DECONSTRUCTING DENSITY:

ASSESSING THE PER CAPITA INFLUENCE

ON VEGETATION AND IMPERVIOUS SURFACE AREA IN CORVALLIS, OREGON.

by

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Abstract

The density at which urban areas are developed has become a contentious issue, with advocates for compact cities in conflict with advocates for larger lots and suburban development. This research paper examines the associated impact of population density (grouped by residential zones) as measured by vegetation (Normalized Difference Vegetation Index) and impervious surface area (Iterative Self-Organizing Data Analysis Technique (ISODATA) unsupervised classification merged with City of Corvallis building data). This research was based on Quickbird imagery, City of Corvallis GIS spatial data, and 2000 Census population data. The findings of the research demonstrate that a clear difference between residential zones was observed based on vegetation and impervious surface area data. A regression analysis showed a reciprocal relationship between both NDVI impact and impervious surface area versus population density. This data suggest that with each doubling of population density the associated per person impact on NDVI is estimated to decrease 50.4% (+/- 1.5%). Likewise, with each doubling of population density, it is estimated that the associated amount of impervious surface area per person decreases 41% (+/- 3%). At a population density of 10 people/acre, over 90% of the impact on vegetation has occurred, whereas with impervious surface area, densities of 40 people/acre resulted in the same threshold of impact. These findings may be used to help in the planning of the Corvallis landscape in order to mitigate impacts on the urban ecosystem.

1. Introduction:

A trend in the past 15 years of urban land use planning has been to advocate for increased density development through zoning changes and new development guidelines. As with most issues surrounding land use, there are both strong proponents and opponents to this trend. Proponents argue that increasing density reduces dependence on the automobile, creates more cohesive communities, increases public health by increasing the likelihood of walking, and creates more compact cities that reduce fragmentation of the local landscape (Calthrope 1989, Eppli and Tu 2000). Opponents of increased density development argue that densely developed areas are less desirable to live in because of increased traffic congestion, less green space, more pollution, and less personal space (O'Toole 1996, Gordon and Richardson 1997). Interestingly, both sides make claims about the impact of density on the local ecosystem, but diverge on their conclusions based on the scale of impact. Pro-density advocates claim that the ecosystem on the regional scale as a whole is better off, whereas anti-density advocates point to the immediate local impacts of high population density areas.

The purpose of the research presented in this paper is to further explore the impact of population density by analyzing remote sensing imagery along with zoning and census data to identify the per capita influence at varying population densities in Corvallis, Oregon based on two environmental metrics: vegetation and impervious surfaces. The first question is whether or not it is possible to identify different levels of residential density zoning based on vegetation and impervious surfaces. Second, an analysis of the relationship between population density and each metric is investigated through the use of regression analysis. Third, a threshold analysis is conducted to identify at what densities the greatest per capita impact occurs in order to provide a tangible planning tool for future development considerations, and to provide guidance on how to plan around important natural features within the Corvallis urban growth boundary (UGB).

2.0 Background:

2.1 Population Density

The effect of human populations on urban ecosystems has been well studied and documented (Ehrlich and Holden 1971, Ehrlich 1990, O'Toole 1996, Gordon and Richardson 1997, Eppli and Tu 2000). The way residential, commercial, government and open spaces are built and clustered on the landscape has a direct relationship to the population density of the area. The dominant urban land use pattern of the last half-century has been to increase the size of residential lots coupled with a decrease in people per residential unit as family sizes have dropped. The result has been the rise of low-density development at the edges of urban areas (Gillham 2002). This pattern of land-use, known as 'sprawl' by its critics, has been defined as a land use that has the following characteristics: "low-density development that is disperse and uses a lot of land, geographic separation of essential services such as work, homes, school, and shopping; and the almost complete dependence on automobiles for travel" (Heimlich and Anderson 2003).

The trend toward low-density development has garnered strong opposition in the past 10-15 years, though earlier opposition began in the 1970s and has been gaining momentum in the past decade. This opposition to low-density development has fallen under the banner of many different movements such as smart growth, new urbanism, and neo-traditional design. Common to all these movements is a call for curbing sprawl by creating more compact cities, thereby increasing population densities. Many strategies have been proposed to increase density including developing urban growth boundaries, changing zoning laws to include mixed-use zoning thereby bringing residential areas nearer to basic services, and maximizing transportation options that move away from sole dependence on the automobile (Congress for the New Urbanism 2003). Oregon has been one of the leading states in encouraging these ideas through statewide enforcement of urban growth boundaries and incentives for dense development (Oregon Transportation and Growth Management 2002).

The result of these two trends (sprawl and smart growth) has led to a heated debate on how cities are planned and what density of development is preferable. While a clear connection between an increase in population and a decrease in ecosystem health has been demonstrated, the spatial extent of per capita impacts on the environment associated with population density are less clear from the literature. The concept of an "ecological footprint" was developed by Wackernagle and Rees (1996) in order to describe the spatial extent that a person, family, neighborhood or city has on the surrounding ecosystem. By quantifying the impact that each person has on the local environment, land use planners can begin to find answers to questions like what is the likely impact on vegetation or local streams of zoning an area for 9 residential units per acre versus 20 residential units per acre; or, how much does adding one person to a certain area increase the impact on the local ecosystem?

2.2. Zoning

Zoning provides an important scale of analysis due to the way urban landscapes evolve. Zoning became the preeminent land use planning tool in the 1920s through the efforts of Herbert Hoover, then Commerce Secretary of the U.S. (Russell 1996). The original intent of zoning was to standardize development in cities, and to keep undesirable land uses from being in close proximity to each other. As the key 1927 Supreme Court ruling put it, zoning will help to "keep the pigs out of the parlor" (Kelbaugh 2002). Such variables as maximum building height and density, extent of pervious surface, open space, and land use designations, are able to be restricted within each land use zone (Wilson et. al. 2003). As a result of zoning, urban land use developed into separate areas for work, homes and shopping (Kunstler 1996).

While some studies have shown the variations within urban landscapes in relation to several environmental processes including atmosphere/surface energy exchange (Grimmond & Oke 1995, Quattrochi & Ridd 1994), surface and subsurface hydrologic systems (Grimmond & Oke 1991, Hammer 1972), and micro to mesoscale weather and climate regimes (Changnon

1992, Oke 1987, Roth, Oke & Emergy 1989), few studies have explored the relationship between zoning and urban ecosystem performance (Wilson et. al. 2003).

2.3 Oregon Land Use Planning

In addition to placing urban land into zoning uses, Oregon has developed statewide planning goals that use urban growth boundaries as a land use planning tool. Oregon is known nationwide for its comprehensive land use guidelines pioneered in 1973 (Knaap & Nelson 1992). Through legislation, Oregon identified nineteen land use goals and guidelines that cover a broad range of planning goals from farmland protection to economic development to protecting natural open space and scenic areas (Knaap & Nelson 1992). While recent trends have been to move toward smart growth and development patterns that encourage mixed-use zoning and increased density within urban growth boundaries (Oregon Transportation and Growth Management 2002), counter currents to Oregon's land use regulations have gained strength as evidenced by the recent passage of Measure 37 which weakens the ability of land use planners to regulate the landscape. Measure 37 entitles private property landowners to receive just compensation when a land use regulation is enacted after the owner of the property took ownership if the regulation restricts the use of the property and reduces its fair market value. In lieu of compensation, the government responsible for the restriction may choose to "remove, modify or not apply" the regulation (Oregon Dept. of Land and Conservation 2005). Critics of Measure 37 fear that Oregon's heralded landscape of distinct urban and agricultural areas will be slowly degraded and turned into a sprawling landscape. While the impact of Measure 37 is too early to tell, what is clear is that land use issues in Oregon can stir up passionate debates.

2.4 Corvallis, Oregon Land Use Planning

The city of Corvallis, Oregon, the site of this research, is located in the Willamette Valley and has a population of 52,450 (City of Corvallis 2004). Corvallis has 42 different zoning categories ranging from residential to civic open space to commercial (see Fig. 1). Most of the

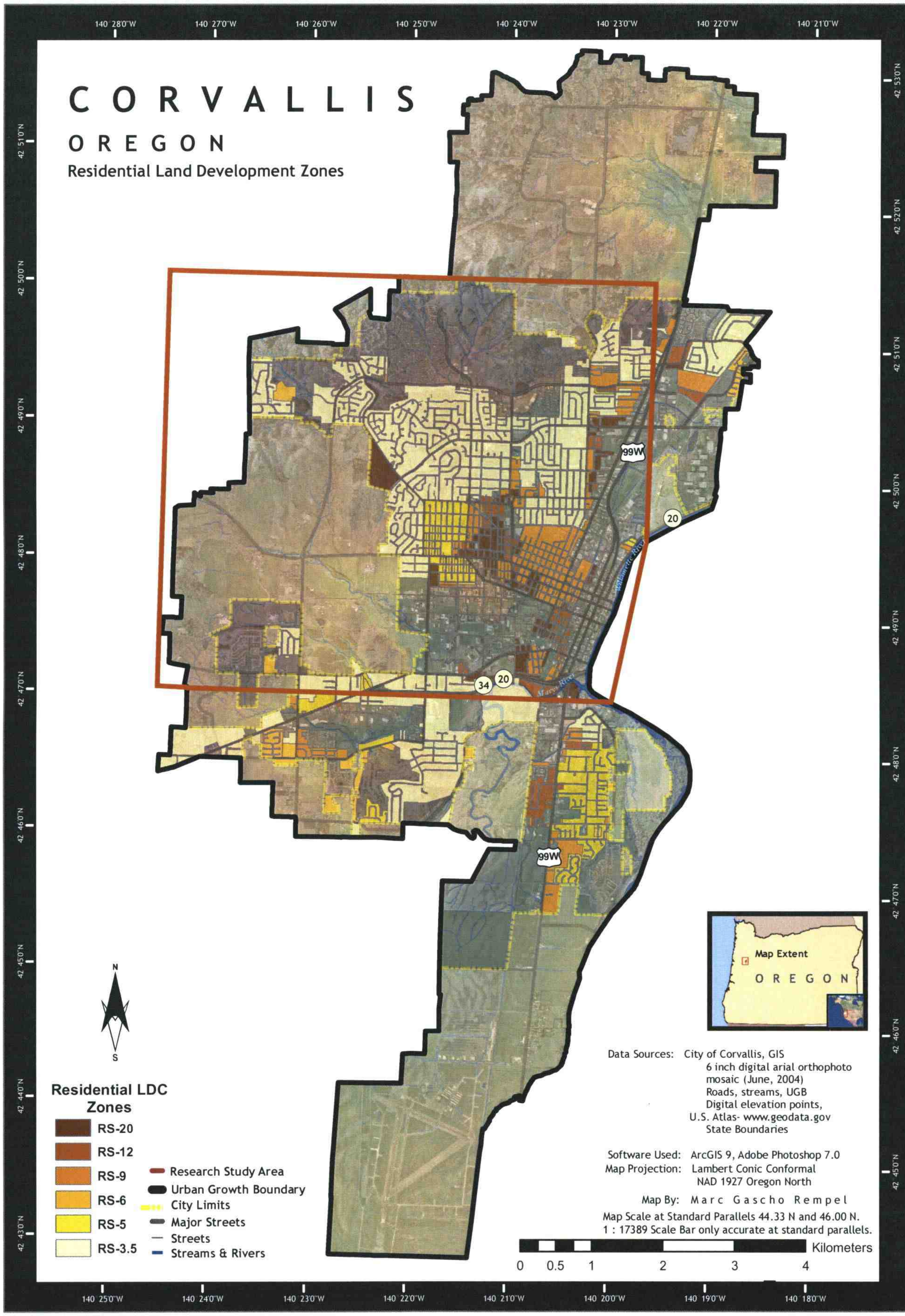


Fig. 1. Residential development code zones for Corvallis, Oregon.

topography of the city is relatively flat with the exception of several hills on the borders of the city.

Land use planning in Corvallis has mirrored the trends statewide, seeing a rise in suburban development in the last half of the past century, and more recently concerted efforts to curb sprawl by focusing on a compact city design (Gruzca 2001). In 1998, the City of Corvallis identified nodes of development (neighborhood centers) throughout the city. The intention of the nodes is to focus development in dense areas close to basic services (City of Corvallis Comprehensive Plan 2004).

In 2001, the City of Corvallis started a multi-year land use planning project, called the Corvallis Natural Features Project. This project identified important natural features within the Corvallis urban growth boundary, prioritized areas to be conserved, restored or developed, and created a rational, defensible plan for future land use decisions (Winter Brook Planning 2003). The Corvallis Natural Features Project illustrates the increasing importance of identifying, assessing, and protecting natural ecosystems within the local urban planning community, and the need for tools to assess the likely impact that development may have.

2.5 Remote Sensing Satellite Imagery

Remote sensing data provide the ability to assess land, water, and atmospheric conditions from above the earth's surface. In the context of urban planning, remote sensing imagery has relied primarily on aerial photos, and has been used to develop GIS databases for basic planning elements such as transportation networks, the cadastre, buildings and pavement, land use, and utility infrastructures (Wilson et. al. 2003). Given that urban landscapes are by nature complex and highly heterogeneous, the resolution of remotely sensed data from satellites has been slow to match the spatial detail in the urban landscape. However, with the development of new satellite sensors and the increase in private sources of data collection, the spatial resolution of satellite imagery is becoming increasingly fine (Mesev 2003).

With higher spatial resolution imagery, there is an opportunity for using remote sensing data in urban areas, where just ten years ago this may not have been possible.

2.5.1 Vegetation

The extent and health of vegetative cover is one metric that can provide a synoptic comparison of land use zones from remote sensing data. Vegetation plays an important role in the health of urban ecosystems (Grimm et al. 1998). When land is converted from rural land-cover types such as soil, water, and vegetation and is replaced with common urban land-cover materials such as asphalt, concrete and metal, significant environmental implications result such as reduced evapotranspiration, increased surface runoff, increased storage and transfer of heat, and reduction in air and water quality (Wilson et.al. 2003). In addition, urban vegetation adds aesthetic value and increased psychological well-being to urban dwellers (McPherson et al. 1997).

The measurement and mapping of vegetation density and health has a history of assessment through remotely sensed data (Boone et al. 2000, Chen 1998). Satellite sensors that receive surface reflectance data in the visible and infrared wavelengths provide analysts with the ability to determine the amount of light that is absorbed and reflected by plants. Different indices have been developed to approximate vegetation health and coverage on the landscape (Jensen 2000). The most widespread index is the Normalized Difference Vegetation Index (NDVI) that uses mathematical calculations on the near infrared and red bands. The formula to calculate NDVI is:

$$NDVI = NIR - red / (NIR + red), \qquad (1)$$

where, 'NIR' is the near infrared band that is responsive to near infrared wavelengths (760 to 900-nm) , and 'red' refers to the sensor band that is responsive to red wavelengths (630 to 690-nm) . Calculating the ratio of the visible and near-infrared light reflected back to the sensor yields values between minus one (-1) to and one (+1). An NDVI value of zero means no green vegetation, whereas a value close to +1 (0.8 - 0.9) indicates the highest possible density of green leaves. Vegetation values typically range between 0.1 and 0.8 (Tucker 1979).

2.5.2. Impervious Surfaces

Impervious surfaces have been a recognized indicator of urban growth and habitat health for many years (Brabec et. al. 2000). As communities become more urbanized, land that was once forest, wetland, farmland, or open space is converted to roads, parking lots, and rooftops (Leopold 1968, Carter 1961, as cited in Brabec et. al. 2000). With fewer surfaces to absorb rainfall, individual storm events transport more sediment and pollution directly to streams without being filtered through the landscape (Marisawa and LaFlure 1979, Arnold et al. 1982, Bannerman et al. 1993, as cited in Brabec et. al. 2000).

Numerous studies have focused on the threshold or continuum of degradation associated with impervious surfaces (Arnold and Gibbons 1996, Booth and Jackson 1997, May et al. 1997). Arnold and Gibbons (1996) broke the impact down into rough categories of “protected” (less than 10% impervious surface), “impacted” (10-30% impervious surface), and “degraded” (over 30% impervious surfaces). Another study by the 1000 Friends of Washington (2001), found that stream health begins to deteriorate when impervious surfaces cover from 10 to 15 percent of the landscape, or about the density associated with one house per acre. When 25 percent or more of a watershed is covered with impervious surfaces, the ability of streams to support aquatic life becomes very low (1000 Friends of Washington 2001).

Remote sensing data have been used to assess the extent level of impervious surfaces and to gauge the relative health of stream habitat (Goetz et. al. 2003). In the Goetz et. al. study (2003), IKONOS imagery along with planimetric data from city and county records were used to identify the extent of impervious surfaces neighboring streams. Both supervised (maximum likelihood classification) and unsupervised classifications (Iterative Self-Organizing Data Analysis Technique (ISODATA)) were used to classify of the IKONOS image. Both classifications resulted in an accuracy of 75-85%. The researchers coupled this classification with planimetric maps of buildings and roads to increase the accuracy of the classification. From these data, the researchers inferred the relative impact of impervious surfaces on stream health.

3.0. Significance of Research

In light of the contentious land use debate over the degree of density that is desirable for urban areas, an objective analysis of the relative per person impact on vegetation and impervious surfaces would provide a valuable tool for urban planners in making critical decisions on the amount of density to encourage.

Past studies have looked at components of this research for different areas of the country. Ong (2002) presented a green plot ratio that identified leaf area index as a way to assess ecological health. Wilson et al. (2003) did a similar study in Indianapolis using remote sensing data and a GIS to assess the impact of zoning on ecosystem health by analyzing vegetation health and surface temperature (Wilson 2003). Goetz et. al (2003) demonstrated that remote sensing imagery can be used to assess the amount of impervious surfaces and their relative impact on ecosystem stream health.

After a review of the literature, it is clear that a better understanding of the per person impact on vegetation and impervious surface area at varying population densities would be a useful analysis for the City of Corvallis.

4.0 Research Methods

4.1 Data

Data for this research were collected from the City of Corvallis, the U.S. Census Bureau, and Digital Globe Inc. Shapefiles of zoning polygons (land development code) and building polygons were acquired from the City of Corvallis. Population block data were also received from the City of Corvallis, with the data originally collected by the U.S. Census 2000. The

Quickbird remote sensing satellite image was donated by Digital Globe Inc. and covers the downtown and northwest areas of Corvallis (NE corner 123° 20' 14.48" W, 44°36'20.75 N, SW corner 123°14'51.95 W, 44°33'15.85"N). The Quickbird image contains four spectral bands (blue, green, red and NIR) (see Fig. 2) and was taken on June 11, 2001, at a spatial resolution of 2.44 m x 2.44 m and 11-bit digitization (up to 2048 levels of gray scale). The image was received with geometric and atmospheric corrections already performed.

Figure 2. Quickbird Basic Imagery Spectral Characteristics

Spectral Characteristics	Blue	Green	Red	Near IR
	450 to 520-nm	520 to 600-nm	630 to 690-nm	760 to 900-nm

4.2 Research Design

The research was designed to test the hypothesis that low population density development is associated with a higher per capita impact on the local landscape as measured by vegetation (NDVI) and impervious surface area. The following research questions were examined to test this hypothesis:

- Is there a statistically significant difference in the per person impact on vegetation and impervious surface area between residential density land development code zones?
- What is the relationship between population density and vegetation and impervious surface area?
- Is there a population density threshold where adding more people has a negligible impact on vegetation and impervious surface area?

The research was based on population census blocks as the scale of analysis. The City of Corvallis has six categories of residential land use zoning specified by the amount of residential units per acre. These categories are: RS 3.5, RS 5, RS 6, RS 9, RS 12, and RS 20. For this study, all the residential land use zones were initially selected to be included in the study. After overlaying the land development code (LDC) zones on the population block zones, only those LDC zones that had population block data for one LDC zone were included in the sample. This filtering was done to ensure that population data were connected directly to one LDC zone and not split between two or more zones with an unknown population distribution. The result of this filtering was that all RS 6 zones were removed from the sample, as there were no "pure" polygons not sharing another LDC zone for RS 6 in the study area. In addition to removing any double association of population blocks to zones, all LDC zones that remained with zero population were removed to maintain the integrity of further analysis (not dividing by zero). This had the effect of removing parks from all of the RS LDC zones. The resulting sample area included a total of 372 polygons with 142 polygons for RS 3.5, 67 polygons for RS 5, 77 polygons for RS 9, 32 polygons for RS 12, and 55 polygons for RS 20 (see Fig. 10).

4.3 Vegetation Impact

Vegetation data was mapped and assessed using NDVI values from the Quickbird image (see Fig. 3). The NDVI image was imported into ArcGIS 9.0. Zonal statistics of the mean, sum, standard deviation, count, minimum and maximum of the NDVI values were computed for each polygon. Since the question of interest was the impact on vegetation, the mean scores for each polygon were subtracted from 1 in order to reverse the scale. Normal NDVI values range from –1 to 1 with higher numbers representing more vegetation. By reversing the scale, all NDVI values reflect their distance from 1 (the maximum value) thereby providing information on the relative lack of vegetation. This could also have been achieved by picking an "ideal" control point (e.g., park), but as long as all the values are subtracted from the same value, the result would be the same.

Once the mean of all '1 minus NDVI' values were computed for all the polygons, the impact NDVI value was then multiplied by the count (number of pixels) in each polygon in order to adjust for the varying sizes of polygons. The product of the impact NDVI value and the count represents the total impact NDVI for each polygon. This value was then divided by the population values associated with each polygon to arrive at the per person impact on NDVI.

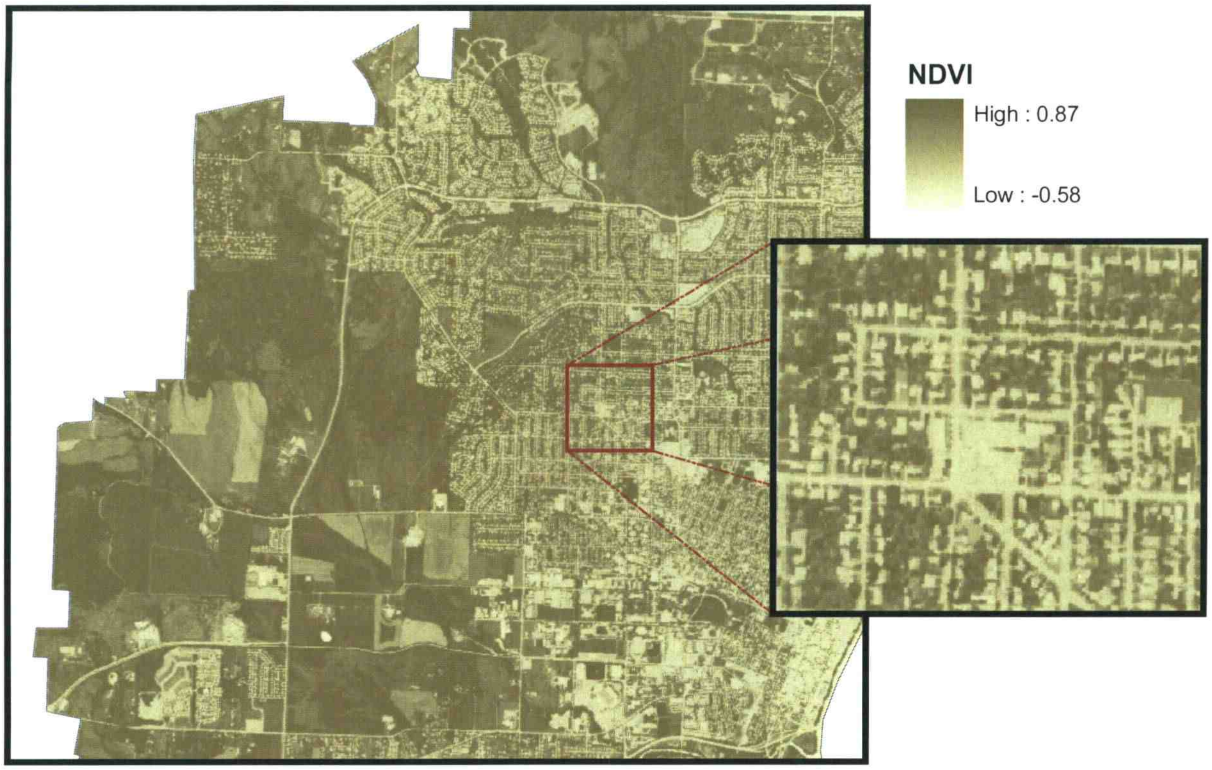


Fig. 3. NDVI values for the study area. This is a false color image where dark green indicates high NDVI values with greater vegetation density and light green indicate low vegetation density areas.

3.4 Impervious Surface Area

To determine the per person relationship on impervious surface area, a City of Corvallis building polygon layer was combined with an unsupervised ISODATA classification performed in ENVI 4.0 (Research Systems Inc.) on the Quickbird image. The Corvallis building polygon shapefile was created in 1999 and contains the footprint of most of the buildings in the city. Since this shapefile was somewhat dated and did not include sidewalks, driveways and roads, an unsupervised ISODATA classification was also performed to help increase the accuracy of the findings. An ISODATA unsupervised classification is a standard classification procedure that is useful in highly heterogeneous areas. The ISODATA algorithm is an unsupervised classification of the image that uses numerical operations to search for natural groupings of spectral properties in multi-spectral feature space (Jensen 2005). The ISODATA classification algorithm is an analyst-specified iterative process that merges clusters if their separation distance in multi-spectral feature space is below a user defined threshold (Schownegerdt 1999, as cited in Jensen 2005). For this classification, 10 iterations were chosen with a change threshold of 5%, which resulted in 10 classes. The 10 classes were then merged into two classes, impervious or pervious, for the final classification (see Fig. 4). A supervised maximum likelihood classification was also performed, but resulted in a less accurate classification.

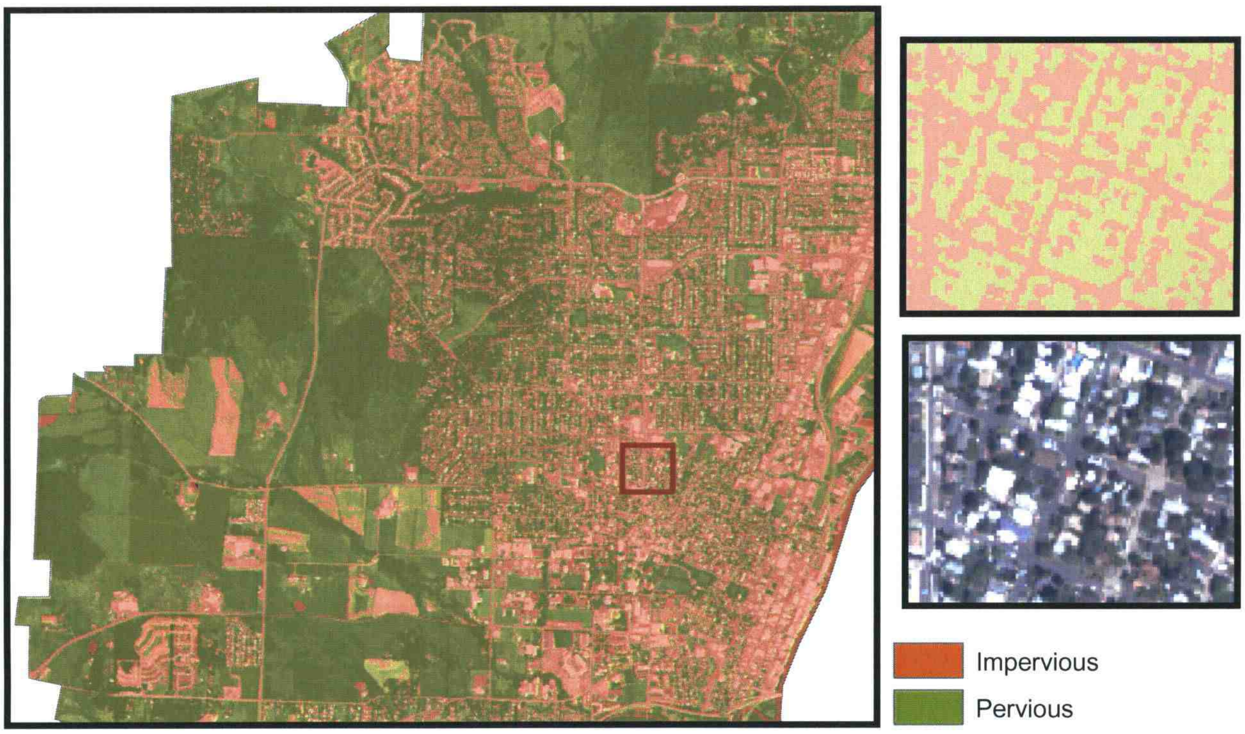


Fig. 4. Impervious surfaces. ISODATA unsupervised classification overlaid on Quickbird image. The top inset is the merged classification; the bottom inset is the Quickbird image of the same area.

The ISODATA classification and the building shapefile were then merged into one shapefile. A polygon-in-polygon zonal analysis was performed to obtain impervious area data for each residential zone. The area of impervious surfaces was then divided by the number of people in each population block to arrive at the amount of impervious surface area per person.

5.0 Results

5.1 Difference between zones

An initial analysis of the data was performed by looking at the mean values for each metric for each residential land development code (LDC) zone (see Fig. 5 & 6). These graphs show a general decline in impact as residential LDC zones increase in unit density.

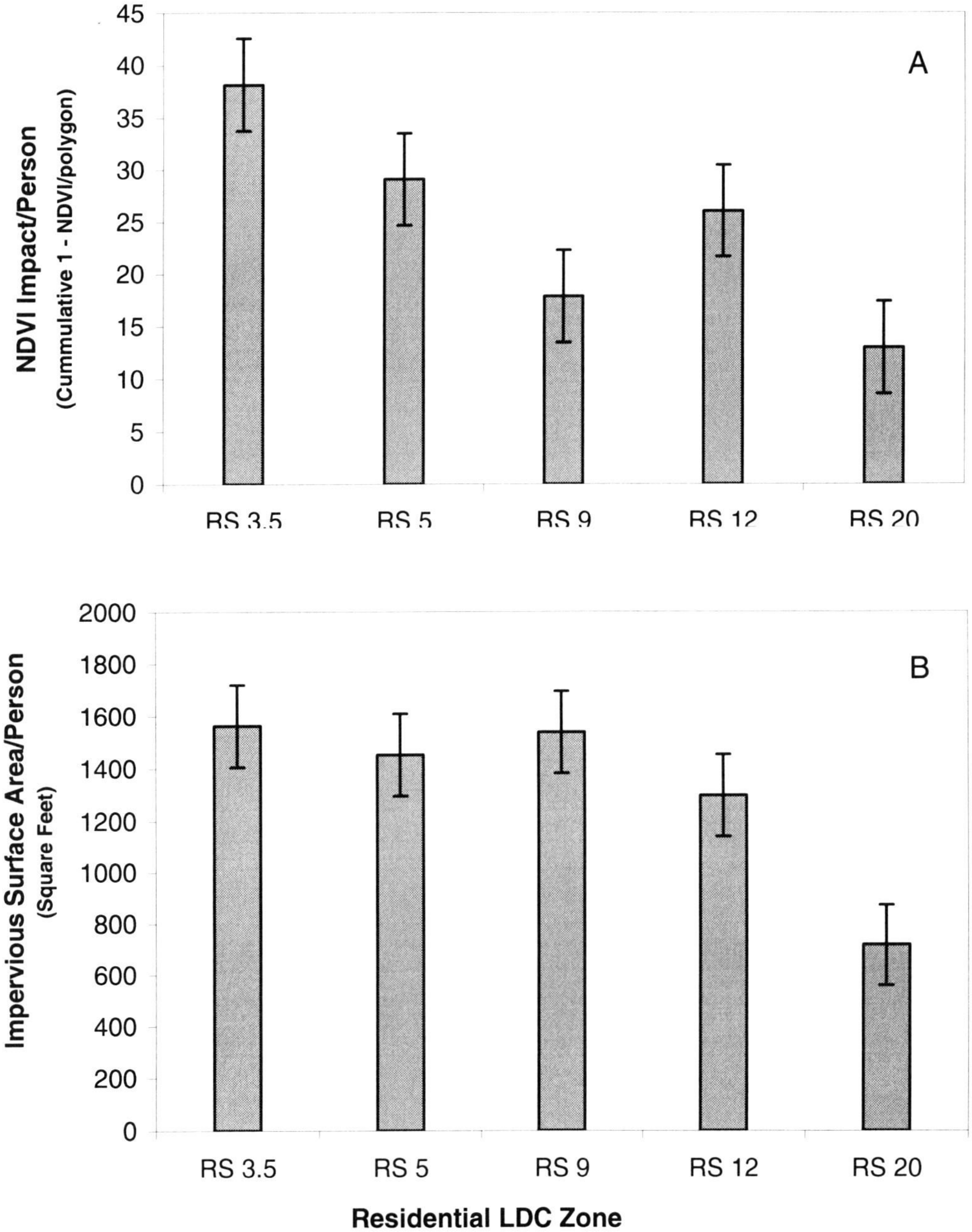


Fig. 5. A) Mean NDVI impact values for each residential zoning area. B) Mean impervious surface area per person for each residential zoning area.

Residential Zone	Pop Density	Impact on NDVI/person	% Impervious Surface	Impervious surface area/person
3.5	12.36	38.16	36.61	1563.29
5	15.00	29.10	40.61	1452.23
9	31.87	17.84	54.46	1538.75
12	27.32	26.01	59.33	1296.56
20	31.17	12.93	64.17	714.82

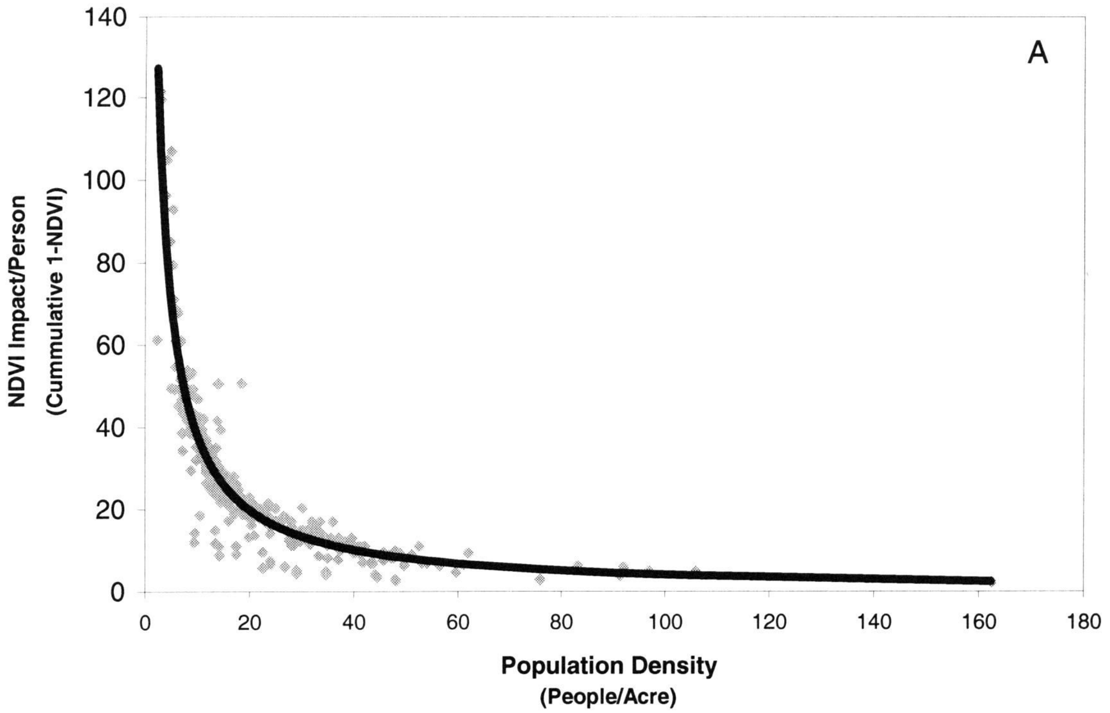
Fig 6. Table of summary statistics for each residential land use zone.

A Kruskal-Wallis Nonparametric Analysis of Variance test was performed on the NDVI and impervious surface data from each zone to see if the variation in the data could be explained by random chance alone, or if there was evidence of significant difference between zones that random chance could not explain. The Kruskal-Wallis test was chosen due to the data having unequal standard deviations, uneven data counts, and the presence of several outliers. The Kruskal-Wallis test replaces all observation values with their ranks in a single combined sample and then applies a one-way analysis of variance F-test on the rank-transformed data (Ramsey & Shafer, 2002).

The result of the Kruskal-Wallis test on both the per person impact on NDVI and the per person square feet of impervious surface area data showed that there is overwhelming evidence to reject the null hypothesis that there is no significant difference between group means, and to accept the alternative hypothesis that the NDVI impact and impervious surface area mean values are significantly different between residential zones (p-values, 1.59E-38 (NDVI), and 2.93E-19 (Impervious surfaces)).

5.2 Relationship between Population Density and Metrics

In order to directly address the hypothesis that high density residential areas have a smaller impact per person on the local landscape as measured by NDVI and impervious surfaces, an exploration of the following two scatter-plots showed some clear relationships that were tested further through a regression analysis (see Fig. 7).



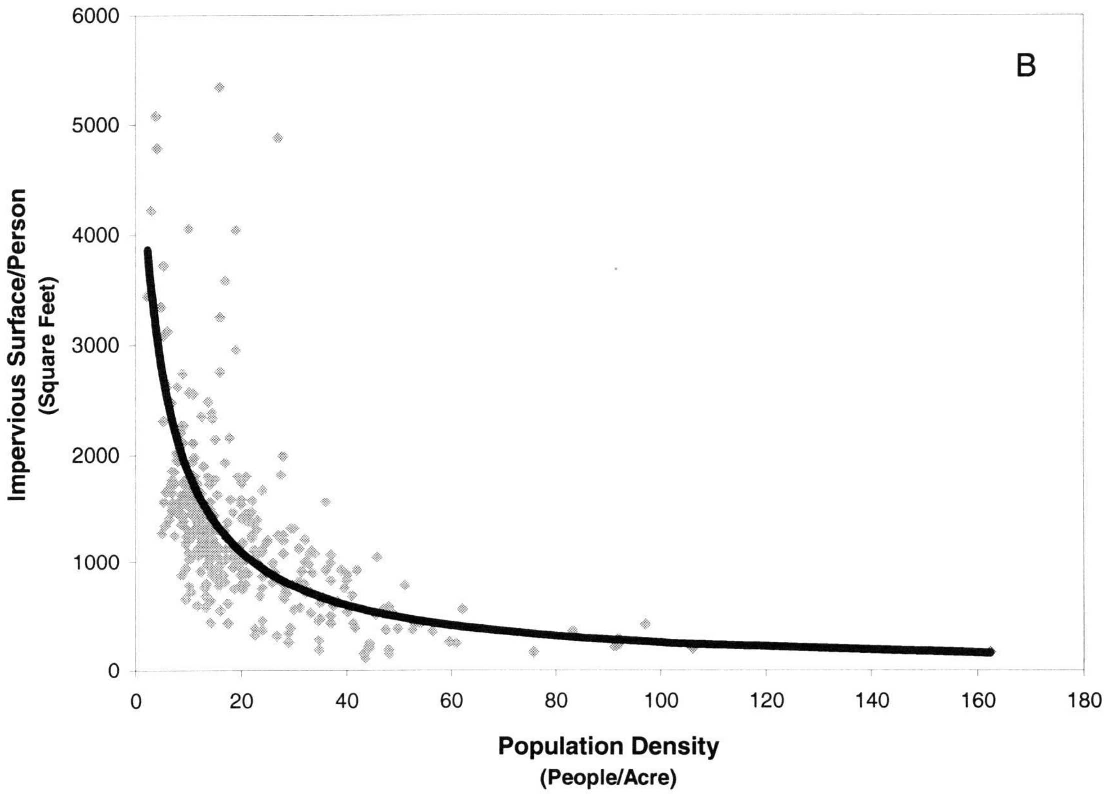


Fig. 7. (A) NDVI impact/person vs. population density (B) Impervious surface area/ person vs. population density.

Fig. 7 (A) shows a clear reciprocal or inverse relationship of population density to vegetation impact per person. As population density increases, vegetative impact decreases. Fig 7. (B) also demonstrates this relationship though to a lesser extent with impervious surface area per person and population density. This relationship matches a simple reciprocal or Shinozaka and Kira (1956) model that can be expressed:

$$f(x) = 1/(\beta_1 + \beta_2\ x),$$

Where, the reciprocal of β_1 can be interpreted generally as the value of the per person impact on NDVI at very low population densities, parameter β_2 is related to the value NDVI at the highest observed population density, and X refers to the value of population density, since $x*y$ approaches $1/\beta_2$ at as population density approaches infinity (Ratkowsky 1983, Umble 2005).

Both scatter plots indicated that the log transformation of each axis could provide further meaningful analysis. Fig 8 (A) & (B) show the log transformed axis and the resulting linear relationships.

Due to the linear trend in the logarithmic plots, a linear regression analysis was performed with vegetation impact per person and impervious surface area data as the dependent variables and population density as the independent variable in each analysis. An R^2 value of 0.83 was obtained for the vegetation impact on population density relationship, and an R^2 value of 0.54 for the impervious surface area per person on population density relationship. From these results, the data suggest that 83% of the variability in the vegetation impact per person data can be attributed to the linear model of $y = -0.9807x + 2.5446$, where –0.9807 is the slope value and 2.5446 is the intercept value. Likewise, for the log impervious surface area per person vs. log population density data, 54% of the variability in the data can be attributed to the linear model of $y = -0.7446x + 3.9593$, where -0.7446 is the slope and 3.9593 is the intercept.

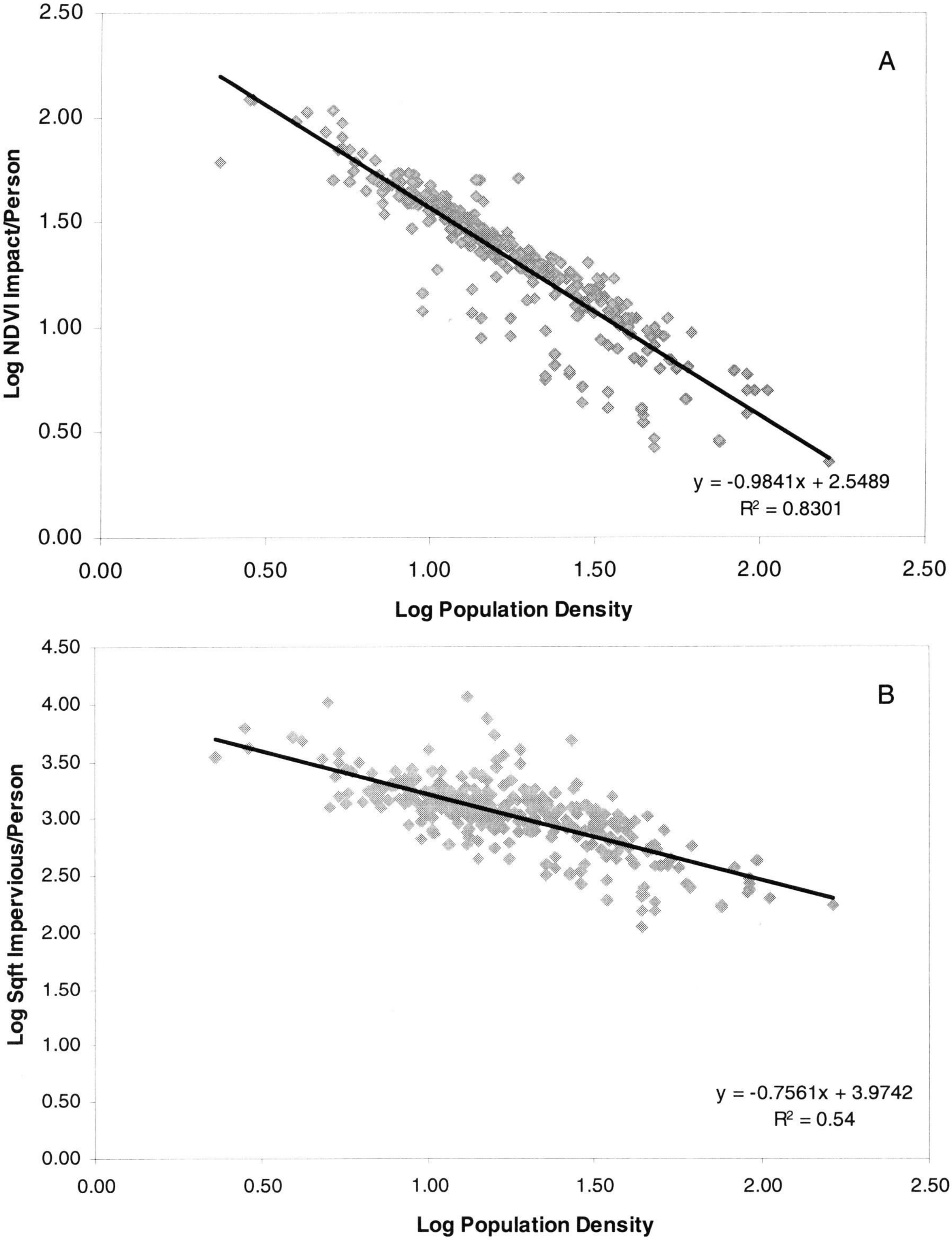


Fig. 8. (A) Log-log transformation of NDVI impact/person vs. population density. (B) Log-log transformation of impervious surface area per person vs. population density.

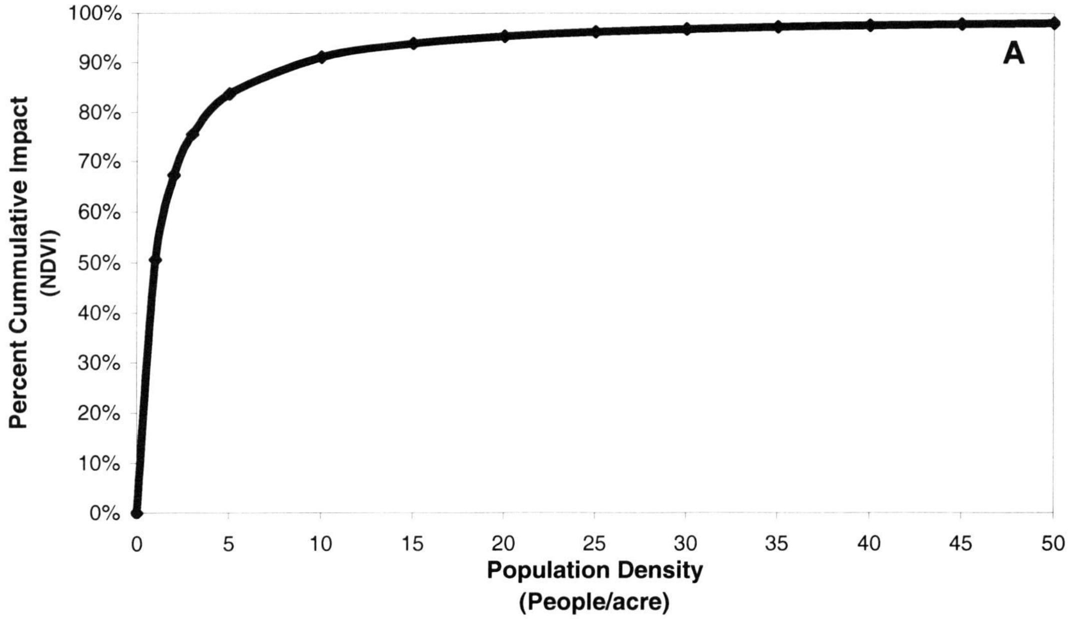
To check for the independence of the data, the residuals of each linear model were analyzed in a semi-variogram to look for signs of spatial correlation. If the data were found to be spatially correlated, the data values could have been predicted based on their spatial arrangement, thereby negating the independence of the data (Umble 2005). After an exploration of the semi-variograms, no clear signs of spatial correlation were found.

Interpreting the linear relationship of the log-log data results in a multiplicative relationship where with each doubling of the population density the associated per person impact on NDVI is estimated to decrease 50.4% (+/- 1.5%). Likewise, with each doubling of population density, it is estimated that the associated amount of impervious surface area per person decreases 41% (+/- 3%).

5.3 Density Thresholds

To investigate whether or not a density threshold exists, further examination of the nonlinear reciprocal model was used to identify where adding one more person to an area (increasing density) is associated with a negligible impact on the selected metric, or conversely where taking one person out of an area is associated with a large increase in impact. By computing the change in impact (NDVI impact/person or impervious surface area/person) for each 5 person/acre increase, and by computing the percent of cumulative impact up to that population density, a graph of the relative impact of density was made (see Fig. 9). For the NDVI impact/person (see Fig. 9A) a clear threshold emerges at population densities of 10 people/acre. Ninety-one percent of the associated total impact on NDVI occurred at populations of 10 people/acre and under.

The same analysis of impervious surface area per person results in a less dramatic threshold. Not until population densities approach 40 people/acre does 90% of the associated impervious surface area per person impact occur (see Fig 9B).



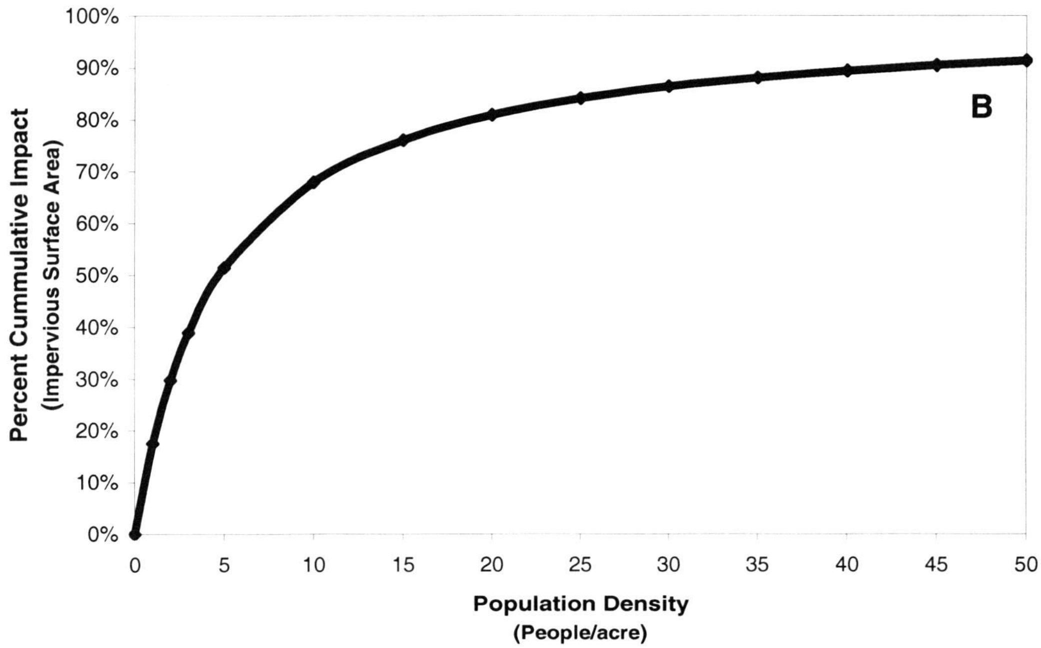


Fig. 9 (A) Percent cumulative NDVI impact vs. population density. (B) Percent cumulative impervious surface area impact vs population density.

The following maps (Fig. 10) illustrate the relative per person impact by each polygon with an interval scale. It becomes clear that the lighter areas (less impact/person) are found generally in the center of the city, and as one moves out of the center of the city the impact increases with lower population densities.

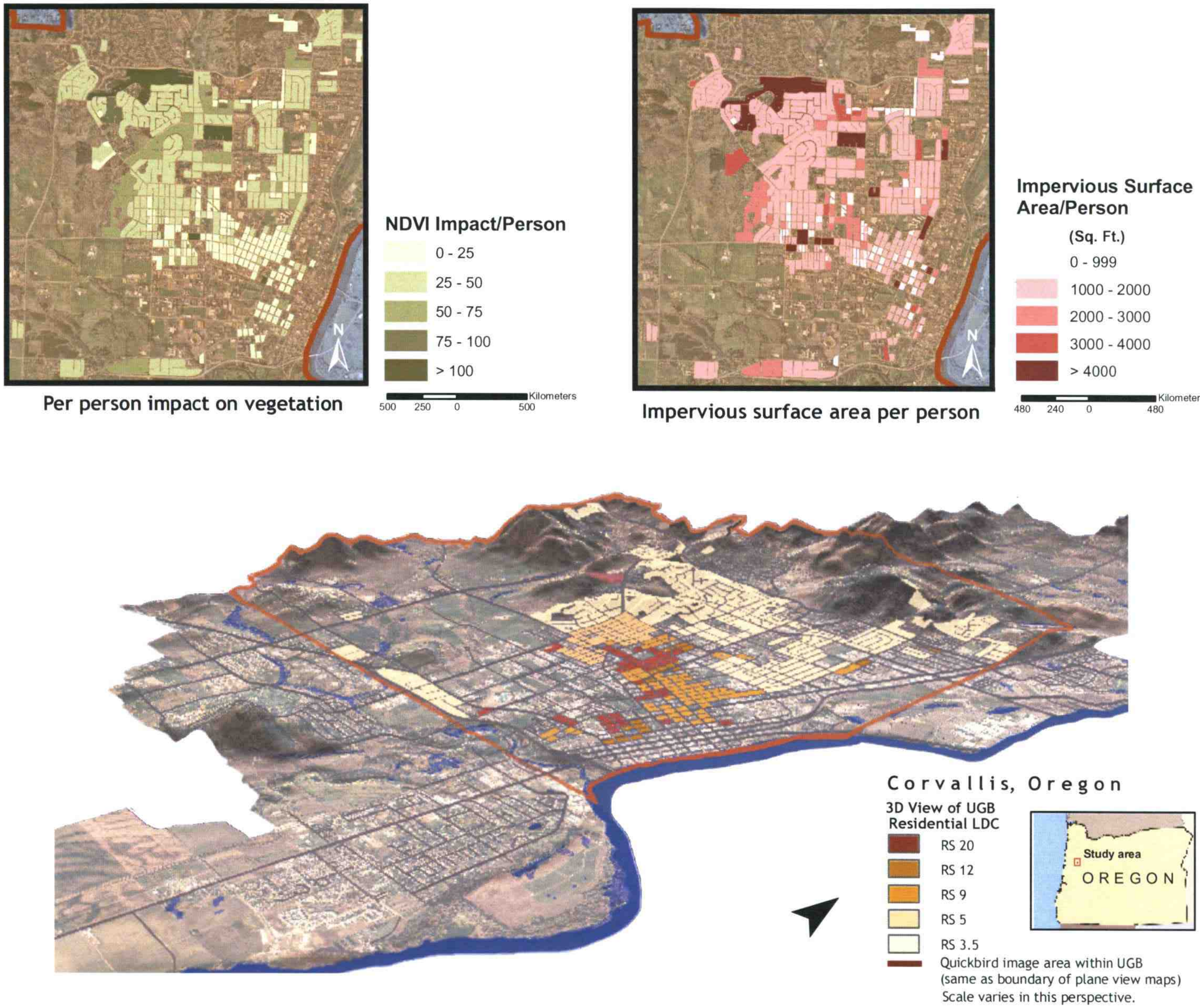


Fig. 10 Maps of the per person NDVI impact and impervious surface area by polygon. 3D perspective view of study area with residential zones used for study.

4.0 Discussion

The results of this research support the hypothesis that lower population density residential areas are associated with a greater per person impact on the local landscape, as measured by vegetation and impervious surface area. From an urban land use perspective, assuming that the population of the city of Corvallis will continue to increase in its city limits and urban growth boundary, the data suggest that efforts to increase density in new and redeveloped areas may help mitigate additional impacts on overall vegetation and the area of impervious surfaces.

It is also worth noting that the relationship between population density and the impact on vegetation and impervious surface area is not linear. There is not a one-to-one relationship where one unit increase of population density is equal to one unit increase/decrease in either metric, rather there is a reciprocal, multiplicative relationship. As population density increases, there is a multiplicative decrease in either metric. This suggests the need for a nuanced understanding of the relative impact associated with increased population density.

The threshold analysis provides a useful gauge of the associated impact that population density has on vegetation and impervious surfaces. If the choice is between zoning an area for population densities of 5 or 15 people/acre, versus zoning an area for population densities of 15 or 30 people/acre, the 5 versus 15 people/acre choice may have the greater impact.

While this research suggests associated impacts related to population density, additional research is needed to further test these findings. Some sources of error that may have affected the results include the viability of the census data (some population data values seemed highly unrealistic based on an analysis of the area covered [note: these highly suspect polygons were removed from the analysis but bring into question the overall reliability of the population numbers]). In addition, the polygons associated with the census data did not initially overlay correctly on the land-use data, requiring substantial editing to overlay the two datasets cleanly.

While the spatial resolution of the remote sensing imagery was relatively fine at 2.4 m x 2.4 m, some additional error in the classification of impervious surfaces was still present. Sidewalks are rarely more than 2.4 meters wide, and depending on their proximity to roads may or may not have been adequately included. Alternate image classification procedures based on fuzzy classification or object-oriented classification may provide increased accuracy to the classification for impervious surface area. The City of Corvallis GIS department is expecting to receive a data set of the impervious surface area from the most recent orthophoto set (2004). This data set, based on the six-inch resolution aerial photos, would drastically improve the accuracy of the classification. Unfortunately, this file was not yet ready for this research.

This study of Corvallis demonstrates the potential use of high spatial resolution satellite imagery and a GIS to assist in urban land use decisions. Further work that expands the metrics of the landscape to include such variables as surface temperature and animal populations would further help assess the per capita impact associated with development. Additional examination of the degree to which the age of development can be considered a predictive variable of the associated impact of development would be beneficial since older residential areas generally have older trees and more vegetation. However, they also have more impervious surface area due to smaller lot sizes.

6.0. Conclusion

As the debate continues on how best to plan urban/rural areas, objective measures of the associated impact of various development patterns will help to guide decision makers to best plan for growth and the natural landscape. By analyzing density on a per capita basis, the debate shifts to what impact each individual may be associated with as opposed to the generalized impact of development. This approach helps to bridge the opposing views on density development by moving the discussion to a pragmatic discussion of what impacts may be associated with added population growth at varying densities. Policy makers and planners can then decide what their local landscape should look like depending on community values such as costs, transportation, and aesthetics.

References

Arnfield A. J. and C. S. B. Grimmond. 1998. An urban canyon energy budget model and its application to urban storage heat flux modeling. Energy and Buildings. 27 (1): 61-68.

Arnold, C. I. Jr., and C. J Gibbons. 1996. Impervious surface coverage: Emergence of a key environmental factor. Journal of the American Planning Association. 62, 2:243-58.

Barr, S., & M. Barnsley, 2000. Reducing structural clutter in land cover classifications of high spatial resolution remotely-sensed images for urban land use mapping. Computers and Geosciences. 26: 433-449.

Boone, R. B., K. A. Galvin, et al. 2000. Generalizing El Nino effects upon Maasai livestock using hierarchical clusters of vegetation patterns. Photogrammetric Engineering & Remote Sensing 66(6): 737-744.

Booth, D. B., and C. R. Jackson. 1997. Urbanization of aquatic systems: Degreation thresholds, stormwater detection and the limits of mitigation. Journal of the American Water Resources Association. 33,5:1077-90.

Brabec, E., S. Schulte, P. L. Richards. 2002. Impervious Surfaces and Water Quality: A Review of Current Literature and Its Implications for Watershed Planning. Journal of Planning Literature. 16(4): 499-514.

Chen, D. and W. Brutsaert. 1998. Satellite-sensed distribution and spatial patterns of vegetation parameters over a tallgrass prairie. Journal of the Atmospheric Sciences 55(7): 1225-1238.

Changnon, S. A. 1992. Inadvertent weather modification in urban areas: Lessons for global climate change. Bulletin of the American Meteorological Society. 73: 619-627.

City of Corvallis, 2004. FAQ and information about Natural Features Inventory. http://www.ci.corvallis.or.us/index.php?option=content&task=view&id=289&Itemid=241 Accessed 5/5/05.

Congress for the New Urbanism, 2003 Charter[On-line]. Available: http://cnu.org/aboutcnu/index.cfm?formaction=charter&CFID=9770249&CFTOKEN=60700837 Accessed 5/5/05.

Ehrlich, Paul R. and Ann H. Ehrlich. 1990. The Population Explosion. New York: Simon and Schuster.

Ehrlich, Paul R., and John P. Holdren. 1971. "Impact of Population Growth." Science 171: 1212-17.

Eppli, M. J. and C. C. Tu 2000. Valuing the New Urbanism: The impact of the New Urbanism on prices of single-family homes. Urban Land Institute: Washington, D.C.

Gillham, O. 2002. The Limitless City: A Primer on the Urban Sprawl Debate. Washington, D.C.: Island Press.

Goetz, S. J., R. K. Wright, A. J. Smith, E. Zinecker, E. Schaub. 2003. IKONOS imagery for resource management: Tree cover, impervious surfaces, and riparian buffer analyses in the mid-Atlantic region. Remote Sensing of Environment, 88: 195-208.

Gordan, P. & Richardson, H. 1998. Are compact cities a desirable planning goal? Journal of the American Planning Association, 63(1): 95-106.

Grimm, N. B., J. M. Grove, S. T. A. Pickett, and C. L. Redman. 2000. Integrated Approaches to Long-Term Studies of Urban Ecological Systems. BioScience. 50 (7): 571-584.

Grimmond, C. S. B., and T. R. Oke. 1991. An evapotranspiration-interception model for urban areas. Water Resources Research. 27: 1739-1755.

____. 1995. Comparison of heat fluxes from summertime observations in the suburbs of four North American cities. Journal of Applied Meteorology. 34: 873-889.

Gruzca, A. 2001. Residential Development and Resulting Landscape Patterns in Corvallis, Oregon. Unpublished, Term paper for GEO 422. Oregon State University.

Hammer, T. R. 1972. Stream channel enlargement due to urbanization. Water Resources Research, 8: 1530-1540.

Heimlich, R. E. and W. D. Anderson, 2003. Development at the Urban Fringe and Beyond / AER-803, Economic Research Service/ USDA.

Kelbaugh, D. 2002. Repairing the American metropolis. University of Washington Press: Seattle.

Knapp, G. and A. C. Nelson. 1993. The Regulated Landscape: Lessons on State Land Use Planning from Oregon. Lincoln Institute of Land Policy: Cambridge, MA.

Kunstler, J.H. 1996. Home from nowhere: Remaking our everyday world for the twenty-first century. Simon & Schuster: New York, N.Y.

May, C. W., R. R. Horner, J. R. Karr, B. W. Mar, and E. B. Welch. 1997. Effects of urbanization on small streams in the Puget Sound lowland ecoregion. Watershed Protection Techniques, 2:(4)483-94.

McPherson, E. G., D. Nowak, G. Hesler, S. Grimond, C. Souch, R. Grant, R. Rowntree, 1997. Quantifying urban forest structure, function, and value: The Chicago Urban Forest Climate Project. Urban Ecosystems. 1: 49-61.

Mesev, V. 2003. Remotely Sensed Cities. London, England: Taylor & Francis.

Oke, T. R. 1987. Boundary Layer Climates. New York: Methuen Press. 435 pp.

Ong, B. L. 2003. Green plot ratio: an ecological measure for architecture and urban planning. Landscape and Urban Planning. 63: 197-211.

Oregon Department of Land and Conservation. Measure 37 Information. http://www.oregon.gov/LCD/measure37.shtml. Accessed 5/5/05.

Quattrochi, D. A., and M. K. Ridd, 1994. Measurement and analysis of thermal energy responses from discrete urban surfaces using remote sensing data. International Journal of Remote Sensing. 15: 1991-2022.

Ratkowsky, D. A., 1983. Nonlinear regression modeling: a unified practical approach. M. Dekker: New York.

Roth, M., T. R. Oke, and W. J. Emery. 1989. Satellite-derived urban heat islands from three coastal cities and the utilization of such data in urban climatology. International Journal of Remote Sensing. 10: 1699-1720.

Russell, J. 1996. The Need for New Models of Rural Zoning. Zoning News. June: 1-7.

Shinozaki, K. and T. Kira. 1956. Intraspecific competition among higher plants: VII. Logistic theory of the C-D effect. J. Inst. Polytech, Osaka City University, D 7:35-72.

State of Oregon Department of Land Conservation and Development, 2001. Commercial and Mixed-Use Development: Code Handbook. Oregon Transportation and Growth Management (TGM) Program.

Tucker, C.J. 1979. Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of the Environment, 8:127-150.

Umble, J. 2005. Personal communication regarding statistical analysis.

Voogt, J. A. and T. R. Oke. 2003. Thermal remote sensing of urban climates. Remote Sensing of Environment. 86: 370-384.

Wackernagle, M. and W. E. Rees. 1996. Our ecological footprint:: reducing human impact on the earth. Gabriola Island, BC: Philadelphia, PA: New Society Publishers.

Wilson, J. S., M. Clay, E. Martin, D. Stuckey, and K. Vedder-Risch. 2003. Evaluating environmental influences of zoning in urban ecosystems with remote sensing. Remote Sensing of Environment. 86: 303-321.

Winter Brook Community Resource Planning. 2003. City of Corvallis: Natural Features Inventory; City Council Acceptance.

1000 Friends of Washington. 2001. Land Use and Water Quality. November 15, 2001. www.1000friends.org/waterq.htm.