Ischemic Heart Disease Geography of the United States: Models of Environmental Influence With a Focus on the Eastern Highlands[1]

ANTHONY J. DZIK, Social Science Division, Shawnee State University, Portsmouth, OH 45662

ABSTRACT. **Regional differences exist in ischemic heart disease (IHD) mortality rates in the United States. These variations may in part be related to environmental factors. An examination was conducted in the U.S. on a sample of 101 county age-adjusted ischemic heart disease death rates and several possible environmental factors. A multiple regression model suggests that a combination of altitude, snowfall frequency, median family income, air pollution, and location in the Eastern Highlands may explain about 46% of the variance in ischemic heart disease mortality rates. Some facet of the environment in the Eastern Highlands may contribute to the higher rates found in that region. Coal worker's pneumoconiosis was suspected and tested with no concrete conclusion. The results suggest the importance of environment in the suspected multi-factorial etiology of ischemic heart disease, but replication and further research is required.**

OHIO J. SCI. 91 (3): 134–138, 1991

INTRODUCTION

Regional variations exist in IHD mortality rates in the United States. Higher rates are generally found in the southeastern part of the Atlantic Coastal Plain (Tidewater) and in the Manufacturing Belt of the Northeast, while low rates are more characteristic of the Mountain States and western Great Plains (Enterline and Stewart 1956; Sauer 1962, 1978, Dzik 1988). These variations persist even though the mortality rates for IHD have been in decline for more than 25 years (Thom and Kannel 1981; Ragland, Selvin, and Merrill 1988). Such geographic differences cannot be attributed solely to personal factors such as genetic composition, occupations, dietary habits, use of tobacco, and so forth (Meade 1983). Because cardiovascular disease is ubiquitous, there is no reason to believe that persons having genetic predisposition or detrimental lifestyles would aggregate in certain parts of the country. There is the question of geographic scale. At one level, there exist enclaves such as urban "Chinatowns" and small ethnic farming communities, but at the regional level there is considerable heterogeneity. Therefore, environmental risk factors may have better explanatory value.

A number of extrinsic risk factors in cardiovascular disease have been proposed over the years (Bean 1938, Daubert 1952, Stallones 1965, Carroll 1966, Schroeder and Kraemer 1974, Rogot and Padgett 1976, Smith and Crombie 1987). Factors such as water hardness, air pollution, elements of climate, and socio-economic stress are not randomly distributed in space, and the spatial association of any such variable with the occurrence of ischemic heart disease might suggest some type of causal relationship.

The present study examined associations of several environmental factors and IHD mortality rates in the United States without consideration of the role of personal factors such as diet and tobacco usage. The analysis was conducted through the building and testing of linear regression models that might help explain the degree to which extrinsic factors may account for variations in the mortality rates.

[1]Manuscript received 20 November 1989 and in revised form 14 January 1991 (#89-30).

MATERIALS AND METHODS

One hundred-one counties in the coterminous United States were selected to serve as the sample for analysis (Fig. 1). Because spatial contiguity presents problems of social, economic, and environmental interaction between adjacent enumeration units, the sampling method employed was a random areal sample chosen in a manner that would preserve geographical separation to avoid spatial autocorrelation and reduce measurement errors.

Ischemic heart disease (International Classification of Disease, Adapted #410-413 [Ragland et al. 1988]) county mortality rates (mean rate 1976-78) were computed and age-adjusted to the 1980 U.S. population structure. Rates are for the entire population; no adjustments for race or gender were made. These age-adjusted IHD mortality rates served as the dependent variable.

Seven environmental variables were selected based upon literature review. These variables were: 1) drinking water hardness (as ppm $CaCO_3$); 2) mean annual number of days with snowfall exceeding 1 in (adjusted for latitude); 3) an index of weather instability (based on the annual number of days with unsettled weather); 4) mean elevation above sea level; 5) air pollution as determined from the average annual arithmetic mean concentration of sulfur dioxide (Note: SO_2 appears to be an acceptable surrogate for general air pollution [Wark and Warner 1976, Dzik and Cember 1985]); 6) median family income; and 7) county unemployment.

In an attempt to uncover other possible environmental factors which might also serve as variables, a simple regionalization of the U.S. was constructed based on some homogeneity in physical and social elements such as landforms, climate, and occupational structure (Fig. 2). It was believed that the regions may be "hiding" factors which could help explain variations in IHD mortality rates. The five regions (Coastal Plain, East Interior Plains, Eastern Highlands, West Interior Plains, and Western Plateaus and Mountains) were utilized as dummy (binary) variables.

In order to develop predictive models that might help in explaining the geographic differences in IHD death rates in the U.S., a forward addition stepwise regression procedure was applied to the data using the Statistical

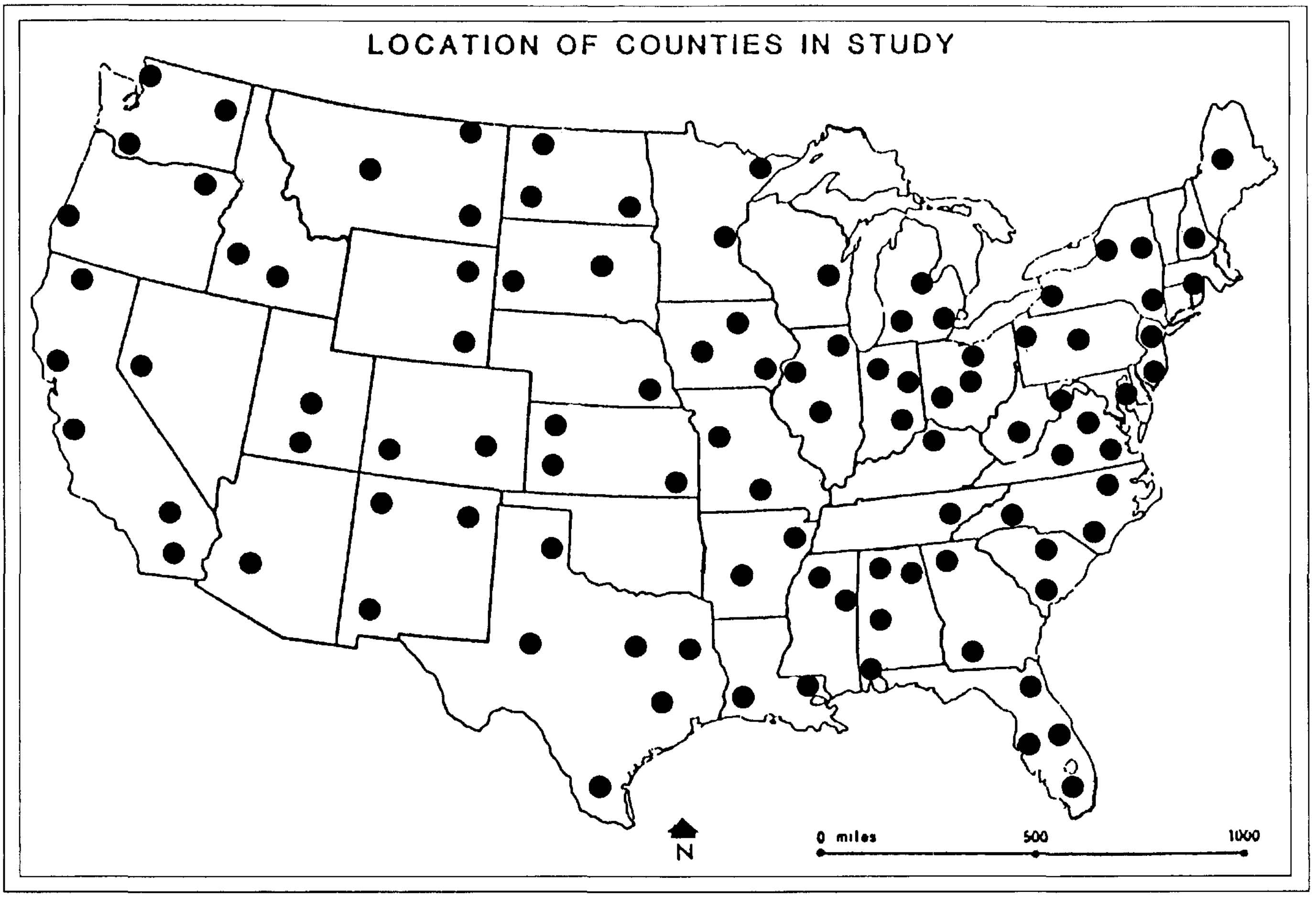

FIGURE 1. Location of counties in study.

Package for the Social Sciences (SPSS®) computer program. Stepwise regression is one method for selecting the "best" regression equation ("best" implies that the model is the one which produces the highest r^2 statistic when including only statistically significant coefficients and also possesses the least amount of deviation about the regression line).

RESULTS

The best explanatory model for IHD mortality rates utilizes four environmental variables: elevation, mean annual number of days with snowfall exceeding 1 in, median family income, and average annual concentration of sulfur dioxide; as well as the dummy variable, Eastern Highlands (Table 1). The coefficient of determination (r^2) shows that together, these five characteristics can explain 45.9% of the variance in IHD mortality rates. The model suggests that higher rates are likely to be found in areas of cold climate at low elevations in which there is a considerable amount of air pollution and in which incomes are low. The inclusion of the Eastern Highlands variable suggests that some factor or factors in that region may also partly explain the pattern of mortality rates. According to the intercept of the model, counties in the Eastern Highlands should, on the average, have about 50 more IHD deaths per 100,000 population per year than counties outside of that region.

DISCUSSION

What is it about Eastern Highlands that makes it stand out in terms of ischemic heart disease? The answer may lie somewhere in the physical and human geography of the region. Much of the region is characterized by a rugged ridge-and-valley topography with a paucity of level land. This is Appalachia and that term has long connoted poverty, isolation, and coal. There are limited transportation facilities in parts of the region and many residents live far from even mid-order central places (Bowman and Haynes 1963, Raitz and Ulack 1984).

Poverty does not appear to be the reason for the appearance of the Eastern Highlands in the model because of the median family income variable already present. Perhaps isolation or coal may be involved in some direct or indirect manner.

The greater propensity toward IHD mortality in the Eastern Highlands may be in part related to the dearth of medical resources in the region (Appalachian Regional Commission 1979; U.S. Department of Health and Human Services 1990). Much of the region, except for the larger communities, is clearly underserved; this could have an adverse effect on IHD rates as a substantial number of persons might go undiagnosed until time of death or may succumb to an immediate manifestation (heart attack) of IHD without receiving medical care that might delay death

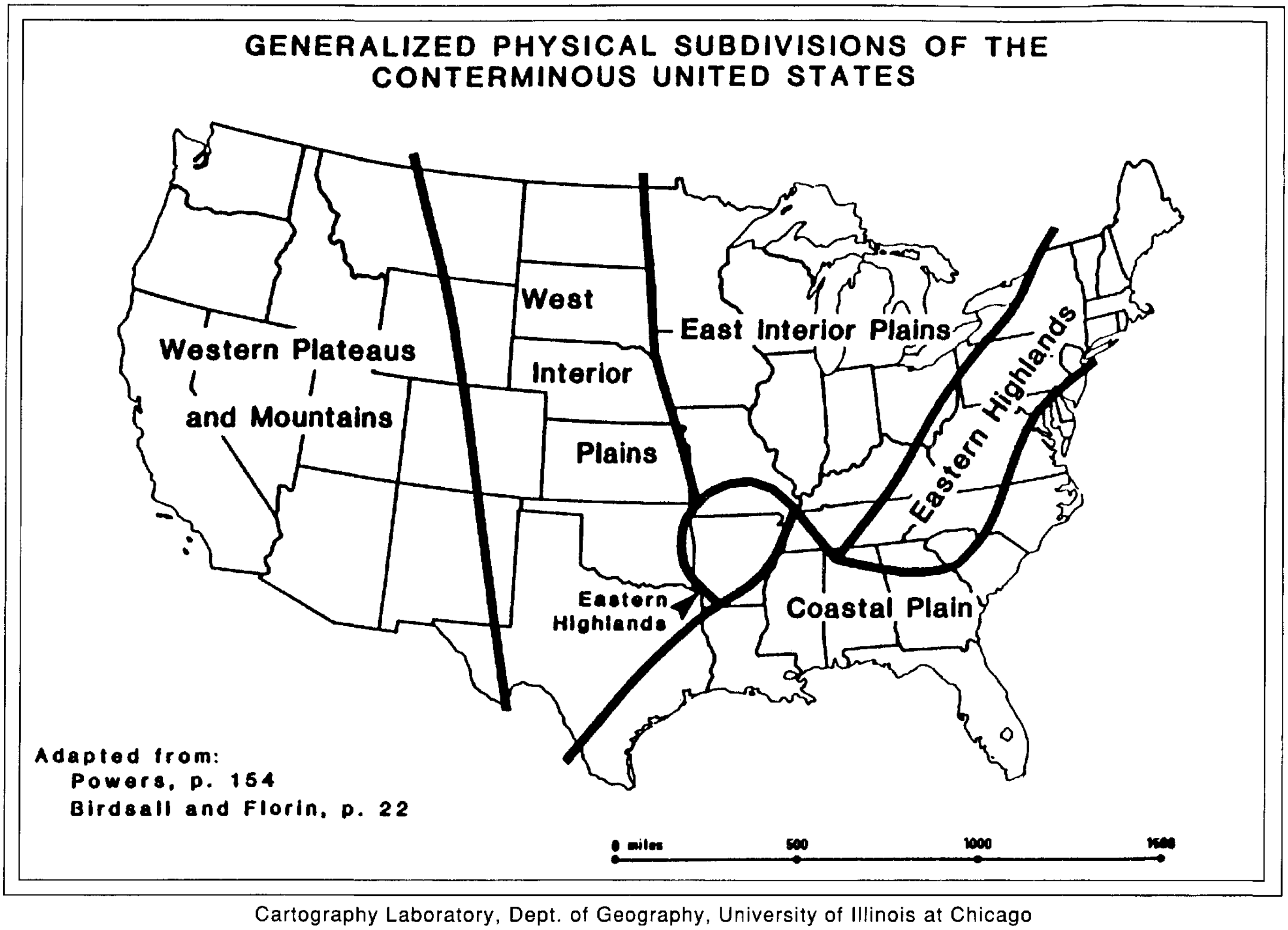

FIGURE 2. Generalized physical subdivisions of the conterminous United States.

TABLE 1

Model for ischemic heart disease mortality rates.

Equation: $Y = 416.8 + 47.5X_1 - .029X_2 + 314X_3 - .011X_4 + 2.9X_5$
Standard deviation about the regression line: 93.9
$r^2 = .459$ $F = 15.2$, significant at $p < .01$

Variables		Standardized Coefficient	*t*-Statistic
X_1 :	Eastern Highlands Region	.161	1.9 *
X_2 :	Mean elevation above sea level	-.438	-5.2 **
X_3 :	Mean annual number of days with snowfall exceeding 1 in	.366	4.3 **
X_4 :	Median family income	-.317	-3.6 **
X_5 :	Annual mean concentration of atmospheric sulfur dioxide	.233	2.6 **

* significant at $p < .05$
** significant at $p < .01$

or control the condition. Consultation rates may be significantly affected by distance from care providers (Phillips 1979). Because physicians tend to aggregate in places where there are existing medical facilities, and since these facilities tend to be market-oriented in location (Joroff and Navarro 1971), it was thought that the county physician/population ratio might serve well as a variable indicating the degree of medical services available. Pearson product-moment correlation indicated no real association ($r = 0.053$) between IHD death rates and the physician/population ratios in the 101 sample counties. An examination of the data also showed that many counties in other regions (especially the West Interior Plains) with low IHD rates also possess low physician/population ratios. Dearth of medical care does not appear to be a strong candidate for explaining the spatial variation of IHD death rates.

The apparently higher rates of IHD mortality in the Eastern Highlands may be in part related to the occurrence of coal worker's pneumoconiosis within the region. This disease is not limited just to coal miners as symptoms have been also noted in the wives of miners residing near mines in West Virginia and Pennsylvania (Lanehart, Boyle, and Enterline 1968). Persons with advanced pneumoconiosis may succumb to ischemic heart disease, and the IHD mortality rates in the Eastern Highlands could be in part reflecting the prevalence of pneumoconiosis. Bivariate correlation shows a weak positive ($r = 0.236$, $p < .05$) association between IHD mortality rates and coal miner's pneumoconiosis mortality rates in the sample. The stepwise procedure was reenacted, this time with the pneumoconiosis death rates as a variable candidate. This variable entered the model and replaced the dummy Eastern Highlands while the other environmental variables remained in the equation (Table 2). The r^2 for this model is .477 (compared to .459 for the one with the Eastern Highlands). From this it might appear that the dummy Eastern Highlands variable was masking the contribution of pneumoconiosis prevalence to the variance in the IHD mortality rates. The emergence of the pneumoconiosis variable, however, must be viewed with caution since its appearance could be mere statistical accident; all of the rates are low (less than 1.9) and there are several counties with rates of 0. The pneumoconiosis variable may have behaved like a binary variable, with the stepwise procedure simply replacing one binary variable for another. Its appearance, however, does suggest further investigation, perhaps a study of morbidity data in the Eastern Highlands.

Of the five regions in the study, the Eastern Highlands is the most homogeneous with regard to ancestry. The majority of the inhabitants are of Scotch-Irish or German descent (Raitz and Ulack 1984). This leads to suspicion that a genetic or lifestyle trait may partly be responsible for the appearance of the Eastern Highland variable in the model.

Another possible explanation for the higher rates in the Eastern Highlands may be related to tobacco use. The IHD-tobacco connection is well-documented (U.S. Department of Health and Human Services 1983; Barry, Mead, Nabel, et al. 1989). Parts of the region (e.g., the Piedmont and eastern Kentucky) are tobacco growing and processing areas, and one can presume greater tobacco consumption in such areas. However, as noted at the outset, personal factors such as cigarette smoking were excluded from analysis in the present study.

Two models were found which can be used to partly explain the spatial differences in IHD mortality rates in the United States. The first model was concerned with environmental factors and a regional element. The second model, presented with reservations, may aid in interpreting the regional element. In both models, elevation above sea level, the number of days with snowfall exceeding 1 in, median family income, and the average annual arithmetic mean concentration of sulfur dioxide (an index of air pollution) were the explanatory variables found to be significant. The environmental factors which surfaced in the models are particularly consistent with findings regarding snowfall (Rogot and Pudgett 1976), elevation (Singh, Cholan, Lal, et al. 1977), and income (Marmot and Theorell 1988). The role of air pollution is probably that of an aggravating agent (Strauss and Mainwaring 1984). The first model also incorporated the Eastern Highlands region as a significant variable, while in the second model that variable was supplanted by coal worker's pneumoconiosis mortality rates. The models explain a little less than 50% of the variance in IHD death rates in the United States.

The unexplained variance might be in part related to personal risk factors which are difficult to quantify and, more likely, to environmental factors not considered in this study. The predictive capability of the models is limited because there is a substantial amount of spread about the regression lines. The models indicate that, on the average, IHD death rates will be greater in counties at low elevation, with greater frequency of heavy snowfall, lower income levels, and considerable air pollution. The risk of IHD may be less in higher altitude places which have little air pollution, infrequent snowfall, and higher income levels.

TABLE 2

Model for ischemic heart disease mortality rates using the pneumoconiosis variable.

Equation: $Y = 428.5 - .032X_1 - .012X_2 + 3.1X_3 + 337X_4 + 95.7X_5$
Standard deviation about the regression line: 92.3
$r^2 = .477$ $F = 14.8$, significant at $p < .01$

Variables		Standardized Coefficient	*t*-Statistic
X_1 :	Mean elevation above sea level	-.441	-5.8
X_2 :	Median family income	-.344	-4.2
X_3 :	Annual mean concentration of atmospheric sulfur dioxide	.250	3.1
X_4 :	Mean annual number of days with snowfall exceeding 1 in	.339	5.1
X_5 :	Coal worker's pneumoconiosis mortality rate	.177	2.6

All coefficients significant at $p < .01$

There are, of course, some problems (especially the possibility of ecological fallacy) with using aggregate data, but the results here do appear to lend further support to several hypotheses concerning the epidemiology of ischemic heart disease, namely:

a) High altitude dwellers may be in some way protected from IHD because of their physiologic attributes which may be developed in response to barometric pressure conditions at high altitudes.
b) Air pollution has an aggravating role in cardiovascular disorders because some pollutants disrupt pulmonary functions and indirectly stress the heart.
c) Snowfall may bring about physical strain, mental stress, and access to service problems, all of which may raise the possibility of mortality from IHD.
d) Stress from poor living conditions may be a contributory factor in IHD. Poverty may also be a barrier to accessing medical treatment.

CONCLUSIONS

This study suggests that there may be some environmental factor or factors (perhaps, an association with coal worker's pneumoconiosis) present in the Eastern Highlands region of the United States which plays a role in that region's higher IHD mortality rates. Further research in terms of field study and/or statistical analysis in this region is necessary. A long-term investigation of persons who have migrated from suspected high risk environments to perceived lower risk areas (e.g., from the Eastern Highlands to the Western Plateaus and Mountains) might also provide some clues if the rates for migrants lessen with residence in the lower risk area.

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