average PM <sub>10</sub> concentration (µg/m <sup>3</sup> ) 1998 to 2002.....	331
Figure 24. Kriging-based model of annual average PM <sub>10</sub> concentration (µg/m <sup>3</sup> ) between 1998 and 2002.....	332
Figure 25. The number of sprawl indices (max: 6) that rank each MSA/CSA within the top 10 most sprawling in the United States .....	333
Figure 26. The number of sprawl indices (max: 6) that rank each MSA/CSA within the top 10 least sprawling in the United States.....	334
Figure 27. Urban landcover, Carolina Piedmont megapolitan area.....	335
Figure 28. Urban landcover, Georgia Piedmont megapolitan area.....	336
Figure 29. Two common urban spatial patterns at the megapolitan scale include the linear corridor and the galactic cluster .....	337
Figure 30. Edge density (ED) of urban landcover by MSA/CSA.....	338
Figure 31. Landscape shape index (LSI) of urban landcover by MSA/CSA.....	339
Figure 32. Largest patch index (LPI) of urban landcover by MSA/CSA.....	340
Figure 33. Area-weighted mean shape index (AWMSI) of urban landcover By MSA/CSA.....	341
Figure 34. Area-weighted mean patch fractal dimension (AWMPFD) of urban landcover by MSA/CSA .....	342

Figure 35. Contiguity (CONTIG) of urban landcover by MSA/CSA .....	343
Figure 36. Contagion (CONTAG) of urban landcover by MSA/CSA .....	344
Figure 37. Percentage of like adjacencies (PLADJ) index of urban landcover by MSA/CSA .....	345
Figure 38. Clumpiness (CLUMPY) of urban landcover by MSA/CSA .....	346
Figure 39. Getis-Ord $G_i^*$ hot-spot analysis for edge density (ED) .....	347
Figure 40. Getis-Ord $G_i^*$ hot-spot analysis for landscape shape index (LSI) .....	348
Figure 41. Getis-Ord $G_i^*$ hot-spot analysis for largest patch index (LPI).....	349
Figure 42. Getis-Ord $G_i^*$ hot-spot analysis for area-weighted mean shape index (AWMSI) .....	350
Figure 43. Getis-Ord $G_i^*$ hot-spot analysis for area-weighted mean patch fractal dimension (AWMPFD) .....	351
Figure 44. Getis-Ord $G_i^*$ hot-spot analysis for contiguity (CONTIG) .....	352
Figure 45. Getis-Ord $G_i^*$ hot-spot analysis for percentage of like adjacencies (PLADJ) index .....	353
Figure 46. Getis-Ord $G_i^*$ hot-spot analysis for clumpiness (CLUMPY) .....	354
Figure 47. Getis-Ord $G_i^*$ hot-spot analysis for contagion (CONTAG) .....	355
Figure 48. Largest patch index (LPI) among 86 metropolitan-scale areas within four U.S. regions.....	356
Figure 49. Landscape shape index (LSI) among 86 metropolitan-scale areas by U.S. region .....	357
Figure 50. Edge density (ED) among 86 metropolitan-scale areas within four U.S. regions .....	358
Figure 51. Area-weighted mean shape index (AWMSI) among 86 metropolitan-scale areas within four U.S. regions.....	359
Figure 52. Area-weighted mean patch fractal dimension (AWMPFD) among 86 metropolitan-scale areas within four U.S. regions.....	360

Figure 53.	Contiguity (CONTIG) among 86 metropolitan-scale areas within four U.S. regions .....	361
Figure 54.	Contagion (CONTAG) among 86 metropolitan-scale areas within four U.S. regions.....	362
Figure 55.	Percentage of like adjacencies (PLADJ) index among 86 metropolitan-scale areas within four U.S. regions .....	363
Figure 56.	Clumpiness (CLUMPY) among 86 metropolitan-scale areas within four U.S. regions .....	364
Figure 57.	Urban “continuity,” derived from spatial metrics calculated at the high urban threshold, by MSA/ CSA .....	365
Figure 58.	Urban “continuity,” derived from spatial metrics calculated at the low urban threshold, by MSA/ CSA .....	366
Figure 59.	Urban “shape complexity,” derived from spatial metrics calculated at the high urban threshold, by MSA/ CSA.....	367
Figure 60.	Urban “shape complexity,” derived from spatial metrics calculated at the low urban threshold, by MSA/ CSA.....	368
Figure 61.	Hot spot analysis using Getis-Ord $G_i^*$ for the urban form factor urban “continuity,” derived from spatial metrics calculated at the high urban threshold .....	369
Figure 62.	Hot spot analysis using Getis-Ord $G_i^*$ for the urban form factor urban “continuity,” derived from spatial metrics calculated at the low urban threshold.....	370
Figure 63.	Hot spot analysis using Getis-Ord $G_i^*$ for the urban form factor urban “shape complexity,” derived from spatial metrics calculated at the high urban threshold .....	371
Figure 64.	Hot spot analysis using Getis-Ord $G_i^*$ for the urban form factor urban “shape complexity,” derived from spatial metrics calculated at the low urban threshold.....	372
Figure 65.	Urban “continuity,” calculated at the high urban threshold, among 86 metropolitan-scale areas by U.S. region .....	373

Figure 66.	Urban “continuity,” calculated at the low urban threshold, among 86 metropolitan-scale areas by U.S. region .....	374
Figure 67.	Urban “shape complexity,” calculated at the high urban threshold, among 86 metropolitan-scale areas by U.S. region .....	375
Figure 68.	Urban “shape complexity,” calculated at the low urban threshold, among 86 metropolitan-scale areas by U.S. region .....	376
Figure 69.	The urban “continuity” and urban “shape complexity” of 86 MSAs and CSAs, calculated at the high urban threshold .....	377
Figure 70.	The urban “continuity” and urban “shape complexity” of 86 MSAs and CSAs, calculated at the low urban threshold .....	378
Figure 71.	Urban “continuity” and urban “shape complexity” of 19 megapolitan areas, calculated at the high urban threshold .....	379
Figure 72.	Urban “continuity” and urban “shape complexity” of 19 megapolitan areas, calculated at the low urban threshold.....	380
Figure 73.	Annual average 4 <sup>th</sup> maximum 8-hr concentration of ozone (O <sub>3</sub> ) from 1998 to 2002 throughout Los Angeles, CA .....	381
Figure 74.	Annual average 24-hr concentration of fine particulate matter (PM <sub>2.5</sub> ) from 1998 to 2002 throughout Los Angeles, CA.....	382
Figure 75.	Urban landcover, Los Angeles, CA.....	383
Figure 76.	Annual average 4 <sup>th</sup> maximum 8-hour concentration of ozone (O <sub>3</sub> ) from 1998 to 2002 in central California.....	384
Figure 77.	Annual average 24-hour concentration of fine particulate matter (PM <sub>2.5</sub> ) from 1998 to 2002 in central California.....	385
Figure 78.	Annual average 4 <sup>th</sup> maximum 8-hour concentration of ozone (O <sub>3</sub> ) from 1998 to 2002 in the Atlanta, GA area.....	386
Figure 79.	Annual average 4 <sup>th</sup> maximum 8-hour concentration of ozone (O <sub>3</sub> ) from 1998 to 2002 along the Northeast Megalopolis from Washington, D.C. to Boston, MA (“BosWash”) .....	387

Figure 80. Annual average 24-hour concentration of fine particulate matter (PM <sub>2.5</sub> ) from 1998 to 2002 along the Northeast Megalopolis from Washington, D.C. to Boston, MA (“BosWash”) .....	388
Figure 81. Location of the Southeast “Sprawl Belt” in relation to the “Rust Belt” and Northeast Megalopolis.....	389
Figure 82. Urban landcover, Portland, OR .....	390