Nina Siu-Ngan Lam, Ming Fan, and Kam-biu Liu

Spatial-Temporal Spread of the AIDS Epidemic, 1982–1990: A Correlogram Analysis of Four Regions of the United States

We applied correlogram analysis to county-level AIDS data of four regions—the Northeast (Delaware, the District of Columbia, Maryland, New Jersey, New York, and Pennsylvania), California, Florida, and Louisiana—for the period 1982–1990 to characterize the spatial-temporal spread of the AIDS epidemic. Correlograms computed from yearly incidence rates differ substantially among these four regions, revealing regional differences in the spatial patterns and intensity of AIDS spread. A general trend of increasing spread to rural America, however, can still be detected. Contagious spread was predominant in the Northeast throughout the nine-year period, whereas California was dominated by hierarchical spread through time. The spatial-temporal changes of AIDS incidence patterns were most drastic in Florida, where the correlograms show hierarchical spread in the early years and then contagious spread in the later years. As a representative region for most other states in the United States, Louisiana has low spatial autocorrelation and no definite spatial pattern of spread. Grouping data into three-year periods for states with low yearly incidence rates such as Louisiana should help identify the dominant trends for these states. The correlogram results could provide useful insights into the specification of spatial models for AIDS forecasting.

INTRODUCTION

First diagnosed in 1981, the Acquired Immune Deficiency Syndrome (AIDS) epidemic has entered its second decade with many unanswered questions. The World Health Organization estimates that roughly thirteen million people have

This research is supported by a research grant (no. LEQSF(1990–92)-RD–A–05) and an enhancement grant (no. LEQSF(1991–92)ENH–29) from the State of Louisiana Board of Regents. The authors thank the government health agencies of all fifty states for providing the AIDS caseload data.

Nina Siu-Ngan Lam is professor of geography, Ming Fan was a Ph.D. student, and Kam-biu Liu is professor of geography in the Department of Geography and Anthropology of Louisiana State University. Professor Lam is also adjunct professor in the Department of Epidemiology and Community Health, Louisiana State University.

Geographical Analysis, Vol. 28, No. 2 (April 1996)
Submitted 8/93. Revised version accepted 9/94.

been infected with the human immunodeficiency virus (HIV) and that by the year 2000, that number may triple (Jasny 1993). In the United States, the Centers for Disease Control and Prevention (CDC) estimates that 1 to 1.5 million people carry the HIV, all of whom will develop AIDS after an average ten-year incubation period (Merson 1993).

In the absence of a cure or vaccine, effective prevention and health care allocation programs must be developed. Such programs require adequate information on *where*, *when*, *how*, and *how much* of the disease has spread. Many AIDS researchers have already pointed to the need for more detailed AIDS data, such as data by county, and more spatial analysis of the data (for example, Layne et al. 1988; Gardner et al. 1989a; Casetti and Fan 1991; Shannon, Pyle, and Bashur 1991; Gould 1989; Gould et al. 1991; Loytonen 1991; Golub, Gorr, and Gould 1993). Toward this end, we have collected the AIDS caseload data by county from individual state agencies for the entire United States for the period 1982–1990. An important national trend of increasing spread of AIDS in rural America during this nine-year period has been documented by Lam and Liu (1994). The present study utilizes the technique of correlogram analysis (Cliff and Ord 1973, 1981; Cliff et al. 1975, 1981) to quantify the spatial-temporal patterns of spread and to examine if such trends existed in four selected regions in the United States—the Northeast (Delaware, the District of Columbia, Maryland, New Jersey, New York, and Pennsylvania), California, Florida, and Louisiana.

PREVIOUS STUDIES

Previous studies concentrating on the spatial dimension of the AIDS epidemic generally fall into two categories. The first focuses on the broader cultural aspects of the disease, and the second on technical modeling and forecasting. Dutt and his group (Dutt et al. 1987) analyzed the geographical patterns of AIDS in 1981–1986 in the United States using the data from the CDC. The data they used are at the state or large statistical metropolitan areas (SMA) level. Distinct regional variations in AIDS incidence by risk groups (for example, homosexual, intravenous drug user, hemophiliac) were found, while AIDS incidence by age cohort has uniform patterns. Their study is among the first to map the geographical distributions and analyze the spatial dimension of the AIDS epidemic. Unfortunately, the data used in their study are too coarse for further detailed analyses.

Wood (1988) presented an overview of the global pattern of AIDS diffusion and proposes three conceptual models of AIDS diffusion which are similar to those proposed by Chin and Mann (1988). The AIDS North model, referring to North America and western Europe, is urban based and primarily confined to homosexuals and IV drug users. The AIDS South model, of central Africa and the Caribbean, postulates the spread from cities into rural regions and affecting primarily heterosexuals. The third model, an AIDS North/South hybrid, seems to apply to other third world regions. These models are broad generalizations of different AIDS patterns in different parts of the world. Gould (1989) extended the views of Wood and further emphasized the need for modeling using fine-resolution data. Labeling AIDS as a slow plague, Gould later in his book (1993) painted a vivid and horrifying story of the epidemic and urged the need for more spatial modeling. Shannon and Pyle (1989) and Shannon and others (1991) discussed thoroughly the origin and diffusion of AIDS, information essential to an understanding of the present epidemic.

At a more empirical level, Gardner and others (Gardner et al. 1989a and b) used the county-based HIV data obtained through the Department of Defense's HIV screening program for military applicants to identify the trend of expansion diffusion from high-prevalence areas to low-prevalence areas. They contended that these spatial-temporal trends were obscured in previous studies because statewide summary data were used, and that data at a finer scale (county level or finer) should be used for spatial diffusion modeling. Using a national county database on AIDS incidence, Lam and Liu (1994) further confirmed the spread of AIDS in rural America at the national level. Similar conclusions for Finland based on their national HIV data have also been reported (Loytonen 1991).

Literature on modeling the spatial diffusion of HIV/AIDS and forecasting its spread across both time and space is very limited. The addition of the spatial dimension compounds the already complicated forecasting task, as key parameters that are needed for AIDS modeling are unknown, such as the length of incubation period, percentage of HIV infection, and percentage of homosexuals in the population. Casetti and Fan (1991) applied the expansion method to examine the spatial spread of the AIDS epidemic in Ohio. Gould and others (1991) suggested, on the other hand, the use of spatial adaptive filtering method for predicting the next maps of AIDS. More recently, Golub and others (1993) introduced a spatial compartment model for HIV/AIDS transmission which includes hierarchical and expansion spatial diffusion, and they obtained a reasonably good fit for the Ohio AIDS incidence data.

This paper is an empirical study of AIDS incidence rates for four regions in the United States. Using spatial correlograms computed from yearly incidence rates by county for 1982–1990, we examine if the epidemic spreads in a recognizable way, such as hierarchical or contagious spread, and whether the spatial-temporal patterns of spread are similar among the four regions. Specifically, we test if these regions follow the national trend of rural spread and if the intensity and patterns of such spread are consistent among these regions. If there is little variation in the form of the correlograms among the regions, then a uniform spatial diffusion model may be applied subsequently to predict the next AIDS maps. On the contrary, if the correlograms differ substantially among regions, spatial models with different parameters must be specified to produce more accurate forecasting for each region. The results from our correlogram analysis should reveal this information, thus providing useful insights into the specification of AIDS models for more accurate forecasting.

DATA

The data used in this study were collected by us from the state health agencies of all fifty states and contain yearly AIDS caseload data by county or health district for the period 1982–1990. The AIDS caseload data were converted into rates by using the 1986 population figures as the common denominator (number of cases / 1986 population × 100,000). A more detailed discussion of this national database can be found in Lam and Liu (1994). Figure 1 is a map of the 1990 cumulative AIDS incidence rates by county. The four regions selected for this study are (1) the Northeast, which includes Delaware, the District of Columbia, Maryland, New Jersey, New York, and Pennsylvania (178 counties in total); (2) California (58 counties); (3) Florida (67 counties); and (4) Louisiana (64 parishes) (Figures 2–3). The first three regions/states were selected because of their high AIDS incidence rates. California and Florida are two

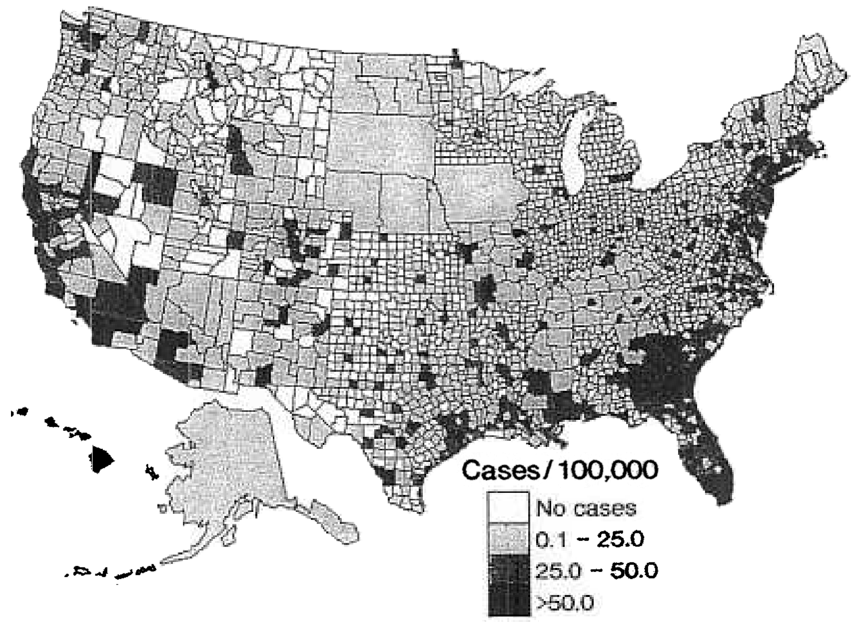

FIG. 1. Cumulative AIDS Incidence Rates by County as of the End of 1990

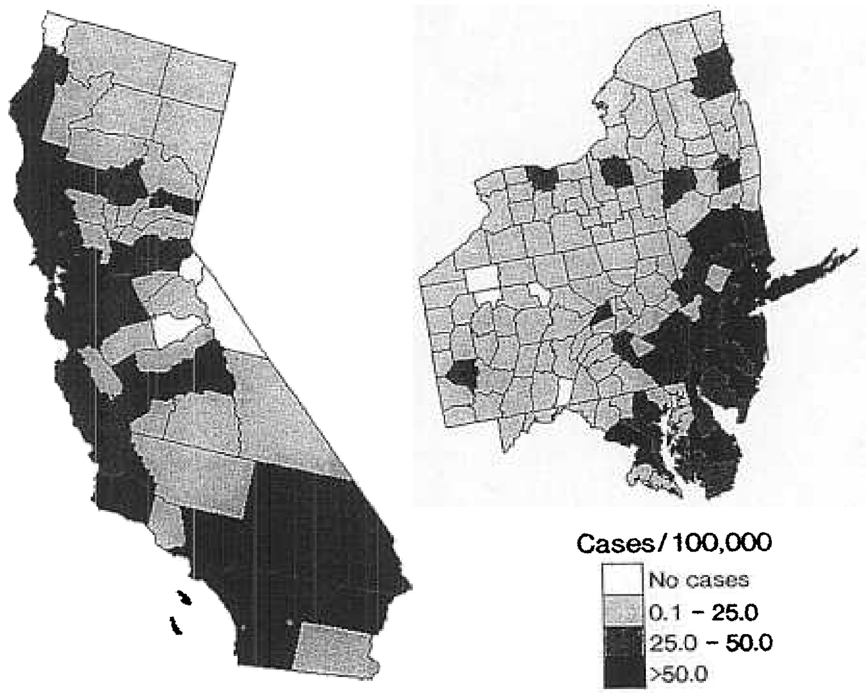

FIG. 2. The Northeast Region and California: Cumulative AIDS Incidence Rates by County as of the End of 1990. (The four regions in Figures 2 and 3 are of the same scale.)

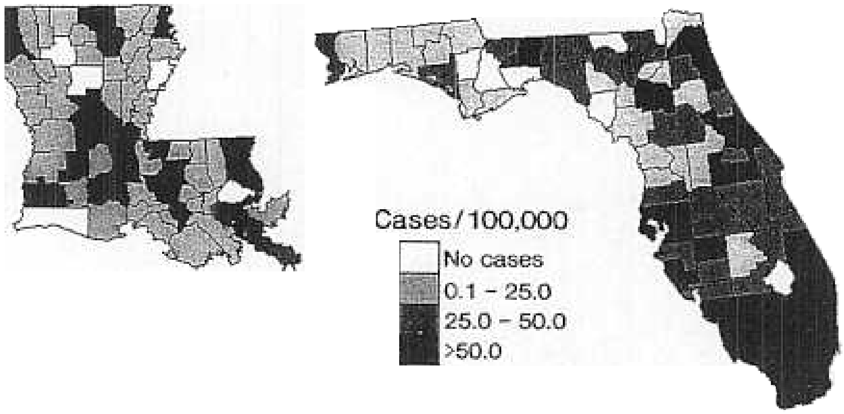

FIG. 3. Florida and Louisiana: Cumulative AIDS Incidence Rates by County as of the End of 1990

distinct regions but they are comparable in terms of area, population size, number of counties, and AIDS incidence rates. We use the Northeast region in lieu of a single state because it provides an example of AIDS spread in a large megapolis region. Louisiana, which ranks twenty-first in number of population and twelfth in the cumulative number of AIDS cases, represents an "average" state in the United States in terms of the magnitude and diffusion stage of the AIDS epidemic. All four regions have AIDS incidence rates above the national average. Together they account for 63 percent of the nation's total AIDS cases.

METHODS

We applied the correlogram method to quantify the spatial patterns of AIDS spread. Spatial correlograms were computed for the AIDS incidence rates each year for each region, resulting in 9x4 correlograms. Spatial correlograms are diagrams showing spatial autocorrelation on the Y axis and the spatial scale or distance interval at which the autocorrelation is computed on the X axis. When comparing the spatial correlograms through time, the spatial-temporal patterns of spread can be revealed systematically. Despite its usefulness, correlogram analysis has seldom been applied to medical or other geographic data, apart from the extensive work by Cliff and Ord (Cliff and Ord 1973, 1981; Cliff et al. 1975, 1981).

Spatial autocorrelation is a central concept in geography that has been discussed extensively in the 1970s (for example, Haggett, Cliff, and Frey 1977). Lately, the push for more spatial analysis in GIS and remote sensing has made the spatial autocorrelation statistic popular again (for example, Anselin, Dodson, and Hudak 1993). Spatial autocorrelation refers to the degree of association of a variable in relation to its location. A useful measure of spatial autocorrelation is Moran's I. Moran's I is positive when nearby areas are similar in attributes, negative when they are dissimilar, and approximately zero when attribute values are arranged randomly and independently in space. Moran's I is often preferred over other indices in the literature and is therefore used here because its values follow closely our intuitive notions of positive and negative autocorrelation and it is less affected by deviation from the normal distribution (Cliff and Ord 1973; Goodchild 1986). The formula for Moran's I index is as follows:

$$I = \frac{\sum_i \sum_j W_{ij} C_{ij}}{S^2 \sum_i \sum_j W_{ij}} \tag{1}$$

where C_{ij} represents the similarity of i's and j's attributes; S^2 is the sample variance; W_{ij} represents the similarity of i's and j's locations, and $W_{ii} = 0$ for all i (Goodchild 1986). In this study, W_{ij} is the simple adjacency matrix in which W_{ij} is given the value of 1 if i and j share a common boundary, and zero otherwise. Alternatively, a continuous measure of proximity can be defined in terms of some function of the distance.

The attribute similarity measure between two areas (C_{ij}) is defined as

$$C_{ij} = (x_i - \bar{x})(x_j - \bar{x}) \tag{2}$$

where x_i is the value of the attribute for area i, $\bar{x}$ is the mean of the attribute.

Moran's I index is based on the covariance of the attribute, which is different from another spatial autocorrelation index, Geary's C, where the variance of the attribute is used. When covariance (Moran's I) is used, the diagram constructed to show the relationship between spatial autocorrelation and spatial lag is called a correlogram, but when variance (Geary's C) is used, the respective diagram is called a variogram.

The significance of the resultant spatial autocorrelation values derived from equation (1) must be tested by computing the z scores using either the normal or randomization assumption (Cliff and Ord 1973). The normal assumption states that the sample values are drawn from a normally distributed population, whereas the randomization assumption states that the samples represent a random arrangement of attribute values (that is, makes no assumption of the underlying distribution). The AIDS data in this study are highly skewed, with most counties having low rates, and the distribution is not a normal one. Therefore, the randomization assumption is more appropriate and used in this study.

The formulas for determining the mean, variance, and the significance level of the two statistics based on the randomization assumption can be found in Cliff et al. (1975, p. 154) and Goodchild (1986, p. 25). The resultant z scores, instead of I values, are plotted against spatial lags. Based on a two-tailed test with a significant level of $\alpha = 0.05$, a z value outside the range of ± 1.96 (shown with two dotted lines in Figures 4–7) is considered significantly spatially autocorrelated in either positive or negative direction.

Spatial autocorrelation measures are highly scale-dependent, that is, the values change if different sizes of polygons or grids are used. One way to overcome this weakness of the measures is to make scale explicit by determining the spatial autocorrelation function over distance and present it as a correlogram. In this study, the spatial scale is made explicit through a redefinition of the adjacency matrix W_{ij}. The first-order adjacency is defined as polygons sharing a common boundary, while the second-order adjacency is defined as two polygons that are adjacent, but separated by exactly one intervening polygon. The same idea can be extended up to any order in space.

We developed a computer program to retrieve topological information (that

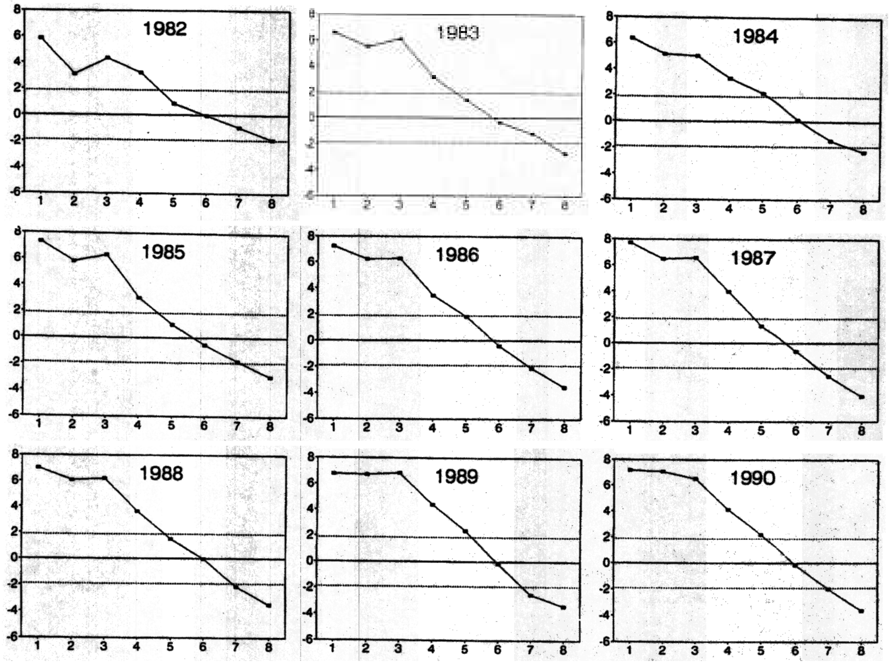

FIG. 4. Correlograms for the Northeast Region, 1982–1990. For Figures 4–7, the x axis represents spatial lag of 1, 2, to 8 counties apart; y axis shows the z values at each lag; values outside the two dotted lines are considered statistically significant at $\alpha = 0.05$ level.

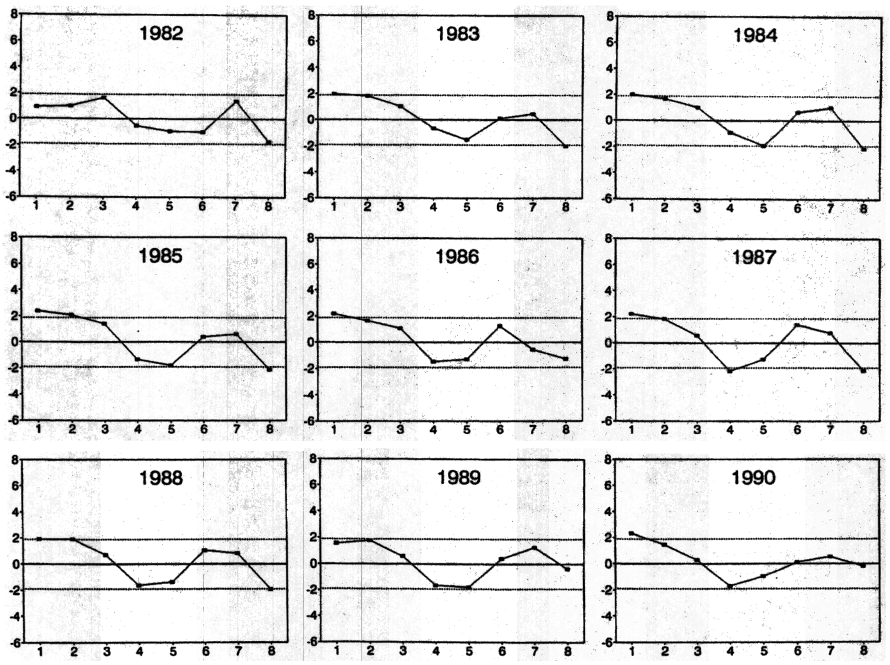

FIG. 5. Correlograms for California, 1982–1990

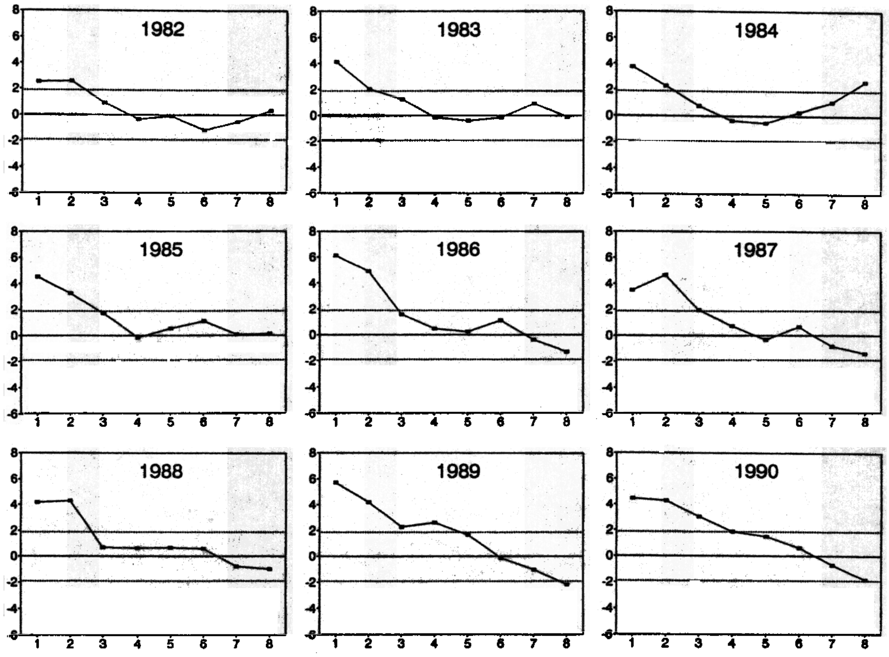

FIG. 6. Correlograms for Florida, 1982–1990

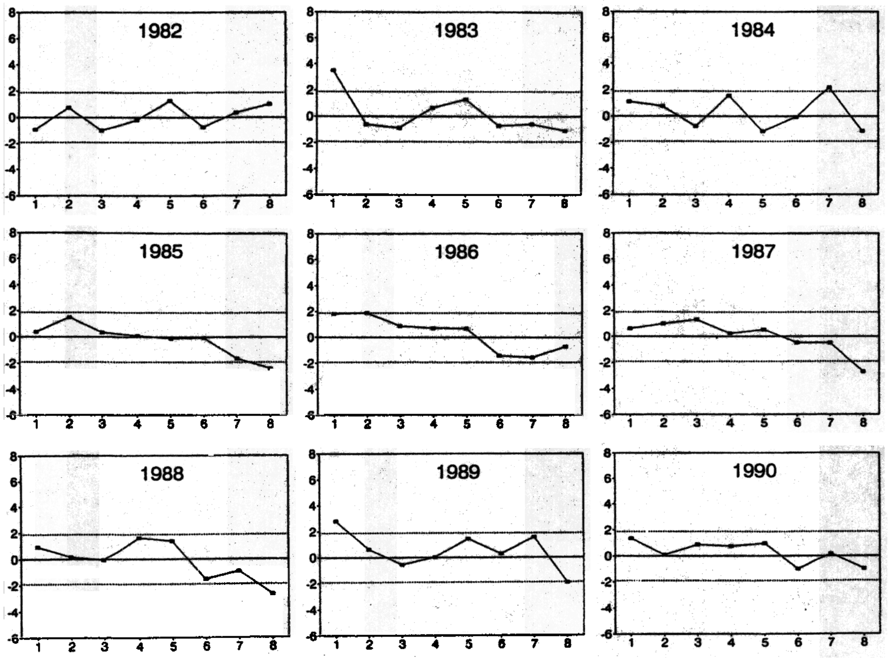

FIG. 7. Correlograms for Louisiana, 1982–1990

is, polygons sharing common boundaries) from the Arc/Info GIS software and to construct the first-order adjacency matrix W_{ij} by coding 1 in W_{ij} if polygons i and j share a common boundary, and 0 otherwise. The higher-order adjacency matrices were derived by powering the first-order matrix and eliminating circular routes using the algorithm by Haggett, Cliff, and Frey (1977, pp. 319–20). A detailed description of the algorithm and procedures can be found in Fan, Lam, and Liu (1993). Once the kth ($k = 1, 2 \ldots$)-order spatial adjacency matrix has been constructed, the kth-order spatial autocorrelation and the corresponding z scores can be computed.

Following the spatial diffusion terminology (Morrill, Gaile, and Thrall 1988), AIDS spread is a form of expansion diffusion, which spreads from one place to another. Expansion diffusion occurs in two ways: contagious or hierarchical spread. Contagious spread is a function of distance, operating in a centrifugal manner from the source region outward. Hierarchical spread transmits the disease through an ordered sequence of places, spreading from cities to cities. We would expect a smoothly declining correlogram if contagious spread is the dominant factor in affecting the spatial pattern of AIDS spread (that is, distance is the main factor in determining the similarity of yearly AIDS incidence rates among counties). If high positive autocorrelation exists at the same time, the spatial pattern is interpreted as strongly symmetrical, with large patches of areas having high yearly increase in AIDS incidence and serving as major centers of spread.

Any departures from smooth decline in the correlogram would suggest the existence of other factors, and in most cases these factors are related to the urban hierarchy of the region, such as population density. For example, if the curve declines and then goes up after several lags, forming a V-shaped curve, then the implication is that similarity of yearly AIDS incidence rates exists for counties that are several counties apart. In such cases, we can interpret that such similarity comes from counties with big cities, which are often several counties apart, and that the spatial patterns are heterogeneous and the diffusion process is mainly hierarchical (Cliff and Ord 1981, p. 22). More often, however, the correlogram curves are irregular and undulating, signaling the existence of a mixed hierarchical/contagious diffusion process, making the interpretation of the correlogram that is not smoothly declining more difficult.

If the AIDS diffusion patterns of the four regions follow what has been suggested in previous studies, that is, that hierarchical spread is predominant in early years and contagious spread to nearby rural counties is predominant in later years (Gardner et al. 1989a and b; Lam and Liu 1994; Loytonen 1991), then we would expect that the time-series correlograms would shift from irregular or V-shape to smoothly declining through time. We examine below if this hypothesis is true at the regional level.

RESULTS AND INTERPRETATION

The yearly correlograms (Figures 4–7) vary substantially between regions, indicating regional variations in the spatial-temporal patterns of AIDS spread. The hypothesis that AIDS diffusion is hierarchical in early years and contagious in later years is most evident in Florida. For the other three regions, AIDS diffusion patterns are more subtle. The following is a synopsis of the results for each region, followed by a discussion of the possible use of our findings from the correlogram analysis. To aid interpretation, basic statistics on the number of new AIDS cases each year, yearly rates, cumulative cases, and cumulative rates are presented in Figures 8 and 9.

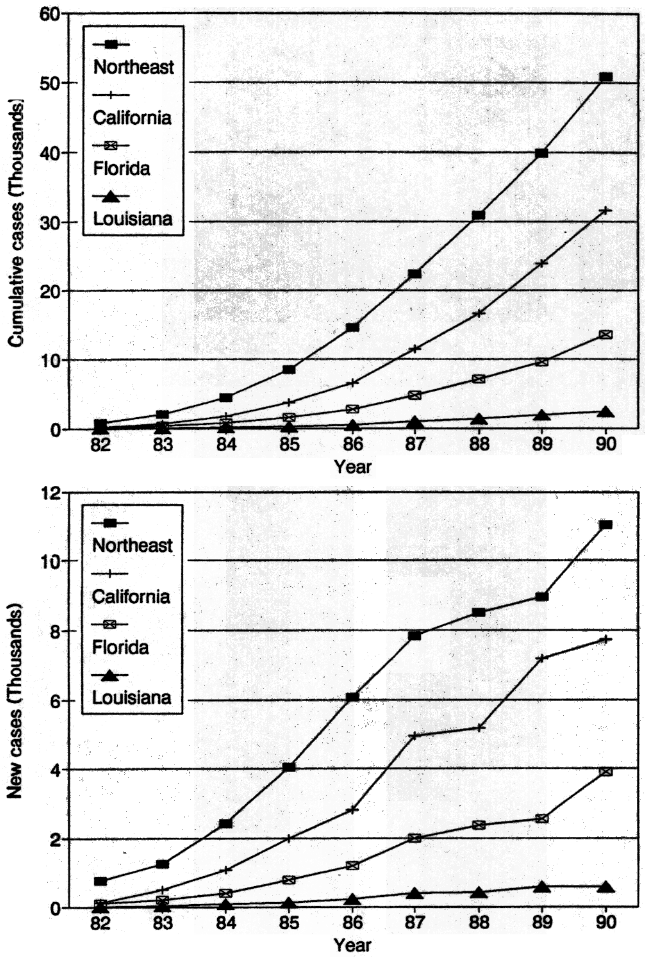

FIG. 8. Comparison of the Four Regions in Yearly and Cumulative Cases, 1982–1990

Northeast

The Northeast region had about one-third of the nation's total cumulative number of AIDS cases (50,926 cases) as of December 1990. High-prevalence areas were along the eastern seaboard at the border between New York and New Jersey and in areas surrounding New York City (Figure 2). New York County ranked second in the nation in terms of cumulative incidence rates (896 cases per 100,000 people), where about 1 in 112 people developed AIDS for the nine-year period, or 1 in 1,005 people each year. A number of counties in New York (Westchester) and New Jersey (Passaic, Middlesex, Onondaga, Mercer, and Morris) were among the top twenty-five counties that had the highest rates of increase in AIDS during the first period, 1982–84, but none of the counties from this region were included in the top twenty-five lists in the later two periods (1985–87 and 1988–90) (Lam and Liu 1994). This indicates that the epidemic occurred in this region much earlier than in other parts of the nation. However, we should caution that although the rates of increase

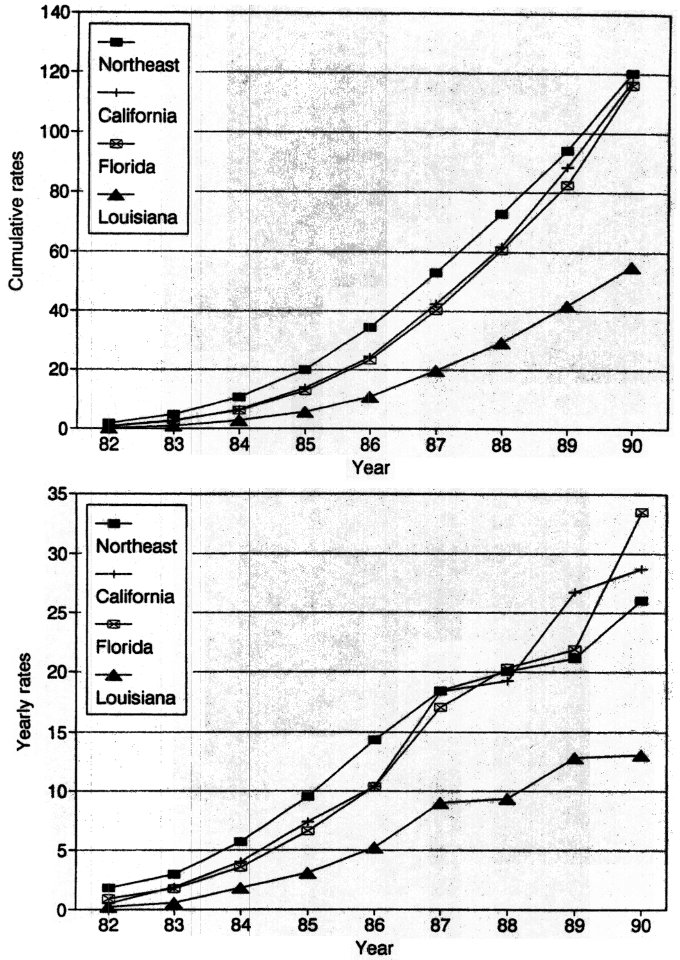

FIG. 9. Comparison of the Four Regions in Yearly and Cumulative Rates, 1982–1990

were not as high as other regions in later years, the number of new AIDS cases was still rising each year (see Figure 8).

The Northeast region had the highest positive and negative spatial autocorrelation (highest z scores) among the four regions, and the form of the correlograms is most distinctive and consistent through time (Figure 4). Throughout the nine-year period, the curves generally maintain the same form of decline with distance, with the first three lags having the highest autocorrelation in the last two years (1989 and 1990). These smoothly declining correlograms show that contagious spread was dominant in the Northeast. Also, the high spatial autocorrelation indicates a symmetrical pattern, with large patches of counties having high yearly AIDS incidence rates serving as centers of spread to the neighboring counties. In the Northeast, such centers of spread were composed of counties that can extend up to three counties apart. Finally, a closer look at the correlograms shows that a weak V-shape in the first three lags does exist in the early years (1982–88), indicating the existence of hierarchical spread in early years, as major cities are close (one or two counties apart) on the eastern seaboard. As a result, we can interpret that the Northeast follows the national trend and the hypothesis that hierarchical spread is predominant earlier and contagious spread occurs later is true in this region.

California

About one-fifth of the nation's AIDS cases came from California (31,617 cases) as of the end of 1990, with high prevalence occurring in San Francisco, Los Angeles, and their neighboring counties (Figure 2). In terms of cumulative incidence rates, San Francisco County with a cumulative incidence rate of 1176.50 (cases/100,000 people) ranked first in the nation, implying that approximately 1 in 85 people had been diagnosed with AIDS during the nine-year period (or 1 in 750 people each year). San Francisco, Los Angeles, and the counties next to them (Marin, Orange) were found to have the highest rates of increase during the first period (1982–84), but in 1988–90, none of the counties from California was among the top twenty-five counties that had the highest rates of increase (Lam and Liu 1994). Similar to the Northeast region, California acquired the epidemic very early.

Despite California's high AIDS incidence, spatial autocorrelations computed for California are unexpectedly low (Figure 5), with only a few of them significant at the $\alpha = 0.05$ level. Similar to the Northeast, the general form of the correlograms throughout the nine-year period is quite stable, but unlike the Northeast, the curves are V-shaped, with another high positive autocorrelation point at lag 6 or 7. These correlograms suggest that AIDS spread in California was dominated by hierarchical diffusion, albeit a weak one. The high positive autocorrelation at lag 6 or 7 corresponds roughly to the distance between major cities such as San Francisco (the center in northern California) and Los Angeles and San Diego (the centers in southern California). Contagious diffusion occurs at spatial lags 1, 2, and 3, indicating the existence of AIDS spread from major urban counties to surrounding counties. Through time, it can be observed that the V-shaped curves become less and less prominent, suggesting a weak trend of contagious spread in the later years. Overall, the correlogram results do not support the hypothesis that hierarchical spread is being replaced by contagious spread in California. Instead, they show that in California hierarchical spread was still predominant as late as 1990.

Florida

Florida ranked third as a state in terms of the total number of AIDS cases (13,534 cases) cumulatively as of the end of 1990, with about 9 percent of the nation's total. But in terms of incidence rates, Florida was a very close third to the Northeast and California (Figure 9). More important, Figure 9 also shows that its annual incidence rate increased drastically and had surpassed the above two regions in 1990, becoming the highest in annual increase in AIDS incidence rate in the four regions. Orlando (Orange County) and Miami (Broward County) were among the top twenty-five counties that had the highest rates of increase in AIDS in 1982–84. But unlike the above two regions, three counties from this region, including Hardee (near Tampa), Okeechobee (near Palm Beach), and Nassau (near Jacksonville) were also included in the top twenty-five list in 1988–90 (Lam and Liu 1994). This is an alarming trend, indicating that a more effective AIDS prevention program is needed, especially in rural Florida.

Of all the correlograms, Florida's correlograms are the most drastic and fascinating. Not only are the spatial autocorrelations high, but also the correlograms change considerably through time. The correlograms have two general patterns: (1) that of 1982 to 1987 and (2) that of 1988 to 1990. In the first two periods (1982–87), high positive autocorrelation occurs at lags 1 and 2, then decreases until it rises again at lag 6, 7, or 8, forming a V-shaped curve. This suggests clearly the existence of contagious spread from major cities such as Miami to neighboring counties and hierarchical spread between cities. From 1988 on, the curve has stabilized to a gentle decline, a pattern similar to the Northeast, indicating the dominance of contagious spread from central cities to surrounding rural counties. The hypothesized pattern of initial hierarchical spread followed by contagious spread is most evident in Florida. The implication is clear: rural Florida should be given more consideration in preventing HIV/AIDS infection.

Louisiana

Louisiana ranked twelfth in the nation in the cumulative total number of AIDS cases (2,482 cases) as of the end of 1990. With less than 2 percent of the nation's total, Louisiana represented an "average" state in terms of the magnitude and stage of the AIDS epidemic. High-prevalence areas were clustered around cities such as New Orleans and Baton Rouge. Orleans Parish was in the top twenty-five list in 1982–84, whereas Avoyelles Parish, a remote parish (next to Alexandria) with population about 43,000, was among the top twenty-five counties in the nation that had the highest rates of increase in AIDS during 1988–90. Steady addition of new cases each year was evident throughout the nine-year period (Figures 8 and 9), and the trend is expected to continue in the next decade.

With only a few exceptions, the spatial autocorrelation indices for Louisiana parishes are generally low, below the statistically significant level. No definite pattern of correlograms can be found in Louisiana, and year-to-year fluctuation is high (Figure 7). This suggests that the region is quite diverse and AIDS incidence fluctuates from one county to another, with no definite centers of spread. The small value of yearly AIDS incidence rates may have contributed to the fluctuation of the correlograms. This small-number problem is common in medical data such as AIDS or cancer mortality statistics, where occurrence is still considered uncommon in most parts of the nation (Glick 1977; Meade, Florin, and Gesler 1988). A strategy to overcome this problem is to group the data into three three-year periods, 1982–84, 1985–87, and 1988–90 (Lam and Liu 1994). Revised correlograms based on data of these three-year periods could be constructed to examine the dominant trends of spread and spatial patterns. Nevertheless, the present correlograms constructed for Louisiana are expected to be "typical" for many other states in the country with relatively low AIDS prevalence.

As with any quantitative measures, the correlograms must be interpreted with caution. In addition to the scale-dependent problem of spatial autocorrelation measures, the definition of the spatial adjacency matrix (in a binary or continuous form) and the choice of a hypothesis-testing assumption (normal versus randomization) may affect the results and subsequent interpretation. Alternatively, future studies could include the experimentation of a series of weighting matrices to identify the appropriate distance functions that lead to high spatial autocorrelation. As for determining the z scores using a different assumption, we also computed the z scores using the normal assumption and found that the two sets of values deviate in some cases. This is expected when the data are not normally distributed (Glick 1977).

To a certain extent, the forms of the correlograms are influenced by the settlement pattern or urban structure of the region. For example, if large cities are located close to each other, a case similar to the Northeast, it would be difficult to identify whether the diffusion process is mainly hierarchical, contagious, or both. A follow-up study could be conducted to identify in each lag the number of urban-urban, urban-rural, and rural-rural links to support the interpretation of the correlograms (Cliff et al. 1975, p. 173).

The correlogram results could shed light on future spatial modeling and forecasting. They can be used to serve as a guide for calibrating and selecting parameter values in these spatial diffusion models. For example, if gravity-based models are used to forecast the future spread of AIDS and if contagious spread is found to be predominant in a region, a large distance-friction parameter might be used to simulate the effect of distance on AIDS spread. On the other hand, if hierarchical spread is found to be predominant, distance effect becomes minimal and a larger city-size parameter may be needed to emphasize its influence.

CONCLUSION

We have demonstrated in this paper the use of correlograms in describing quantitatively the spatial patterns and processes of AIDS diffusion in four regions (Northeast, California, Florida, and Louisiana) of the United States for 1982–90. Correlograms provide an effective and objective means of comparing the spatial-temporal patterns of AIDS spread among regions. The same technique can be applied to other regions or countries as a standard form of analysis for disease diffusion studies and to enhance comparison.

The correlograms show that regional variations in the spatial-temporal patterns of AIDS spread do exist. Yet the general trend of increasing spread to rural America, as documented in previous studies (Gardner et al. 1989a and b; Lam and Liu 1994), can still be detected. However, in some regions, such as Florida, this trend is more prominent, while in other regions, such as California, it is less prominent. The Northeast and Florida were found to be alike in that contagious spread is dominant, despite their differences in terms of area, population size, number of counties involved, and location. The correlograms of Florida also suggest a distinct switch from hierarchical spread in the early years to contagious spread in the later years. Although with low autocorrelations, California has consistently shown that hierarchical spread and contagious spread are equally important in this region, with weaker hierarchical spread in the later years. All these results suggest that in areas of the nation's highest AIDS incidence rates, such as the Northeast, California, and Florida, contagious spread has become a more prominent pattern. The disease is spreading from central cities to neighboring rural counties—a trend that is alarming and more difficult to cope with, as the resources in rural counties are generally fewer.

With due regard to its limitations, the information derived from the correlograms can be used to help determine the parameters used in AIDS spatial forecasting models, in addition to gaining insights into the spatial-temporal patterns of the epidemic. Our findings imply that if a gravity-based model is used, for example, to predict AIDS incidence in the next decade, a larger distance-friction parameter might be used for the Northeast and Florida, whereas for California, a larger population-attraction parameter might be more appropriate to simulate the presence of hierarchical spread. In the case of Louisiana where no definite patterns of AIDS spread was found, our results point to the need to group AIDS data into longer time intervals (for example, three-year periods) for states with relatively low AIDS prevalence for better description and prediction.

LITERATURE CITED

Anselin, L., R. F. Dodson, and S. Hudak (1993). "Linking GIS and Spatial Data Analysis in Practice." *Geographical Systems* 1, 3–23.

Casetti, E., and C. C. Fan (1991). "The Spatial Spread of the AIDS Epidemic in Ohio: Empirical Analysis Using the Expansion Method." *Environment and Planning A* 23, 1589–1608.

Chin, J., and J. M. Mann (1988). "The Global Patterns and Prevalence of AIDS and HIV Infection." *AIDS* 2, S247–S252.

Cliff, A. D., and J. K. Ord (1973). *Spatial Autocorrelation*. New York: Methuen, Inc.

———. (1981). *Spatial Processes: Models and Applications*. London: Pion Limited.

Cliff, A. D., P. Haggett, J. K. Ord, K. A. Bassett, and R. B. Davies (1975). *Elements of Spatial Structure: A Quantitative Approach*. Cambridge: Cambridge University Press.

Cliff, A. D., P. Haggett, J. K. Ord, and G. R. Versey (1981). *Spatial Diffusion*. Cambridge: Cambridge University Press.

Dutt, A. K., C. B. Monroe, H. M. Dutta, and B. Prince (1987). "Geographical Patterns of AIDS in the United States." *The Geographical Review* 39, 456–71.

Fan, M., N. S.-N. Lam, and K.-b. Liu (1993). "Using GIS to Model the Spatial Spread of the AIDS Epidemic in the United States." *Technical Papers, 1993 ACSM*/ASPRS Annual Convention, 186–95.

Gardner, L. I. Jr., J. F. Brundage, D. S. Burke, J. G. McNeil, R. Visintine, and R. N. Miller (1989a). "Spatial Diffusion of the Human Immunodeficiency Virus Infection Epidemic in the United States, 1985–87." *Annals of the Association of American Geographers* 79, 25–43.

———. (1989b). "Evidence of Spread of the Human Immunodeficiency Virus Epidemic into Low-Prevalence Areas of the United States." *Journal of Acquired Immune Deficiency Syndrome* 2, 521–32.

Glick, B. J. (1977). *Environment and Disease: A Spatial Analytic Model and Application to Cancer in Pennsylvania*. Ithaca, N.Y.: Program in Urban and Regional Studies, Cornell University.

Goodchild, M. F. (1986). *Spatial Autocorrelation*. CATMOG (Concepts and Techniques in Modern Geography) 47. Norwich, England: Geo Books.

Golub, A., W. L. Gorr, and P. R. Gould (1993). "Spatial Diffusion of the HIV/AIDS Epidemic: Modeling Implications and Case Study of AIDS Incidence in Ohio." *Geographical Analysis* 25 (April), 85–100.

Gould, P. (1989). "Geographic Dimensions of the AIDS Epidemic." *The Professional Geographer* 41, 71–78.

———. (1993). *The Slow Plague: A Geography of the AIDS Pandemic*. Cambridge, Mass.: Blackwell Publishers.

Gould, P., J. Kabel, W. Gorr, and A. Golub (1991). "AIDS: Predicting the Next Map." *Interface* 21, 80–92.

Haggett, P., A. D. Cliff, and A. Frey (1977). *Locational Analysis in Human Geography*. New York: John Wiley & Sons.

Jasny, B. R. (1993). "Editorial—AIDS 1993: Unanswered Questions." *Science* 260, 1219.

Lam, N. S.-N., and K.-b. Liu (1994). "Spread of AIDS in Rural America, 1982–1990." *Journal of Acquired Immune Deficiency Syndrome* 7, 485–90.

Layne, S. P., T. G. Marr, S. A. Colgate, J. M. Hyman, and E. A. Stanley (1988). "The Need for National HIV Databases." *Nature* 333, 511–12.

Loytonen, M. (1991). "The Spatial Diffusion of Human Immunodeficiency Virus Type 1 in Finland, 1982–1997." *Annals of the Association of American Geographers* 81, 127–51.

Meade, S. M., J. W. Florin, and W. M. Gesler (1988). *Medical Geography*. New York: The Guilford Press.

Merson, M. H. (1993). "Slowing the Spread of HIV: Agenda for the 1990s." *Science* 260, 1266–68.

Morrill, R., G. L. Gaile, and G. I. Thrall (1988). *Spatial Diffusion*. Newbury Park, Calif.: SAGE Publications.

Shannon, G. W., and G. F. Pyle (1991). "The Origin and Diffusion of AIDS: A View from Medical Geography." *Annals of the Association of American Geographers* 79(1), 1–24.

Shannon, G. W., G. F. Pyle, and R. L. Bashur (1991). *The Geography of AIDS*. New York: The Guilford Press.

Wood, W. B. (1988). "AIDS North and South: Diffusion Patterns of a Global Epidemic and a Research Agenda for Geographers." *The Professional Geographer* 40, 266–79.

Richard Thomas

Alternative Population Dynamics in Selected HIV/AIDS Modeling Systems: Some Cross-National Comparisons

This paper examines how demographic representations for the different risk populations influence the epidemic outputs of a simple process-based HIV/AIDS model. Alternative demographic specifications are presented in conjunction with transmission rules for both community and regional settings. Then, the existence, or nonexistence, of equilibrium solutions to these various models is determined to evaluate whether the forecast AIDS series will persist indefinitely or eventually terminate. Last, simulations for countries with distinctive birth and death rates are used to summarize the effect of this variation on the timing and size of the epidemic. All the results assume an epidemic that is unaffected by the practice of safer sex.

In their analysis of chaos and periodicity in childhood disease epidemics, Olsen and Schaffer (1990) note how it is the usual modeling practice to assume that population size remains constant throughout the duration of study. This simplification, which also implies an equality between births and deaths, is justifiable on two counts: first, the incidence of most of these infections displays annual, or biannual, periods during which population change is likely to be negligible; and second, these infections usually make a very small contribution to human mortality. Neither of these statements, however, is applicable to the incidence of HIV (Human Immunodeficiency Virus)/AIDS (Acquired Immune Deficiency Syndrome), where the long incubation period from infection to the onset of overt symptoms of disease is largely responsible for the slow, but deadly, progress (Gould 1993) of a pandemic with an, as yet, unobserved periodicity (Thomas 1993a; 1993b). These revised circumstances suggest that birth and death rates might well vary during the epidemic causing the populations at risk to be replaced unevenly through time. Similarly, the long experience of AIDS in central Africa (Barnet and Blaikie 1992; Smallman-Raynor and Cliff 1991) indicates the potential of the disease to make a significant contribution to total mortality.

To date, the consequences of these demographic effects have not been explored in great detail in the literature on modeling the progress of HIV/AIDS. In their recent review of this topic, for example, Anderson and May (1991) describe a

The author thanks Graham Bowden for preparing the diagrams.

Richard Thomas is reader in geography at the University of Manchester.

Geographical Analysis, Vol. 28, No. 2 (April 1996)