Analysis of Prostate Cancer Incidence Using Geographic Information System and Multilevel Modeling

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This study investigated racial differences in prostate cancer incidence, stage and grade in Florida using individual, community and environmental data from three data sets. Prostate cancer data were obtained from the Florida Department of Health. Census-tract-level characteristics were extracted from census data. County-level environmental data were obtained from the Department of Environmental Protection. Geographic Information Systems (GIS) was used to show racial and geographic disparities. Multilevel modeling was applied to examine the relationship of prostate cancer stage and grade to factors at the aforementioned levels. The results indicated that at the individual patient level, advanced/late cancer stage was significantly associated with older age, being black, being unmarried, tobacco use and being diagnosed in early years. At the census-tract level, late cancer stage was related to low median income and low percentage of people with some college education. No significant association was found for environmental factors. Similar results were found for tumor grade. These findings are consistent with national data demonstrating striking racial/ethnic disparities, improved stage and grade over time, and the importance of socioeconomic status. The GIS results also add local community perspectives important for planning community education and outreach to reduce racial disparities in low-income neighborhoods and low-literacy populations.

Key words: prostate cancer ■ racial disparities ■ geographic information system ■ multilevel modeling

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INTRODUCTION

Prostate cancer is the most common solid malignancy (excluding skin cancer) and the second leading cause of cancer-related death for American men. It has been estimated that there will be 234,460 new cases and 27,350 deaths from this disease in the United States in 2006.[1] The State of Florida ranks second behind California for both incidence (18,090 estimated new cases) and mortality (2,110 estimated deaths) from prostate cancer in 2006.[1]

Striking racial/ethnic differences in incidence and mortality persist in the United States and Florida. Compared to other major cancer sites (e.g., colorectal and lung), racial differences in incidence and mortality are greatest for prostate cancer. Incidence is 60% higher and mortality is 2.4 times greater for blacks compared to whites in the United States.[1,2] All other racial/ethnic minorities have much lower prostate cancer rates compared to whites (Figure 1).

Although prostate cancer-related incidence and mortality have declined recently, the racial differences between black and white men continue unabated.[1-3] The reasons for the racial disparities in incidence and mortality are not well understood and are the subject of much research. Racial differences in mortality have generally been attributed to tumor grade and advanced/late stage of disease at diagnosis and differences in access to definitive and adjuvant treatment.[4-6] Regarding prostate cancer incidence, the literature suggests that variations in dietary fat intake, cooking practices, selenium intake, exposure to pesticides and fertilizers, physical activity, socioeconomic status (SES), access to and use of healthcare services, and genetic susceptibility are among possible factors contributing to these disparities.[7-9] Despite adjustment for individual-level risk factors (e.g., age, height, body mass index at age 21, vigorous physical activity, smoking, diabetes, vasectomy, intake of saturated fat, calcium and fructose), the risk for blacks was found to be slightly higher compared to whites.[10] Overall, the literature supports the argument that area-level socioeconomic factors and dietary practices may contribute to racial disparities in prostate cancer incidence.[7-10]

Geographic Information Systems (GIS) and associated technologies are evolving rapidly and increasingly are used for mapping disease occurrence as a way to explore spatial and temporal patterns.[8,11-15] Specifically, the use of area-level socioeconomic factors and multilevel geographic approaches has been recommended to help evaluate single or multiple influences on prostate cancer incidence[7,8,16] and other cancers and health conditions[14,15,17] using statistical and spatial analysis. For example, a recent study examined the racial disparities in prostate cancer incidence using spatial analysis of data from the Virginia Cancer Registry data, 1990–1999 (37,373 cases).[8] The data were geocoded to the census tract and county levels to produce crude and smoothed maps to determine geographic patterns of racial disparities in prostate cancer incidence. Results showed that prostate cancer incidence was elevated in the eastern and central portions of the state. Poverty and lower education were associated with a decreased incidence among whites but not blacks. To examine racial differences in prostate cancer incidence, various measures of relative risk (e.g., black/white incidence ratio) and units of analysis (e.g., census block group, census tract, county, ZIP codes) may be used depending on the constraints of the data set and issues of privacy and confidentiality.[8,11-13]

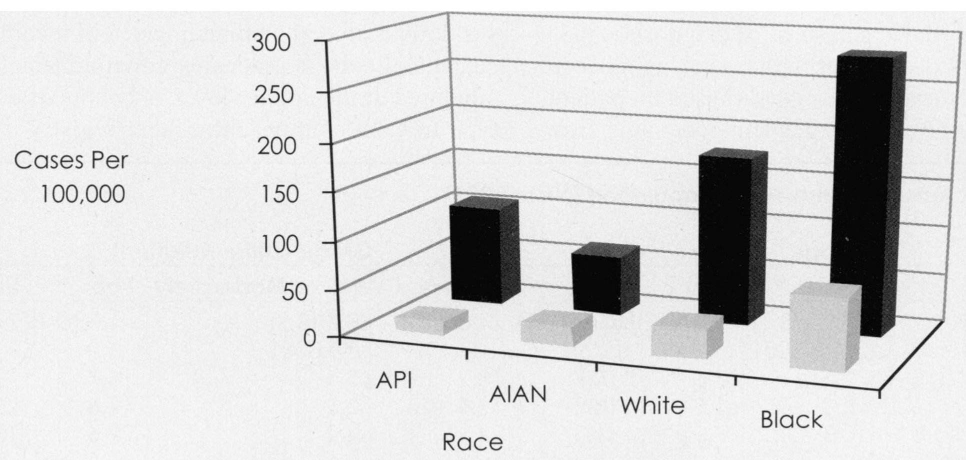
The existence of racial disparities in prostate cancer incidence is well documented. However, virtually no published studies have used GIS and multilevel modeling to examine racial disparities and the association of SES and other area-level measures with prostate cancer incidence in Florida. To reduce racial/ethnic disparities in prostate cancer incidence and outcomes, a better understanding of the geographic variation and racial differences in prostate cancer incidence and factors associated with these differences is important. In the current study, prostate cancer incidence in Florida was mapped using two measures of relative risk (black/white incidence ratio, black/white advanced-/late-stage disease ratio), stratified by race. The association of prostate cancer stage and grade of tumor was evaluated in relation to individual and disease characteristics, area-level census measures of education and income (at census tract level), and county-level environmental exposure variables using descriptive and multilevel modeling statistical procedures.

METHODS

Data Sources

We obtained data for this study from three sources. Prostate cancer incidence data for years 1990–2001

Figure 1. Age-adjusted prostate cancer incidence and mortality rate, 1992–2002 by race



	API	AIAN	White	Black
□ Mortality	14.1	21.5	31.2	73.7
■ Incidence	104.6	63.4	175.5	283.8

Rates are age-adjusted to the 2000 U.S. standard population; API: Asian/Pacific Islander; AIAN: American Indian/Alaska native; Data source: Mortality: Surveillance, Epidemiology and End Results (SEER) Program (www.seer.cancer.gov) SEER*Stat Database: Mortality—All COD, Public-Use with State, Total U.S. for Expanded Races/Hispanics (1990–2002), National Cancer Institute, DCCPS, Surveillance Research Program, Cancer Statistics Branch, released April 2005. Underlying mortality data provided by NCHS (www.cdc.gov/nchs). Incidence: Surveillance, Epidemiology and End Results (SEER) Program (www.seer.cancer.gov) SEER*Stat Databases: Incidence—SEER 13 Regs Public Use, November 2004 Sub for Expanded Races (1992–2002) and Incidence—SEER 13 Regs excluding AK Public Use, November 2004 Sub for Hispanics (1992–2002), National Cancer Institute, DCCPS, Surveillance Research Program, Cancer Statistics Branch, released April 2005, based on the November 2004 submission.

were obtained from the State of Florida Department of Health, which contracts with Florida Cancer Data System (FCDS) housed at the University of Miami. The FCDS is the single largest population-based, cancer incidence registry in the nation. More than 150,000 cases have been collected from patient medical records annually since 1981. Cancer cases are submitted by hospitals, free-standing ambulatory surgical facilities, radiation therapy facilities, private physicians and death certificates. The FCDS database contains approximately 2.3 million cancer records, 3.5 million discharge records and 3.1 million mortality records. Ninety-six percent of all records in the FCDS database are histologically confirmed. The data are collected and coded by the FCDS in accordance with national standards as set forth by the North American Association of Central Cancer Registries (NAACCR). In addition, the FCDS uses the International Classification of Diseases—Oncology, 3rd edition (ICD-O-3) to code primary site and morphology.

The FCDS is part of the Centers for Disease Control and Prevention National Program of Cancer Registries (CDC-NPCR) and is nationally certified by the NAACCR at the highest level, gold certification. Gold certification is conferred on central cancer registries that exceed all standards for completeness, timeliness and quality.

The data from the FCDS contained information on patient demographics (age, race and marital status), residence (census tract and ZIP code), prostate tumor characteristics (year of diagnosis, stage of diagnosis, grade of tumor, etc.) and other information such as tobacco use history. The data were geocoded (based on patient residential address) by an independent geocoding firm contracted by the Florida Department of Health. Data from the U.S. Census Bureau (Census 2000, Summary File-3) public files for the State of Florida were used to extract census-tract-level sociodemographic characteristics. Environmental data, including water quality, superfund site locations and toxic release sites, were obtained from the Florida Department of Environmental Protection. The investigators signed the data use agreements. The project was approved by the institutional review boards at Florida A&M University, University of South Florida/Moffitt Cancer Center and the Department of Defense, which sponsored this research.

Study Population

Records for Florida males ≥40 years who were diagnosed with prostate cancer during 1990–2001 were selected for the study. The rationale behind the age criterion is the much higher incidence rate in men aged ≥40 years. Due to small numbers, American-Indian/Alaska-native and Asian/Pacific-Islander men were included only in the descriptive statistics.

Data Extraction

Patient age, race, marital status, tobacco use history, census tract, year of prostate cancer diagnosis, and stage and grade of tumor were extracted from the prostate cancer incidence data. Records with incomplete (any missing) information were removed from data analyses. Census tract characteristics extracted from Florida Census 2000 included median household income and percentage of college graduates. Environmental data were tabulated at the county level as counts of each hazard type in each county. The cancer registry, census and

Table 1. Characteristics of the study population (N=167,386)

	Stage				Grade (Differentiation)		
	In Situ*	Early	Late	Unstaged	Well or Moderately	Poor	Unknown
Age (Mean, SD)	72.7 (8.1)	70.0 (8.2)	70.0 (9.1)	74.8 (9.0)	69.7 (8.3)	71.5 (8.7)	74.2 (9.1)
Race (%)	p=0.0001				p=0.0001		
White	0.3	67.6	13.9	18.2	65.3	15.7	19.0
Black	0.3	61.5	18.8	19.4	60.3	17.6	22.1
American Indian/ Alaska native**	0.0	66.0	11.3	22.6	64.2	22.6	13.2
Asian/Pacific Islander	0.5	72.2	12.3	15.0	66.1	18.0	15.9
Other and unknown**	0.2	49.2	10.7	40.0	63.5	16.5	20.0
Marital Status	p=0.0001				p=0.0001		
Unmarried	0.3	56.3	14.6	28.8	54.1	15.9	30.0
Married	0.3	70.0	14.4	15.3	67.9	15.9	16.2
Unknown	0.2	62.0	10.9	26.9	62.1	16.2	21.7
Tobacco Use	p=0.0001				p=0.0001		
Nonuser	0.4	70.3	15.1	14.2	67.3	16.3	16.4
Past user	0.2	70.9	14.2	14.7	67.3	16.0	16.7
Current user	0.3	67.8	18.2	13.7	65.9	18.1	16.0
Unknown	0.3	55.8	10.9	33.0	57.0	14.0	29.0

P values are from Chi-squared tests; * This stage was included only in the descriptive analysis but was excluded from the regression analyses; ** Figures do not add up to 100% due to rounding.

environmental data were merged into one file using the SAS software.

GIS Mapping

ArcView 9.1 (Environmental Systems Research Institute) was used to perform GIS functions. Environmental data sites were tabulated at the county level by superimposing point layers of site location onto a map of Florida counties. The total combined number of sites falling within each county was appended as an attribute to each county record. Environmental data included EPA toxic release inventory sites for the 1990s, water-quality monitoring sites for which water quality was listed as poor from the EPA National Water Quality Inventory Report to Congress (305b report of 2000), and EPA Superfund sites as of 2002.

FCDS records included geocoded latitude-longitude coordinates, which were used to create a point shapefile for the incidence records. This point shapefile was overlaid onto a map of Florida county boundaries for thematic mapping. In addition, age-adjusted incidence rates were calculated by race and by prostate cancer stage for each county according to the procedures of the National Cancer Institute Surveillance, Epidemiology and End Results (SEER) database (http://seer.cancer.gov/seerstat/tutorials/basic.html) using the FCDS online Interactive Rates system. Age-adjusted rates were used to prepare thematic maps with counties color coded by: 1) the ratio of black incidence rate to white incidence rate (e.g., a ratio >1.0 indicates that prostate cancer incidence in blacks is greater than in whites) by county, and 2) the ratio of incidence of late stage prostate cancer in blacks compared to whites by county.

Statistical Analysis

Descriptive statistics were used to show the study population characteristics, and multilevel logistic regression was applied to examine the relationship of prostate cancer stage and grade to factors at the following levels: patient, census tract and county. All analyses were conducted using SAS 9.1.

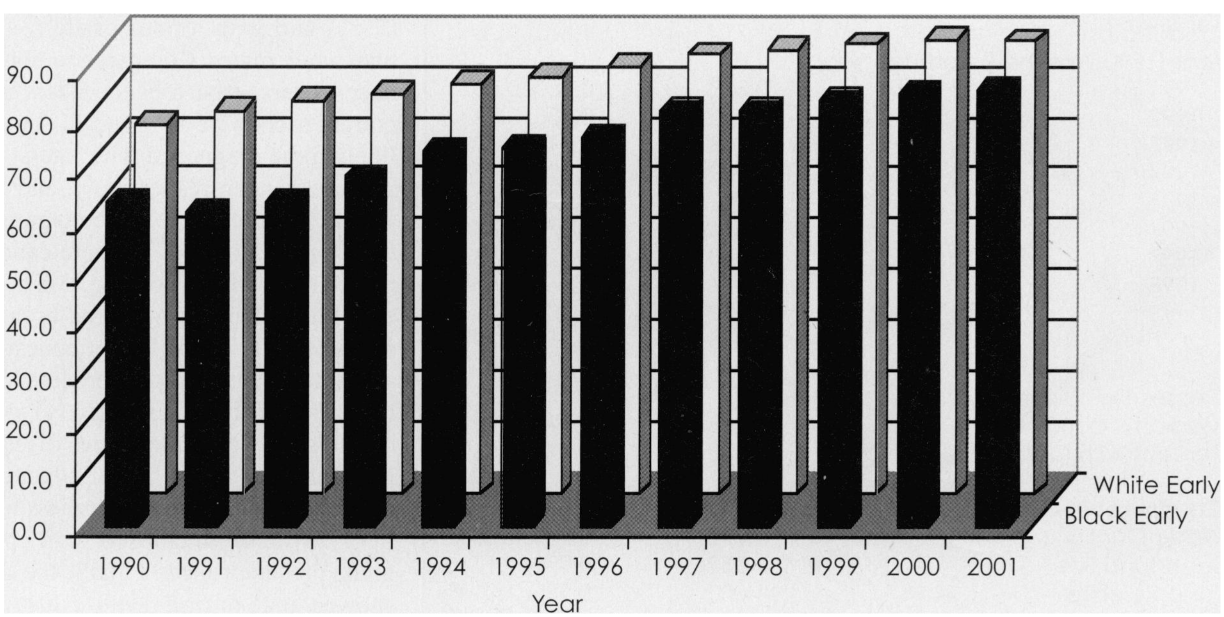
The dependent variables in the logistic regressions were stage of tumor at diagnosis (late versus early) and grade of tumor (poorly versus well differentiated). Independent variables included three levels of factors. At the individual patient level, age, race, marital status and tobacco use history were included; at the census tract level, median income and percentage of college graduate were included; at the county level, water quality, superfund and toxic release counts were included. Odd ratios for each independent variable at the different measurement levels were produced.

RESULTS

Population Characteristics and Trends

During 1990–2001, 167,435 men were diagnosed with prostate cancer in Florida. Seventy-eight percent were non-Hispanic white, 10% were non-Hispanic black and 10% were Hispanic. There were fewer American Indians/Alaska natives, and Asians/Pacific Islanders, 0.03% and 0.23%, respectively. For 1.03% of the sample, race was indicated as other or unknown. The average age at diagnosis was 71 years, and 75% of the men were married. Forty-one percent of the sample had used tobacco in their lifetime. Among the 167,435 men, 49

Figure 2. Trend of early-stage prostate cancer diagnosis by race in Florida



had incomplete records and were deleted from data analyses. The characteristics of the final study population (N=167,386) are summarized in Table 1. The following were observed from the Chi-squared tests. Being black was highly associated with advanced-/late-stage prostate cancer diagnosis compared to being white (18.8% vs. 13.9%). Although being American Indian/Alaska native and Asian/Pacific Islander were associated with poor (higher Gleason) grade of prostate cancer, these results warrant caution due to the small numbers of American-Indian or Alaska-native and Asian/Pacific-Islander males in the sample. As a result, American-Indian/Alaska-native and Asian/Pacific-Islander males were excluded from the multilevel logistic regression analysis. In addition, more married men were diagnosed with localized/early prostate cancer than unmarried men (70% vs. 56.3%). Moreover, tobacco users were more likely to be associated with advanced-/late-stage prostate cancer (18.2%, 15.1% and 14.2%, respectively, for current smokers, past smokers and nonsmokers).

During 1990–2001, the proportion of early-stage prostate cancer increased over the 12 years for both white and black men. In addition, the gap in percent diagnosed at early stage between white and black men narrowed during the 12-year period. Nonetheless, the percentage of black men with early-stage diagnosis remained slightly lower than that of their white counterparts (Figure 2).

County-Level Mapping

Figures 3 and 4 show the results of comparative county-level mapping of incidence rates and prostate cancer stage. The state as a whole had an average ratio of 1.54, indicating a 54% higher rate of prostate cancer in black males than in white males (Figure 3). Thirty-three out of 67 (49%) Florida counties had higher black-to-white incidence ratios than the state average (1.54). Union County and Glades County had the highest ratios—4.14 and 3.37 respectively—indicating higher incidence among black males. Gulf and Hendry counties, on the other hand, had the lowest ratios—0.79 and 0.98, respectively—indicating a slightly higher incidence among white males.

Figure 4 shows how early-stage prostate cancer was distributed in the state in terms of black-to-white ratio. The color scheme is consistent with Figure 3. For the state as a whole, black men suffered from late-stage prostate cancer 48% more than white men during 1990–2001. Sixteen of the 67 (24%) Florida counties had higher than the state average (1.48) black-to-white ratios, indicating higher rates of late stage prostate cancer among blacks than among white males. Holmes and Dixie counties had the highest black-to-white ratio (8.69 and 3.82, respectively), suggesting black males were nearly nine and four times, respectively, more often diagnosed with late-stage prostate cancer than white males.

Table 2. Results from multilevel logistic regression models predicting the likelihood of late-stage prostate cancer

Independent Variables	Odds Ratio	95% CI
Individual Level		
Age	1.028	1.027, 1.029
Black	1.391	1.339, 1.444
Marital Status	0.647	0.631, 0.663
Tobacco Use (Before)	1.107	1.079, 1.135
Tobacco Use (Current)	1.714	1.665, 1.764
Year (1990 Was the Reference Year)		
1991	0.820	0.780, 0.862
1992	0.775	0.738, 0.814
1993	0.788	0.749, 0.829
1994	0.729	0.692, 0.768
1995	0.767	0.729, 0.808
1996	0.611	0.579, 0.645
1997	0.540	0.512, 0.569
1998	0.476	0.451, 0.502
1999	0.422	0.400, 0.446
2000	0.376	0.355, 0.397
Census Tract Level		
Median Income	0.998	0.998, 0.999
Percent with College Education	0.863	0.776, 0.961
County Level		
Water Quality	0.996	0.988, 1.003
Superfund Site	1.050	0.970, 1.136
Toxic Release	1.003	0.992, 1.014

Multilevel Modeling

Results from the multilevel logistic regressions are shown in Tables 2 and 3. The results are similar for the two models. Specifically, older men were more likely to be diagnosed at a late stage and with a poor grade. Black males were more likely to be diagnosed with late-stage prostate cancer (39%) and with a poor grade (32%) than white males. Compared to nontobacco users, past tobacco users and current users were 11% and 71% more likely to be diagnosed with late-stage prostate cancer, respectively; and 6% and 49% more likely to be diagnosed with a poor grade of prostate cancer, respectively. Men who resided in higher median income (measured in thousands of dollars) and higher education attainment census tracts were less likely (0.2% and 14%, respectively) to be diagnosed with late-stage disease. Men who resided in higher education attainment census tracts were less likely (17%) to be diagnosed with poor-grade prostate cancer. Finally, the data showed that during 1990–2001, the incidence of late stage and poor grade of prostate cancer declined continuously. The effects of all county-level environmental factors were not statistically significant.

DISCUSSION AND CONCLUSIONS

The gap between white and black men in rates of prostate cancer incidence and mortality has been a public health issue for a long time. Our study is the first to use GIS and multilevel modeling to examine disparities of prostate cancer in the State of Florida. In Florida, during 1990–2001, there were more counties with greater incidence and greater rates of late-stage prostate cancer for black men than for white men. Spatial maps show that racial disparities in incidence and late stage at diagnosis are greatest in the northern and central counties. These geographic spatial patterns inform and may facilitate the design of intervention programs to target counties with the greatest racial disparities in outcomes. The value of this approach has also been illustrated elsewhere.[8] To better understand the geographic disparities, we carefully examined various characteristics of the counties with greater black–white disparities to see if there were specific reasons for the higher incidence or higher grade of tumor. Generally, the higher-incidence counties tended to be more rural and had a higher proportion of the population living on farm land. Additional analysis is needed to disentangle the observed geographic differences. Without further research, we cannot elucidate the reasons (or influences) for these differences, which are needed to plan targeted interventions.

The proportion of early-stage diagnosis increased over the study period for both racial groups, and the disparity between black and white men declined as evidenced by the shrinking gap between the two racial groups over time (Figure 2). Older men tended to have poorer outcomes in terms of prostate cancer stage and tumor grade. Married men were more likely to be diagnosed with early-stage disease, compared to single, divorced or widowed men. Although the reasons and mechanisms of the observed effects of marital status are unknown, our findings suggest an important role for social support by the wife in the early detection of prostate cancer. This observation is consistent with studies of couples showing that wives have a proscreening preference and do want to be involved in decisions about prostate cancer screening.[18-21] Additional studies are needed to explore this finding. Possible interventions need to involve wives.

At the area (census tract) level, median income and education attainment were found to contribute positively to early stage of diagnosis. These study results are consistent with the literature.[1-10] Although our findings showed that the county-level environmental factors considered were nonsignificant, prostate cancer risk in farmers and areas with poor water quality and/toxic release have been evaluated in previous epidemiologic studies with mixed results.[22-35] Further research is needed to consider additional data and assess other measures of environmental conditions.

Our findings on tobacco use support the detrimental effect of tobacco use on prostate health. However, the good news is that once smokers quit, they have a better chance of being diagnosed early than current smokers. Although evidence of direct benefits is lacking, it appears that smoking cessation interventions could help to reduce late-stage prostate cancer. For this reason and for other health benefits, campaigns and interventions to promote smoking cessation can be implemented and targeted at those counties with high late-stage prostate cancer cases.

Despite the unique contribution of this study, it has several limitations which warrant future studies. First, the

Table 3. Results from multilevel logistic regression models predicting the likelihood of poor-grade prostate cancer

Independent Variables	Odds Ratio	95% CI
Individual Level		
Age	1.042	1.041, 1.043
Black	1.320	1.273, 1.368
Marital Status	0.663	0.647, 0.679
Tobacco Use (Before)	1.107	1.079, 1.135
Tobacco Use (Current)	1.401	1.363, 1.441
Year (1990 Was the Reference Year)		
1991	0.837	0.796, 0.881
1992	0.831	0.791, 0.873
1993	0.919	0.873, 0.968
1994	0.975	0.925, 1.027
1995	1.062	1.009, 1.119
1996	0.886	0.841, 0.935
1997	0.817	0.775, 0.861
1998	0.701	0.665, 0.739
1999	0.649	0.615, 0.684
2000	0.611	0.579, 0.645
2001	0.614	0.581, 0.649
Census Tract Level		
Median Income	1.000	0.999, 1.000
Percent with College Education	0.828	0.748, 0.916
County Level		
Water Quality	0.993	0.986, 1.000
Superfund Site	0.959	0.889, 1.034
Toxic Release	1.005	0.994, 1.015

Figure 3. Age-adjusted incidence of prostate cancer, black–white ratio, 1990–2001

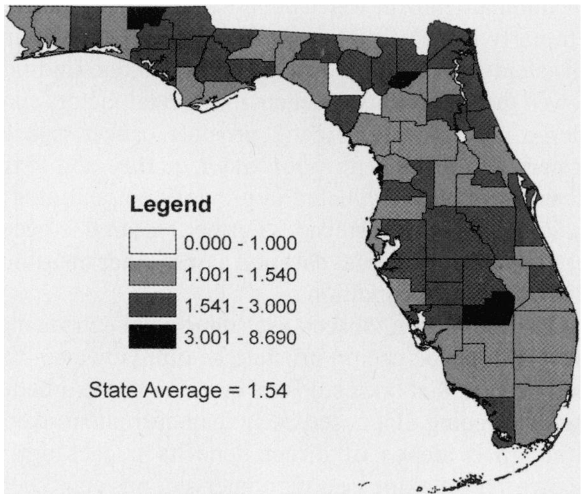
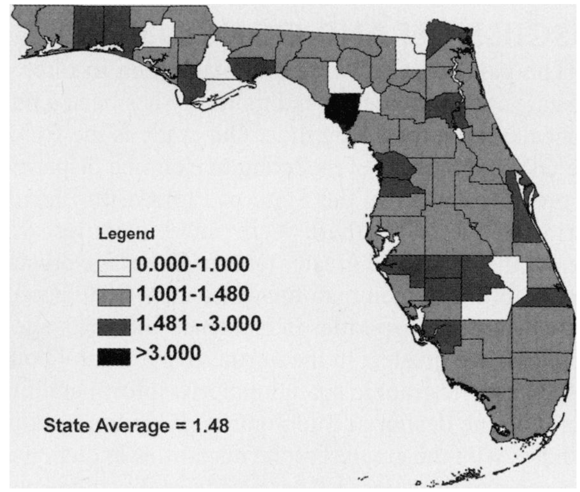


Figure 4. Late-stage prostate cancer by county, black–white ratio, 1990–2001



environmental data were examined at the county level. It may be advantageous to examine the impact at a smaller level, such as census tract level, because some environmental data factors may be very localized. That may be one of the reasons for the insignificant results regarding the association of environmental factors with prostate cancer stage and grade. In addition, no information was available on the residential history of the study subjects; therefore, environmental status of residential areas at diagnosis may not be a good determinant of incidence if the study subjects moved frequently before their diagnosis. Second, because individual screening data were not available, it is possible that our findings showing a higher incidence for black men in some counties could be solely a reflection of increased screening among black men. Finally, changes over time can be examined geographically using Spatial scan or similar programs. However, the bar chart (Figure 2) showed trends for both black and white men, suggesting temporal improvements in both early detection (reduction of late-stage diagnosis) and tumor grade at diagnosis.

Overall, our GIS results add local community perspectives important for planning community education and outreach to reduce racial/ethnic disparities and improve early detection in lower-literacy and low-income populations. In addition, specific counties with a disproportionate burden of disease could be targeted for intervention, although not enough data are available at this time to inform the specific nature of such targeted efforts. In order to eliminate racial/ethnic disparities in prostate cancer outcomes, additional analyses focused on identifying geographic patterns of other measures (including treatment and mortality data) are needed. These analyses are underway for Florida.

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