Boston-Cambridge-Newton MSA Urban Gradient Analysis

MSA Composition & Definition

The Boston-Cambridge-Newton MSA (hereafter referred to as the Boston MSA) is composed of several counties from both eastern Massachusetts (MA) and southern New Hampshire (NH) which surround the Boston central business district (CBD) located in census tract 303[1] (Fig. 1). The counties defining the Boston MSA region, in both 2000 and 2010, were largely the same with 8 counties in 2000 and 7 in 2010, as shown in Table 1. The key difference, however, is that in 2010, county-level census tracts were used to classify the extent of the metropolitan region as opposed to 2000 in which the census tracts of county parts, such as individual towns and cities, were used. As a result, the number of census tracts within the MSA increased by 42% from 702 in 2000 to 998 in 2010 (Table 2) as can be seen by the large change in area from 2000 (grey overlay) to 2010 (tan shading) in which most of the area in 2000 is still included in the MSA but large additional swathes of land are added to the north and into New Hampshire (Fig. 1).

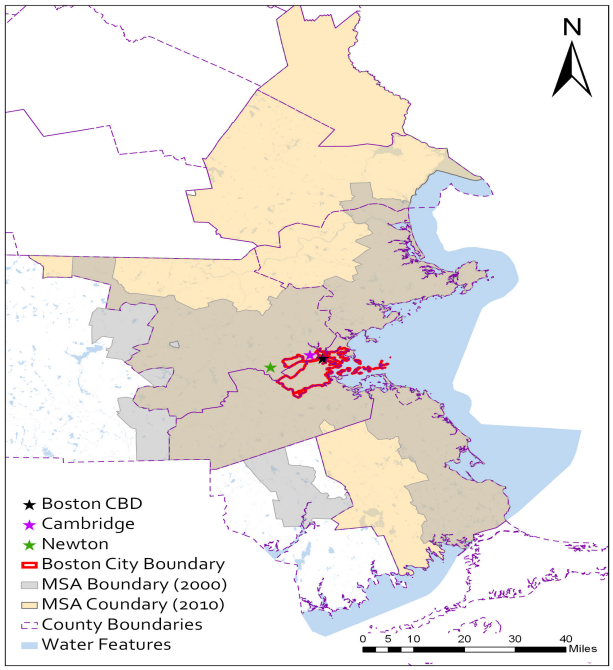


Figure 1: Boston MSA Extent in 2000 & 2010

Table 1: Counties within MSA for a given year

County Parts (2000)	Counties (2010)
Bristol, MA	Essex, MA
Essex, MA	Middlesex, MA
Middlesex, MA	Norfolk, MA
Norfolk, MA	Plymouth, MA
Plymouth, MA	Suffolk, MA
Suffolk, MA	Strafford, NH
Worcester, MA	Rockingham, NH
Rockingham, NH	

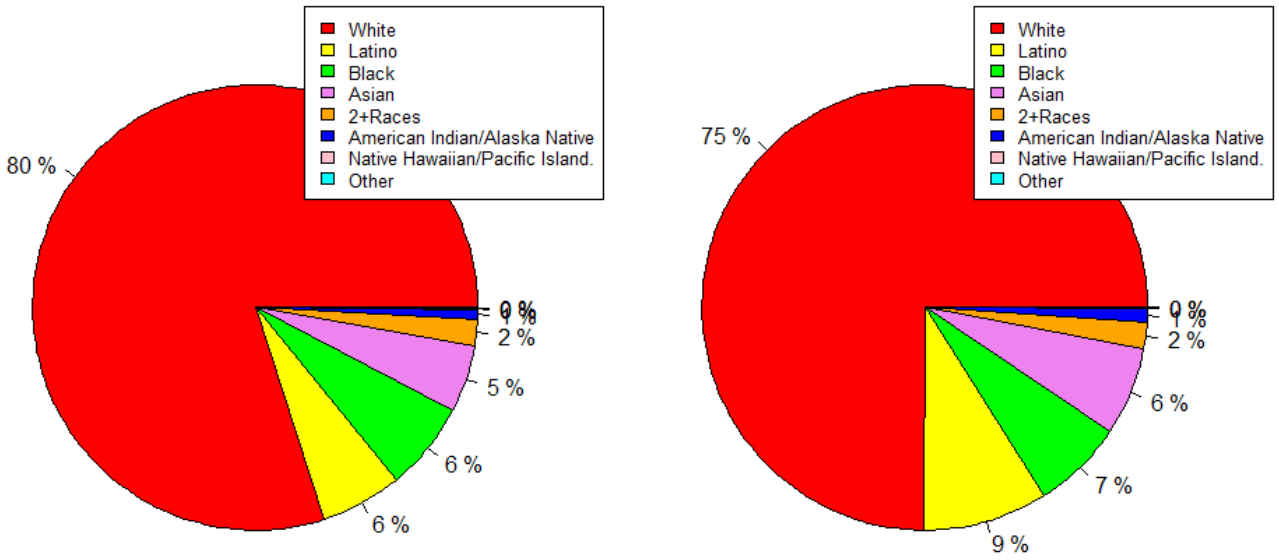
Statistical Profile

The Boston MSA is bounded by the Atlantic Ocean to the east and southeast and the Providence and Worcester MSA's to the south and west respectively. The region is predominantly low-lying forested terrain providing little impedance to the urban form. As mentioned above, from 2000 to 2010, the addition of nearly 300 census tracts increased the total area of the MSA increased by approximately 70% from 2034 to 3484 square miles (Fig. 1). Likely due, in part, to this large change in metropolitan land area, the profile of the the metropolitan region has changed in many aspects as summarized in Table 2. While both MSA area and population have greatly increased from 2000 to 2010, area growth has increased at a rater faster than the population (+69% versus +34%), leading to an overall 22% decrease in density. Other selected spatial changes that occurred in this decade were that a smaller percentage of the Boston MSA's population and amount of income

[1]Defined as the location of the Boston City Hall: (1 City Hall Square, Boston, MA 02201)

Table 2: MSA Profile Changes from 2000 to 2010

	2000 Value	2010 Value	% Change
Number of Census Tracts (n)	702	998	+42 %
Area (square miles)	2034	3428	+69%
Population	3,408,722	4,552,402	+34 %
Overall Density (people/mi^2)	1676	1307	-22 %
City/MSA Population	0.173	0.136	-21 %
City/MSA Income	0.153	0.125	-18 %



(a) 2000 (b) 2010

Figure 2: Racial & Ethnic Composition of Boston Metropolitan Region in 2000 & 2010

resided in the city center as both ratios decreased by approximately 20% (Table 2). Since 2000, the average census tract also saw an increase in yearly income of approximately $15,000 despite the fact that the percentage of the region's inhabitants living below the poverty line increased from 8% to 9%. In addition to income and land changes over this time period, the racial and ethnic composition of the metropolitan area also changed as the region become less white and more significantly Latino, Black, and Asian (Fig. 2a & 2b).

Density Statistics

While the makeup of the increasingly large region has become richer, more diverse, and more populated, the density gradient has also changed within the metropolitan area. Despite an aggregate density decrease of over 20% in the decade following 2000, the range of census tract densities within the MSA became much greater with the minimum density decreasing by 96% and the maximum increasing by roughly 5% (Table 3). Due to the fact that the decrease in minimum density was much larger than the increase in maximum density, the mean and median densities dropped

6.9% and 21% respectively to values of 8,978 and 3,897 people per square mile mile.

Table 3: **Complete MSA** Density ($\frac{people}{mi^2}$) Statistics

	2000 Value	2010 Value	% Change
Minimum	138	5	-96 %
Maximum	105,190	110,108	+4.7 %
Mean	9642	8978	-6.9 %
Median	4933	3897	-21 %

While these statistics begin to shed light on how inhabitants of the Boston metropolitan region are spatially dispersed, they are still only aggregate macro level values that paint the region as one complete unit rather than an agglomeration of many towns, neighborhoods, and regions, each with their own unique characteristics. Thus, to gain more insight into the regional density intricacies one must observe the distribution of the densities. As illustrated by the fact that the median is much less than the mean density in both 2000 and 2010, one can conclude that the density data is skewed right, or that a lower percentage of the population actually lives in an area with density of equal or greater value than the mean. Specifically, in 2000, only 29% of the regional population lived in higher-than-average densities while in 2010, just 27% lived in above-average densities. In this context, the mean density is much higher than the median value because the few regions of high density have densities that are markedly greater than the more common low density regions, thus pulling the average (mean) value higher.

Table 4: **Density Statistics Measured in** $\frac{people}{mile^2}$

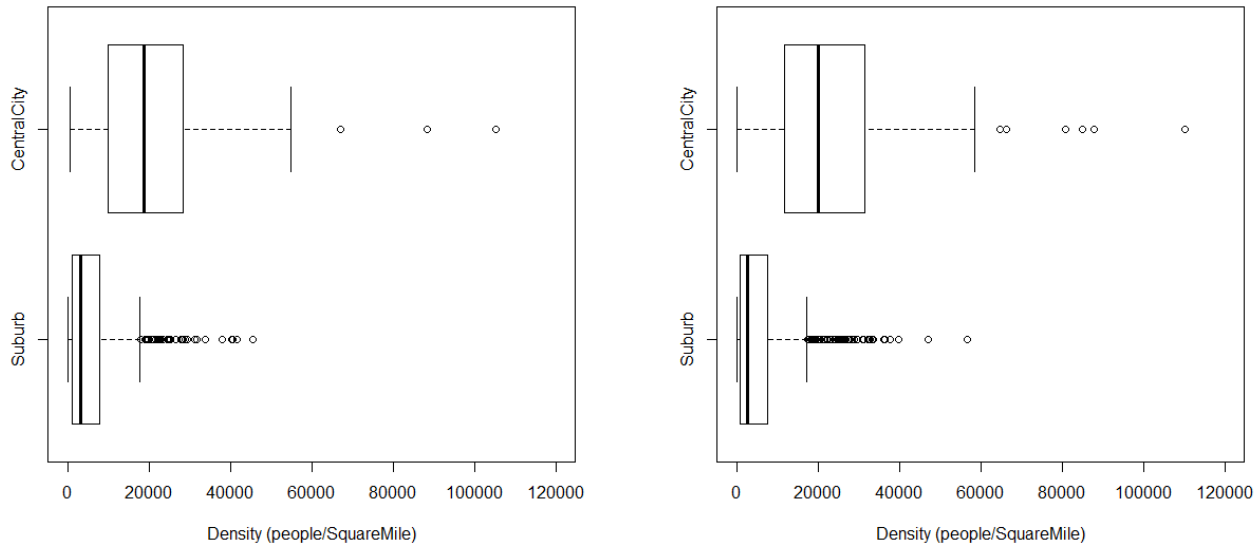
(a) **Central City** Statistics

	2000 Value	2010 Value	% Change
Minimum	483	5	-99 %
Maximum	105,190	110,108	+4.7 %
Mean	21,397	23,704	+11 %
Median	18,812	20,123	+7.0 %

(b) **Suburban** Statistics

	2000 Value	2010 Value	% Change
Minimum	138	74	-46 %
Maximum	45,561	56,819	+25 %
Mean	6,256	5,801	-7.3 %
Median	2,266	2,721	+20 %

Given the positive skew of the density data, it is critical to break the metropolitan area into the central city and suburban regions to more accurately picture the density gradient. As shown in Tables 4a & 4b, almost all central city statistics have higher densities than those in the suburbs, with only the minimum central city density having a smaller value than its respective value in the suburban area. Additionally, when comparing the spread in densities for both the central city and suburb in 2000 (Fig. 3a) and 2010 (Fig. 3b), it is clear that the two regions have distinctly different densities despite some overlap between outliers.



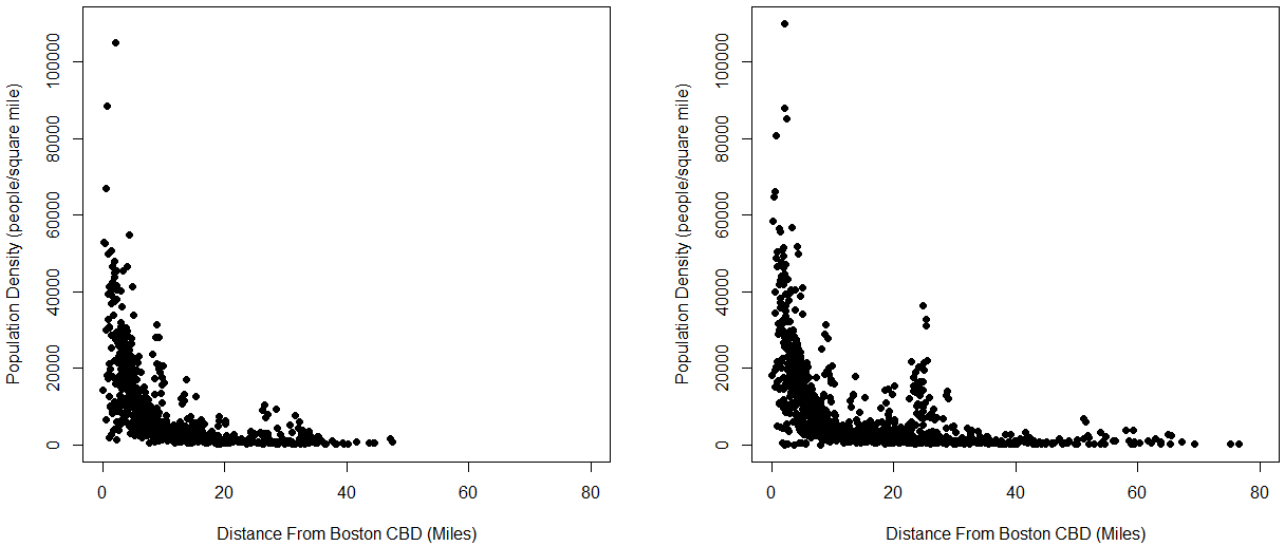
(a) **2000** (b) **2010**

Figure 3: Density Distribution Between Suburb and Central City in 2000 & 2010

Conformity to Monocentric Density Gradient Theory

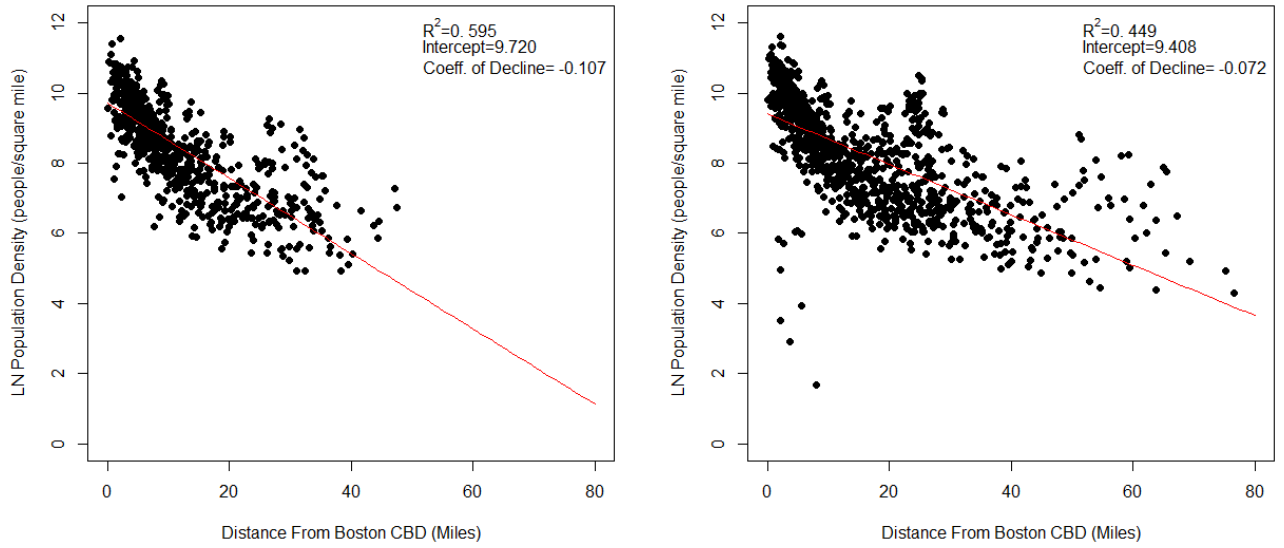
As described by Colin Clark in 1951, most cities have a falling off of density as the distance from the CBD increases, and this characteristic behavior can be approximated by a negative exponential of the form $density = A * e^{-b*(distFromCBD)}$ where the parameter "A" estimates the density at the city center while "b" is the coefficient of decline and represents how quickly density will decline as one moves further away from the city center. As illustrated in Figures 4a & 4b, this type of negative exponential relationship between density and distance is, in fact, seen for the Boston region. In both 2000 (Fig. 4a) and 2010 (Fig. 4b), there is a very rapid drop in density even when only moving out approximately 10 miles from the central business district. Compared to the relatively smooth relationship in 2000, the data in 2010 exhibits a second smaller peak at a distance of around 25-30 miles from the CBD indicating that the growth pattern in 2010 is more typical of a poly-centric region rather than the more mono-centric relationship in 2000. Thus, it appears that when the area of the Boston MSA increased in the decade following the year 2000, the metropolitan area grew to encompass at least one additional area which had densities a factor of 2-3 times smaller than the Boston city center density.

When plotting and regressing the natural log of density against distance for the 2000 (Fig. 5a) and 2010 (Fig. 5b) data, one is able to extract the coefficients described by the theory above as well as an R^2 value for each of the regressions. Given that these are a linearized depiction of the exponential plots in Figures 4a & 4b, in order to get the true values of the "A" coefficient in the model described above, one must exponentiate the value obtained from the linearized regression. Upon performing this transformation, the central city density estimated by $e^{intercept}$ is approximately 16,650 in 2000 and 12,190 in 2010. When comparing these values to the median central city densities in Table 4a, it is clear that the estimated statistic is much closer in 2000 (approximately 11% variation from the



(a) **2000** (b) **2010**

Figure 4: Population Density vs. Distance From CBD in 2000 & 2010

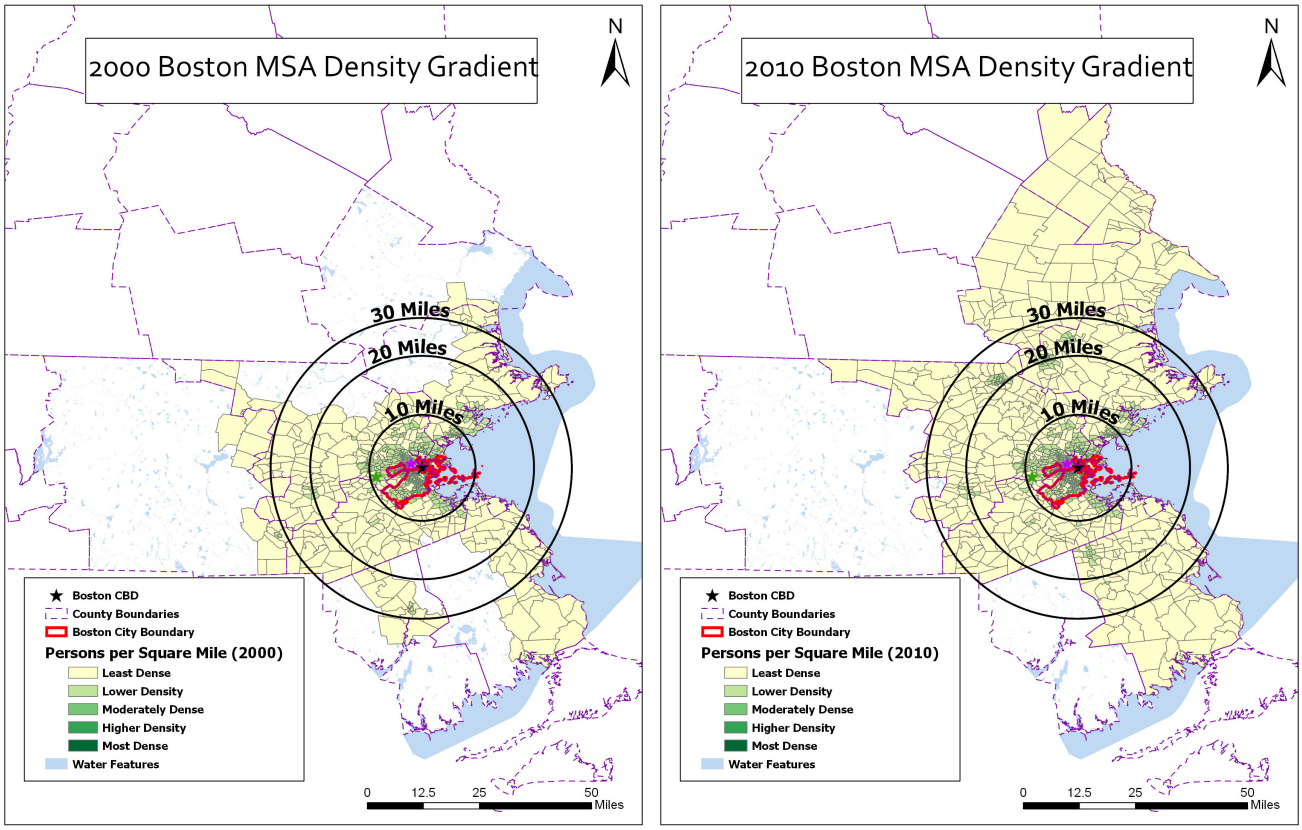


(a) **2000** (b) **2010**

Figure 5: Regressed LN Population Density vs. Distance From CBD in 2000 & 2010

reported median) as opposed to 2010 (approximately 39% variation). This departure from the calculated statistics for the central city likely come from two sources: Boston is not a strictly monocentric region, and Table 4a described the entire central city rather than the exact core. By taking the ratio of the coefficients of decline (b value) for 2000 and 2010, 0.107 and 0.072 respectively, one can conclude that in 2000, density drops off at a rate nearly 1.5 times faster than in 2010 as distance increases from the CBD. The large difference in density gradient steepness can partially be attributed to the spike in 2010 density around 25 miles from the CBD causing the drop-off in

density to be less rapid than it otherwise may have been. This reasoning is supported by the R^2 values for both time periods which indicate that the monocentric theoretical model used in estimating the coefficients of decline described approximately 60% of the variation in population density in 2000 while only 45% in 2010.



(a) **2000** (b) **2010**

Figure 6: Density Patterns in 2000 & 2010 with approximate distances from CBD

When observing the visual depiction of the density gradient for both 2000 and 2010 (Fig. 6a & 6b), the statistical analysis and behavior can easily be observed by locating the areas of high density (dark color). From these figures, it is readily apparent that the monocentric density gradient model fairly accurately portrays the region in 2000 given that the density declines from the CBD (denoted by the black star) in fairly regular concentric circles with limited nodes of high density outside approximately 10 miles from the city center. In 2010, on the other hand, the monocentric theory falls apart as described in the analysis of the scatterplots above. Specifically, while the density does decline in roughly concentric rings from the city center, their are several pockets of high density located near the New Hampshire border approximately 25 miles away from Boston's city center. The presence of these high density nodes at 25 miles distance explains the density peak at the same distance in Figure 4b and the proportionately smaller R^2 value in 2010 when compared to 2000. Finally, as previously discussed in the statistical profile of the region, after inspecting the visual depiction of the density gradient, it is clear that the median density of the region is lower than the mean largely due to the fact that the fast majority of the region's census tracts, in both years,

had the lowest range of densities.

Greater Boston Settlement Pattern Summary

During the decade from 2000 to 2010 the greater Boston region experienced many significant changes which influenced its settlement pattern. Perhaps the most significant change was the redefinition of the metropolitan area's boundaries which resulted in an area increase of approximately 1,400 square miles (up 70% from 2000). While this increase in land area is certainly a contributing factor in many of the other demographic and density changes in the region, these changes are important to highlight. For example, despite encompassing a larger area in the suburbs, the metropolitan region actually became more diverse as the share of the population that was white dropped from 80% to 70%. Furthermore, over the studied decade, more and more inhabitants chose to live further from the suburbs and those that did live in the suburbs composed a larger percentage of the total MSA income than their counterparts in the central city. Despite this outward migration of individuals, the central city still remains significantly more dense than the suburbs as the average density of the central city increased from approximately 5 times that of the suburbs in 2000 to roughly 6.5 times more dense in 2010. Finally, paired with individuals behavioral trends to move to the suburbs, the increase in metropolitan area changed the Boston MSA from a primarily monocentric region to a more polycentric region with a band of dense areas occurring at a radial distance of approximately 25 miles to the north of the Boston CBD. Thus, in just 10 years, the Boston region has become larger, more populous, more diverse, and the destinction between downtown densities and suburban densities has become more stark as the region spreads outwards in roughly concentric circles from downtown Boston.