POPULATION AND BIOLOGY

Bridge between Disciplines
Proceedings of a Conference

Edited by

Nathan KEYFITZ

ORDINA EDITIONS
10, place St Jacques
B-4000 Liège (Belgium)
1984

CHAPTER 12

DEMOGRAPHY AND MORBIDITY: A SURVEY OF SOME INTERACTIONS

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SUMMARY

This paper surveys the interactions between demographic variables and morbidity. Morbidity is defined as non-fatal diseases or the effects of disease prior to death. The paper describes empirical studies of how demographic variables affect morbidity and of how morbidity affects demographic variables. The review aims to be comprehensive in scope but selective in detail. Examples are emphasized rather than grand generalizations because the study of these interactions is largely at an early stage of natural history. Several opportunities for further study, as well as some useful research methods, are indicated.

1. INTRODUCTION

The purpose of this paper is to survey some relations between demography and morbidity. Under morbidity, I consider non-fatal diseases or the effects of disease prior to death.

I will emphasize empirical studies. There are many attractive possibilities for tidy modelling. It is not the main purpose of this paper to review or develop models.

The relations between demography and morbidity have not received too much attention from demographers. The standard text of Cox (1976) mentions neither morbidity nor disease in its index. Its discussion of other socioeconomic data having a bearing on population (Cox, 1976, p. 151) includes education, housing and households, labour supply and employment, and savings and investment. Elsewhere, specific diseases are discussed only in relation to the mortality they cause.

Another example of the demographic neglect of morbidity is the United Nations' (1973, 1979) report on *The Determinants and Consequences of Population Trends.* Morbidity is not indexed. Diseases are discussed chiefly as factors in the decline of

mortality in developed countries. There is a brief mention that malaria in developing countries may contribute to absenteeism and decreased productivity of workers (U.N., 1973, p. 313).

Though some standard demographic texts neglect morbidity, workers in public health have long been aware of the importance of demographic factors. The index entries under "Population" in Sartwell (1965) fill more than half a column. The age of this reference indicates that an awareness of population is not a fad of the last few years.

The interactions of disease with the general developments of culture have interested historians (Sigerist, 1943). Indeed, McNeill (1980) sees the balance of two "parasitisms" controlling the destiny of the human species. He defines "microparasitism as "the metabolic activities of minute organisms that compete with human beings for food ... Wheat rusts, animal murrains, and, more loosely, the depredations of insects and rats in human storehouses are instances of this kind of microparasitism" (McNeill, 1980, p. 6). By "macroparasitism" he means the "exploitative relations among groups and classes of human beings ... If microparasitism may be likened to a nether millstone, grinding away at human populations through time, human-to-human macroparasitism has been almost as universal – an upper millstone, pressing heavily upon the majority of the human race" (McNeill, 1980, p. 8).

This survey will concentrate on presently important interactions between demography and morbidity, occasionally using historical illustrations. The approach will be to examine first how demographic variables do or may affect morbidity, and then how morbidity affects demographic variables.

The factors that cause morbidity are usually classified as the agent of disease, the host, and the environment (which conditions the susceptibility of the host to the agent of disease). Demographic variables affect morbidity by altering one or more of the agent, host, and environment. To avoid too formal a structure in the text, I will not always explicitly indicate which of these three factors in morbidity is being discussed.

The reader should keep in mind two possibilities, even if a suggested relation between demographic and disease variables exists. First, the direction of causation may be the reverse of that proposed. Second, the relation may be caused by the action of some unrecognized third variable. Both of these caveats are made clearly and illustrated with examples by Terhune (1975).

2. EFFECTS OF DEMOGRAPHIC VARIABLES ON MORBIDITY

2.1. Population Size

As cities arose, the problems of sewage and water supply became serious. "Even more significant for the long-range future of human populations was the fact that when civilized communities achieved a sufficient size and density, viruses that pass from human to human via airborne droplets found it possible to survive indefinitely" (McNeill, 1980, p. 19). These viruses include smallpox, measles, and whooping cough.

Cartlett (1960) analyses a stochastic model for the periodicity of an infectious disease like measles. The theoretical time for the infection to disappear from a closed community increases very rapidly as the average number of weekly notifications of new cases of measles rises above 100. "This phenomenon suggests that there will be a critical community size, above which measles should tend to maintain itself, whereas for smaller

communities it will die out and require re-introducing from outside before another epidemic can materialize. An actual examination of the Registrar-General's weekly measles returns for England and Wales for various sizes of towns during the period 1940-56 confirmed that this is the case, towns like Bristol (weekly notification 67) and Hull (57) being in the critical range" (Bartlett, 1960, p. 66). Similar confirmation comes from statistics on measles in North American cities.

For communities below the critical size required to maintain a recurrent epidemic, a model predicts, and data confirm, that the modal time between measles epidemics is a decreasing function of the number of people in the community (Bartlett, 1960, pp.71-72).

McNeill (1980, pp. 20-21) draws a grander conclusion about the fate of demographically small, epidemiologically isolated communities. "Disease-experienced populations in densely inhabited civilized centers acquired a notable epidemiological advantage vis-à-vis isolated, disease-inexperienced peoples. When newly inaugurated, contact between civilized populations and such isolated human communities often resulted in the outbreak of massively lethal epidemics among the former isolates. The effect of such vulnerability was to break down the capacity of such communities to resist civilized encroachment. The remarkable fewness of civilizations and the relative homogeneity of massive civilized populations in such places as China, the Middle East, and Europe resulted in large measure from this epidemiological-sociological process". The caveats offered earlier about the direction of causation and confounding variables should be kept in mind.

Among the many diseases that have been studied in relation to population density, two examples are mental disease and cancer.

Srole (1980) reviews attacks on the notion that big cities are psychologically unhealthy compared to small cities or rural areas: " ... psychological well-being in America's biggest cities is over-all at least as favorable as it is in all smaller communities"

Some cancers, on the other hand, increase markedly with population density (Nasca et al., 1980). Cancer incidence from 1963 to 1972 for cities and towns of New York State exclusive of New York City shows a statistically significant linear increasing trend with increasing population density (population per square mile) for cancers of the mouth and pharynx, esophagus, bronchus and lung, stomach and colon, for both males and females. Only males show a significant association between population density and the incidence of cancers of the liver, gallbladder, pancreas, bladder, larynx and rectum, while only females show a significant association for cancers of the brain and nervous system, ovary, and breast. Cancers at several anatomic sites have an incidence apparently unrelated to population density. These patterns in relative incidence reflect both morbidity and mortality.

2.2. Age

One of the basic descriptive devices of epidemiologists is an age-prevalence curve. Such a curve plots the fraction of the population that is affected by a particular disease as a function of age. An age-prevalence curve reveals immediately what age groups in the population are most likely to benefit from attempts to treat or prevent the disease.

Several biological mechanisms, not necessarily exclusive, may explain why disease incidence and prevalence change with age (Oota et al., 1980). For example, Makinodan (1980) suggests that ageing individuals lose immunological vigour because of changes

affecting the normal differentiation of thymus-derived (T) cells, and consequently suffer increased susceptibility to infections, autoimmune and immune complex diseases, and cancer. Everitt (1980) ascribes ageing to a deficiency of specific neurotransmitters or hormones.

Muench (1959) constructs mathematical models to explain the shape of age-prevalence curves for various, mainly infectious, diseases. These attempts continue with growing sophistication (Aron and May, 1980, model malaria, for example). Individuals are assumed to move from one to another of a small number of compartments, such as Susceptible, Infected, and Recovered. Their movements are assumed to be governed by ordinary differential equations. The rates governing acquisition and loss of the disease are taken as constant since some time before the oldest individuals in the population were born. Thus the epidemiological variable of increasing age corresponds to the mathematical variable of increasing time. The transient solution of the differential equations gives a prediction of the steady-state age-prevalence curve.

A remarkable indication of the lack of contact, or difference in interests, between practicing epidemiologists and those interested in the mathematical theory of epidemics is that "age" is not indexed in either of the comprehensive reviews of epidemic theory by Bailey (1957, 1975). None of the models he presents is explicitly age-dependent. In the tradition of mathematical epidemic theory, the first model to allow for the influence of age on rates of gaining and losing infection is due to Hoppensteadt (1974; which is cited in an addendum to the references of Bailey, 1975). It is inevitable that a continuous time formulation of such a model should be complex. Hoppensteadt (1974) proves that his model has a non-negative solution, without attempting to relate it to any particular disease. Hoppensteadt (1975, p. 54) also proves a threshold theorem for his age-dependent model, analogous to a threshold property of a model due to Kermack and McKendrick.

In many infectious diseases, the burden of infection falls largely on younger individuals. The prevalence of infection in yaws, schistosomiasis, malaria and histoplasmosis peaks among children or young adults and declines among older people. This pattern differs from the pattern of morbidity and disability due to chronic diseases in some wealthy countries.

For example, in the Federal Republic of Germany (FRG), the reported "incidence" (probably meaning prevalence) of chronic disease during the period ending April-May 1974 was 9 per cent of persons 14 years and under, 27 per cent of those 15 to 39, 65 per cent of those 40 to 64, and 84 per cent of those 65 and over (Schwarz, 1980, p. 271).

In the United States, in fiscal year 1974, the expenses per person for medical care, by age, were (U.S. Department of Health, Education and Welfare, 1975, p. 31):

Personal health care	Under 19 years	19 - 64 years	65 years and over
Hospital care	$61	$200	$573
Physician's services	$57	$91	$182
Other health services	$65	$129	$463

I believe it would be a worthwhile project to establish comprehensive internationally comparable tables of morbidity by age, sex, income, education and other variables, by cause and by defined levels of disability and treatment. Such tables would reveal that

not all countries are the same (Kohn and White, 1976; White, 1979). Explaining the differences might provide clues to reducing morbidity.

In the FRG, the age distribution of in-patient (hospitalized) and out-patient (non-hospitalized) care has been used to project the demand for medical care (Schwarz, 1980). A 1974 interview survey of households determined the numbers of people, by age and sex, who had received medical care in the four weeks before the survey. Schwarz (1980, p. 262) projected the population of FRG from 1975 to 2000 using a net reproduction rate of 0.7 and a life expectancy at birth of about 73 years. The morbidity rates of 1974 were applied to this projected population. The number of persons under medical treatment as out-patients, per persons of working age, decreases, if 1975 is indexed as 100, to 91 in 1990 and rises only to 96 by 2000. Similarly, the number of persons under treatment as in-patients per person of working age decreases from an index value of 100 in 1975 to 97 in 1990 and rises to 98 by 2000.

Because of the rising numbers of people in the 20 to 29 age class, "we have to expect a substantial growth in the supply of newly trained physicians and auxiliary staff over the next 15 years ... Thus growing numbers of new staff will coincide with declining numbers of sick persons and [later] declining staff numbers with growing numbers of sick persons ... If therefore, in the next few years restrictive measures are taken at medical schools, or if the inclination to enter medical occupations diminishes, the consequences 30 years later would be extremely adverse" (Schwarz, 1980, p. 269).

Schwarz (1980, p. 271) gives examples to support his final remark that, in the future course of demand for medical care, "many other influences also exist that may be much more important than demographic factors are". Among these other influences are those that determine the shape of the age-prevalence curve for chronic disease. It is obvious in retrospect that any projection made in the early decades of this century that assumed constant age-specific incidence rates for infectious diseases would have grossly overestimated the demand for health care arising from infectious disease. At least one serious student (Pries, 1980) has suggested that the same may be true in the future of chronic diseases.

Fries (1980, p. 131) observes that the expectation of life at birth in the United States increased from approximately 47 years in 1900 to approximately 73 years in 1980. Expectation of life increased much less at age 45, and by only three years at age 75, over this same period. Extrapolating the trajectories over time of total expected life at different ages, Fries infers that the total expected life at all ages will have reached a biological limit of 85 years by approximately 2045, and that deaths will be normally distributed about this mean with a standard deviation of 4 years. At that point, nearly everybody born alive will survive to near the biological limit of age, and deaths will be concentrated in a narrow range of ages.

"Until recently, progress in health care could be conceived of as an exchange of acute medical problems for chronic ones ... Since early death would cost relatively little in direct expenses as compared with the expenses of a later chronic problem, the exchange of acute illnesses for chronic ones has resulted in a massive need for additional medical services" (Fries, 1980, p. 133). The most effective strategy for dealing with chronic diseases, Fries suggests, is postponing them to the years when death is imminent anyway. "The amount of disability can decrease as morbidity is compressed into the shorter span between the increasing age at onset of disability and the fixed occurrence of death. The end of the period of adult vigour will come later than it used to. Postponement of chronic illness thus results in rectangularization not only the mortality curve but also of the morbidity curve ... By implication, the practical focus on health

improvement over the next decades must be on chronic instead of acute disease, on morbidity not mortality, on quality of life rather than its duration, and on postponement rather than cure".

If chronic diseases of the aged receive the attention Fries says they should, the age-specific morbidity rates up to, perhaps, age 80 may decline. If the available time and accumulated experience of the elderly could then be mobilized to care for the very young, an unexpected consequence of improved health for the aged might be improved health for children. Whether this speculation could become real depends on whether people can reconstitute some of the constructive functions of extended families out of the needs and skills of nuclear families and socially isolated older people. (For more on ageing, see Butler, 1975). A more general message of this pure speculation is that it may be short-sighted to treat each age-specific morbidity rate as if it were independent of all others.

2.3. Mortality

Here are some examples of how mortality affects the health of those who remain alive.

Kraus and Lilienfeld, according to Cassel (1976), showed that "widowers have a death rate three to five times higher than married men of the same age for every cause of death". An excellent recent survey of the health of the American people (National Academy of Sciences, 1979, p. 147) observes that people who have been recently widowed are at high risk of becoming functionally dependent. "Public concern for the functionally dependent elderly is warranted for economic as well as humanitarian reasons. It is in the interest of both society and the elderly individual to forestall dependency or to minimize its impacts once functional capacity begins to decline". The relation between death of a spouse and functional dependency of the survivor merits experimental programmes of intervention.

In an environment of endemic infectious disease, mortality in childhood may selectively eliminate individuals who, for genetic or environmental reasons, have relatively higher susceptibility to the disease. The surviving adult population then suffers less from the disease than would an unselected population exposed to the same external risks of infection.

McKeown (1979, p. 48) makes this point with characteristic clarity: "The immunological constitution of a generation is influenced largely by the mortality experience of those which precede it. This was particularly true in the past, when the majority of live-born people died from infectious diseases without reproducing. Under such conditions there was rigorous natural selection in respect of immunity to infection".

The classic example of genetically based resistance to disease that results in differential survival arises in African populations subject to *Plasmodium falciparum* malaria (Allison, 1964). At one locus that determines a person's hemoglobin type, two of the commonest alleles are A (normal) and S (abnormal). Individuals with the genotype AA have normal red blood cells. Individuals of genotype AS have the sickle cell trait, and individuals with SS genotype die usually before age 15. Heterozygotes (AS Individuals) have a lower parasite rate (i.e., a lower prevalence of detectable infection) and a lower prevalence of heavy infections (Allison, 1964). Heavy infections are associated with death. In Allison's view, "Malaria exerts its selective effect mainly throuth differential viability of subjects with and without the sickle-cell gene between birth and reproductive age, and to a much lesser extent through differential fertility".

This assertion is completely supported by a recent independent large-scale field study (Fleming et al., 1979). In the Garki district of northern Nigeria, the relative frequencies of AA, AS, and SS individuals at *birth* were just that were expected from applying the Hardy-Weinberg law to the gene frequencies in the entire population. In the population as a whole, however, significantly more AS individuals and significantly fewer AA individuals were observed than were expected from the Hardy-Weinberg law. Heterozygous AS individuals had a nearly 30 per cent advantage over AA individuals in the proportion of newborns that survived to adulthood. This advantage was sufficient to explain the observed frequency of the S allele in the population. By contrast, the fertilities of AA and AS women were not significantly different.

In this example, mortality changes the genetic composition of the population between birth and adulthood so that the adult populalation is less prone to disease and death from malaria.

Where malaria has been eliminated, the frequency of the S allele has declined relative to its former level (Allison, 1964). Consequently, fewer individuals suffer the disadvantages of the sickle-cell trait. The decline of the S allele frequency in American black populations, compared to the frequency in the putative populations of origin, is too large to be explained by gene admixture. The decline may be interpreted as a remarkable genetic adaptation to a changed environment over a period as short as 300 years. The selective death of the SS homozygotes (and the possible reproductive disadvantage of the AS heterozygotes) tends to eliminate the S allele and improve the health of the population surviving in a non-malarious environment.

Another example of selective mortality that increases the resistance to disease of the surviving population arose in India where smallpox was prevalent. Vogel and Chakravartti (1966) found in two rural regions of India that unvaccinated people with blood groups A and AB have two disadvantages in severe epidemics of smallpox when compared with people having blood groups B and O. First, people of blood groups A and AB have a much higher risk of acquiring infection when exposed to smallpox. Second, given that they are infected, people of blood groups A and AB have a much higher risk of a severe attack and of dying. Unfortunately, Vogel and Chakravartti do not give data on the age distribution of deaths from the disease nor on the relative frequency of A and AB blood types as a function of age. Their data make it clear, however, that the survivors of an epidemic must be genetically more resistant to a further epidemic.

Now that smallpox is allegedly eradicated throughout the world, it will be of interest to follow the frequency of gene A through time in rural India and Pakistan. The data on the hemoglobin S allele suggest that in those regions formerly afflicted with smallpox, the frequency of gene A ought to increase relative to its frequency in comparable regions without smallpox.

2.4. Fertility

Fertility affects disease through the distribution of fertility over age, through the distribution of the number of children in sibships, and through the selective effects of fertility on genetic factors associated with disease.

The distribution of fertility over age affects the frequency of diseases arising from recurrent mutations of natural origin."If mutations or mutagenic influences accumulate during the reproductive life spans of individuals, genetically determined harm might be detectably increased in offspring from older parents" (Newcombe, 1965). By linking

records from a British Columbia registry of birth handicaps with birth, stillbirth and death records, Newcombe established that, after excluding birth order effects, children of very young mothers (0 to 19 years, compared to mothers aged 20 to 24 years) had children with increased risk of intracranial and spinal injury at birth (relative risk 2.19) and increased risk of postnatal asphyxia and atelectasis (relative risk 1.66). (Atelectasis is the incomplete expansion of the lungs at birth). Children of older mothers (35 and older, compared to mothers 34 and younger) had increased risks, after excluding birth order effects, of Down's syndrome (relative risk 7.68), cerebral palsy (relative risk 1.84), and congenital malformation of the circulatory system (relative risk 1.66).

Similarly, Newcombe found that children of older fathers (40 years and older, compared to fathers 39 years and younger) had significantly elevated risks of diseases of the respiratory system (relative risk 1.61), congenital malformations excluding the nervous system and sense organs (relative risk 1.28) and other congenital malformations of the nervous system and sense organs (relative risk 2.07).

The associations with increasing parental age are no proof of mutational origin. For example, "most of the deaths from respiratory diseases among British Columbia children occur in North American Indians, and Indian fathers tend to be older than is usual for the rest of the population. The correlation (between diseases of the respiratory system and the age of the father) disappears when the data are broken down by Indian versus non-Indian parentage" (Newcombe, 1965).

The cytogenetic basis (trisomy -21) of Down's syndrome, on the other hand, is well established.

At the lower end of the age distribution of fertility (Menken, 1972), teenage mothers experience a greatly increased risk of premature delivery, which is linked to higher risks for the child of epilepsy, cerebral palsy, mental retardation, deafness and blindness. In addition, young mothers suffer an elevated risk of certain complications of pregnancy such as toxemia, prolonged labour and iron-deficiency anaemia.

A positive aspect of teenage pregnancies is that a girl who has her first child when aged under 18 years has approximately one third the risk of breast cancer of a woman whose first birth arrives at age 35 or later (Menken, 1972).

The distribution of the number of children in sibships determines the frequency distribution of birth orders. According to Terhune (1975), Eysenck and Cookson in 1970 found a correlation of 0.70 between the family size of origin and the birth order of a sample of individuals. By family size is meant the number of siblings including the individual being sampled. (It would be nice to derive such a correlation from a simple model, perhaps negative binomial, of the distribution of family size).

Birth order, after removing the effects of mother's age, appears to affect the health of children. In Newcombe's (1965) study, for example, children of birth order higher than 2 had an increased risk, relative to children of birth order 1 or 2, of epilepsy, spina bifida, congenital malformations of bone and joints, and postnatal asphyxia. Confounding of birth order with family size or other social and economic variables may, of course, account for part of this association.

Family size has been claimed to have a variety of effects on children's health. I rely here on the excellent review of Terhune (1975), who provides citations to the original sources. I first discuss effects on mental health, then effects on physical health.

Several studies "provide vague clues that family size is related to schizophrenia, but not to other forms of severe mental illness. The most frequent indication is that only

children are more at risk than children from other family sizes, but inferences of a causal relation are hazardous. The studies contain serious methodological difficulties ... First, they need to control for social class and birth order. Second, comparisons need to be made within more exact diagnostic categories ... Third, comparisons of disturbed populations with general populations run the risk of noncomparability on such variables as age and social class" (Terhune, 1975, pp. 86-87).

In two studies, "the proportions of only children among alcoholics exceeded the proportions in the comparison groups" (Terhune, 1975, p. 91).

In several studies, "children of large families were significantly more often involved in school problems ... and anti-social behaviour", including delinquency. "In other problem areas where significant family size differences were found (neurotic symptoms, problem habits, interpersonal relations and miscellaneous), the problems were more frequent in smaller families ... Again, social class could be a factor" (Terhune, 1975, p. 94).

Family size appears to affect physical health in several ways.

Three studies, "despite wide variations in the populations sampled, gave highly consistent results in showing the tendency for obesity to be found in small families, particularly among only children". In British families, there were also relatively more obese boys in lower class British families than in upper and middle class families, and the risk of obesity was greatest among lower class children of small families (Terhune, 1975, p. 116).

In studies of deprived populations in Colombia and Thailand, the proportion of malnourished children increased with family size. "Spacing between children seemed to be a very important part of this effect, for 40 per cent of the children were undernourished who had a younger sibling born within a year of themselves. The rate was 27 per cent among those with a 42-month interval to the next child" (Terhune, 1975, p. 119).

On a per child basis, one would expect the risk of contagious disease to rise with family size. First, given that any one child in the family is infected, all the remaining children living in the household are exposed. Second, in a large family there are more children with outside contacts that might lead to infection. Some very limited evidence on 82 middle-class Cleveland families is consistent with these expectations: attacks per year per person of infectious gastroenteritis and of respiratory diseases increase as family size rises from 1 to 6. There is room here for much further investigation. See also section 2.8 for further examples.

Another possible effect of fertility on health merits mention, though at present there is no evidence that such an effect exits. Larger sibships could conceivably enjoy better health in old age for two reasons. First, the larger number of relations could slow the process of psychological and social involution that sometimes leads to functional dependency in ageing. Second, the larger number of siblings could provide more personal, noninstitutional attention to an individual's health problems, preventing the complications that sometimes arise from becoming institutionalized. It remains to be seen whether there is any foundation to this optimistic speculation.

Fertility, like mortality, acts selectively on genetic factors associated with disease. Two examples, both in need of further investigation, are cystic fibrosis and schizophrenia.

Knudson et al. (1967) find that "parents of children with CF (cystic fibrosis of the pancreas) come themselves from larger sibships than do control persons". The average sibship size of normal individuals was 21 per cent smaller in their data, and 10 per cent

smaller in comparable Australian data, than the average sibship size of CF carriers, that is, of parents of children with CF. The difference still favoured carriers significantly after removing a higher infant mortality in the cystic fibrosis group. "If this relative advantage of the carrier is real and still operating, then the gene frequency will continue to rise", by a substantial amount per generation.

Erlenmeyer-Kimling and Paradowski (1966) studied the fertility of female schizophrenics admitted to state hospitals in New York during 1934 - 36 and during 1954 - 56. The mean number of children per woman among the schizophrenics, among female siblings of schizophrenics, and in the general population for the years shown, were :

Status of mother	1934 - 36	1954 - 56
Sibling of schizophrenic	1.2	2.2
Schizophrenic	0.7	1.3
General population	1.2 (in 1940)	1.5 (in 1954)

It is not clear how Erlenmeyer-Kimling and Paradowski standardized the fertilities of the three groups of mothers to allow for possible differences in their age compositions, especially since the fertility of the 1954 - 56 group may not have been completed by 1966. The data do not exclude the possibility that the apparent selective advantage of sibs of schizophrenics is due to an increased risk of schizophrenia, possibly for environmental reasons, in a subpopulation with elevated fertility.

I have paid little attention here to exactly how the selective effects of mortality and fertility are measured. A widely used index of the opportunity for selection, due to James F. Crow, is described with applications by Cavalli-Sforza and Bodmer (1971, pp. 317 - 340). To compute this index, the information required is the proportion of a birth cohort that survives to the age of reproduction and the mean and variance of number of offspring. Mortality of mothers during the reproductive years is neglected. A demographically more sophisticated approach is given by Charlesworth and Charlesworth (1973).

In developed countries, the current low level of fertility is largely a result of contraception. There are health risks associated with child-bearing and with contraception. "The excess risk of thromboembolism, stroke, and myocardial infarction in women who are taking oral contraceptives and their interaction with age and smoking are well established" (Blackburn and Gillum, 1980, p. 1185). Genetic consequences of family planning in Japan are reviewed by Matsunaga (1966). Hansluwka (1980) calls attention to the need for research on the health effects of fertility regulation, including effects on subsequent fertility and the growth and development of subsequent children. The psychological effects of receiving or of being refused an abortion; of repeated abortion; of sterilization; and of out-of-wedlock births all need to be investigated.

Perhaps a major consequence of improving people's ability to control their fertility is that the fraction of all children born who are wanted children will increase. The impact of this change on the psychological well-being of future generations merits attention.

2.5. Marriage and Divorce

Marriage and divorce affect disease through their effects on fertility and directly through effects on the lives of spouses and children.

Though the directions of causality are unclear, there are definite associations between marital status and the health of both parents and children. Somers (1980, p. 1052) gives an excellent summary: "The married have a significantly longer life expectancy than the non-married, especially when compared to the formerly married (widowed, divorced, or separated). In both England and the United States, the married also have less chronic illness, especially mental illness, than the formerly married, and make fewer demands on the health-care system ... Children raised in single-parent families have more illness and make more demands on the health-care system than those with both parents present. Lack of physical and psychosocial supports is probably the major factor, although adverse selection probably plays some part in this complex relationship." Among males 14 years old and over, the age-adjusted admission rates per 100,000 to state and county psychiatric hospitals in the United States in 1975 ranged from less than 150 for married men, to over 800 for never married, to approximately 1650 for separated or divorced men – a 10-fold increase over married men (Somers, 1980, p. 1052).

2.6. Migration

The historical roles of migration in spreading infectious diseases – the white man's diseases to the American Indians, syphilis to the Old World (according to some historians), plague from Central Asia, influenza from East Asia, schistosomiasis from Africa – are well known (McNeill, 1980; Crosby, 1972; Simpson, 1980).

Migration is still an important factor in the control of malaria. "It has happened in several instances that when spraying was discontinued in an area where malaria incidence had reached a satisfactorily low level and where there was sufficient proof of locally interrupted transmission, transmission was renewed after a short while because of large-scale migration of people between this area and neighbouring districts (in the same country or across the border) where transmission had not yet been interrupted, resulting in a large volume of import of parasites ... There are two ways in which parasites are thus imported, one being the temporary or permanent migration of persons from the malarious areas into the cleared area, and the other, not less important, being visits to malarious areas by permanent residents of the cleared area to which they return with an infection acquired in the former area. The most frequent reason for the second phenomenon is seasonal farming or harvesting in sparsely inhabited jungle areas by people having their permanent residence ... in a ... permanently cultivated area in which malaria has practically been eradicated. The two outstanding examples of such occurrences are Ceylon in 1955 - 56 and the Philippines in 1958" (Yekutiel, 1960, pp. 675, 681).

In such examples, migration introduces, or reintroduces, an agent of disease to a susceptible population. A much less well known effect of migration is revealed by epidemiological studies of experimental mouse populations. In a population where an infectious agent is dormant because most individuals in the population have acquired resistance to it, the immigration of enough healthy, susceptible individuals may lead to an epidemic outbreak, with no further importation of infectious agents. "The manner

of recrudescence of epidemic sickness within a community recruited from healthy non-immunes seems to be a function of the rate of addition ... The smaller the number of immigrants the longer the interval between epidemic manifestations ... Small regular additions to a herd at short intervals are more likely to maintain an endemic-epidemic level than irregular large additions at long intervals" (Greenwood, 1932, pp. 39, 41).

Greenwood (1932) suggests that these observations may explain the failure of measures to control foot-and-mouth disease of cattle. "I can see that if every creature upon hooves within an infected area is slaughtered, if the area is maintained as a solitude for months and if thereafter neither fomites nor animals from endemic areas are suffered to enter, that then no fresh epidemic could arise ... But that condition is not in practice fulfilled; in a country like Holland it could not be. Whenever the method of shutting frontiers against infected goods or animals fails – as it usually does – the blame is put upon the lack of stringency of the control; I suggest that ... unless the frontier is wholly closed to healthy non-immunes as well as to suspected carriers, the method is sure fo fail, *if the country concerned has had past experience of the disease*" (Greenwood, 1932, pp. 38-39).

As Greenwood points out, many natural, including human, populations recruit healthy non-immunes not by migration but by birth. The gradual build-up of susceptible populations of children may be the mechanism behind the periodic outbreaks modelled by Bartlett (1960).

Migration is also associated with changes in site-specific risks of cancers and is important in studying factors associated with the risk of stomach cancer (Haenszel, 1980).

For the migrant, migration may bring a radical change in his social environment and may cause a generalized increase in the susceptibility of migrants to environmental disease agents (Cassel, 1976). For example, a Japanese-Hawaiian-American heart study shows that "the incidence of coronary heart disease was higher in Japanese people living in Hawaii than in those living in Japan and still higher for those living in California than in Hawaii. Furthermore, these differences could not be explained by variations in any or all of the standard risk factors" (Cassel, 1976, p. 117). Investigating the reason for this difference, Marmot, according to Cassel, found that "the prevalence of coronary heart disease (whether measured as angina or as myocardial infarction by history or by electrocardiogram criteria) was always higher in those men who had retained less of their traditional cultural matrix" (Cassel, 1976, p. 118).

Thus migration may contribute to morbidity through translation of the agent of disease, translation of the host, or alteration of the environment that conditions the relation between hosts and agents.

2.7. Work

Work is an important factor in the health of many people, in addition to being a leading reason for migration. Changes in the demographic composition of the work-force bring changes in the distribution of morbidity.

For example, in the 4 years starting March 1971, the number of women working or looking for work in the United States increased by 4.8 million (Hunt, 1979, p. 1). It is reasonable to expect that occupationally caused morbidity among these women will increase. Moreover, certain kinds of morbidity appear to affect working women more

than working men. For example, in 1960 to 1962 in the United States, rheumatoid arthritis was more prevalent among adult women than among adult men in every major industrial and occupational category (Hunt, 1979, p. 29). According to William Lowrance, in physically demanding jobs, women have a higher injury and disability rate than men. More women in these jobs has resulted in higher employers' expenses for workmen's compensation insurance.

Bingham and Werner (1980, p. 837) argue forcefully that "the goals of health protection and those of antidiscrimination laws can and must be achieved". They examine "the question of whether the protection of workers' health offered by the Occupational Safety and Health Act in at odds with the Title VII prohibitions on employment discrimination" (p. 829). "In mal-dominated job categories, such as the petrochemical industry, where women are beginning to make inroads in employment, ... women of child-bearing age are being excluded from jobs on the grounds that exposure to toxic substances in a particular workplace may pose a hazard to the unborn ... When a woman is threatened with removal or firing, she may be told that she can keep the job only if she provides proof of surgical sterilization. The broad and unrealistic assumption is that all women, other than those who have been surgically sterilized, are willing and able to carry a fetus to term, at any time, and that only the hypothetical fetus is at risk from the workplace exposure" (pp. 830 - 831). This concern on the part of employers is one-sided. "In fact, toxic substances affect the male reproductive system with various adverse results, including the creation of a defective fetus in an unexposed female" (p. 831). Bingham and Werner, after reviewing the relevant biology, conclude that "the selective use of science cannot be used as a basis far an exclusionary policy that is implemented unilaterally against fertile females" (p. 837).

2.8. Social Organization and Behaviour

I shall neither attempt to define social organization and behaviour nor to claim that they are disjoint from several of the more orthodox demographic variables already reviewed, such as family size, marriage, divorce, migration and work. The purpose of this section is to emphasize, by examples, that social factors deserve to be recognized among the demographic variables that are important in affecting morbidity.

In the epidemiology of cholera, accumulated evidence indicates that "the spreading or appearance of clinical forms of cholera does not necessarily require the presence of a patient with cholera but only the presence of healthy carriers or persons with mild diarrhea" (Bencic and Sinha, 1972, p. 14). How are the healthy carriers distributed in the population ?

A field study of cholera El Tor in the Philippines analysed 90 households which had people who were hospitalized for bacteriologically confirmed cholera. In 84 of these households, only one person was hospitalized; the rest of the people in these households appeared healthy. But study showed that among household contacts the infection rate, i.e., the fraction of people in whom the cholera vibrio could be demonstrated bacteriologically, was 10 times the attack rate for clinically severe cholera (Tamayo et al., 1955, p. 647). When the community contacts, outside the immediate household, of these same hospitalized cholera patients were investigated bacteriologically, the overall rate of infection with the cholera vibrio was much lower than among the patients' household contacts, "in spite of general environmental and sanitary factors such as overcrowding, lack of satisfactory water supplies, lack of toilets, and poor personal hygiene. The low

infection rate among *community* contacts of cholera cases, in contrast to the relatively high infection rate among household contacts reported earlier by Tomayo et al. (1955), suggests that close personal contact is generally necessary for the transmission of cholera" (Mosley et al., 1965, p. 659).

Close personal contact is also required for the transmission of venereal diseases.

On the other hand, close personal contact during childhood may provide protection against Hodgkin's disease during young adulthood. From interviews of young adults with Hodgkin's disease and of random age-matched controls, Gutensohn and Cole (1981) conclude that the risk of developing Hodgkin's disease as a young adult is established during childhood. Young adults are at high risk of the disease if, as children, they belonged to small families, lived in single-family homes, had relatively well-educated parents, and had few neighbourhood playmates. These factors are "a set of correlated markers of childhood social class. The essential elements of the set are family structure (i.e., closeness to siblings) and type of housing (i.e., residential space)" (p. 138). Gutensohn and Cole suppose that young children who are infected by the hypothetical viral agent of Hodgkin's disease do not get the disease and are protected against it later, while young adults not previously exposed to the viral agent get Hodgkin's disease when infected with it. In this case, the age of infection is a major modifier of the risk of disease from a viral infection. The age of infection is largely determined by the intensity of a child's social contacts.

While close personal contact facilitates the spread of certain specific infectious agents, other social situations may increase nonspecific susceptibility to environmental disease agents. Cassel (1976, p. 110) observes that "a remarkably similar set of social circumstances characterizes people who develop tuberculosis and schizophrenia, become alcoholics, are victims of multiple accidents, or commit suicide. Common to all these people is a marginal status in society".

Cassel's main point is that individuals suffer generalized susceptibility to disease in social situations where their actions do not lead to anticipated consequences and where social supports are absent. He describes several studies that illustrate this point. The studies cover rapid social change in the Appalachian mountains, social and family disorganization in North Carolina and Detroit, the competence of the families of schoolchildren with problems, life change in a cohort of pregnant women, and psychologically supported families with chronically ill children. Cassel's important synthesis should focus attention on the social environment as a major factor in morbidity.

Fascinating experimental studies in animal models and observational studies in humans of the effects of social experience on disease susceptibility are collected by Weiner, Hofer and Stunkard (1981). Some of the diseases modulated by social experience include high blood pressure, renal disease, bronchial asthma, and gastric ulcer. These biological studies also try to explain how the brain links social behaviour to disease.

3. EFFECTS OF MORBIDITY ON DEMOGRAPHY VARIABLES

Most of the routes by which demographic variables affect morbidity are two-way streets. The examples in this section describe some ways by which morbidity affects demography.

This section will be briefer than the preceding. Until recently, demographers appear to have been less interested in how disease affects demographic variables than students of

public health have been in how demographic factors affect disease.

3.1. Population Size

"When Champlain dropped anchor at Cape Cod in 1605 he made note of the fact that there was a fairly dense indigenous population inhabiting the area. Fifteen years later, when the Pilgrims landed, the natives on the Cape and along the shoreline were relatively sparse. The reason for this disparity was a furiously violent epidemic occurring in 1617" (Simpson, 1980, pp. 5-6). The specific disease that caused the epidemic remains unknown. But the American Indian's lack of resistance to what was less than a fatal disease for the Europeans created room for subsequent European populations to establish themselves and grow.

McKeown (1979; and many earlier works reviewed in 1979) argues that the rise of European populations in the Western world over the last three centuries resulted primarily from a decline in deaths due to infectious diseases. The main reason for this decline in deaths was an improvement in nutrition. The improvement in nutrition preceded the sanitary reforms of the nineteenth century. Better nutrition changed many infections from causes of deaths to causes of disease.

Banks (1955, p. 85) reviews broadly and historically how, in his view, it has now become "possible to bring under control many of the major causes of death so rapidly as to unbalance the whole biological, economic and social structure of large areas of the world".

3.2. Mortality

Here are two examples of how health and resistance to disease can affect mortality.

Susceptibility to falciparum malaria results in increased death rates from individuals of hemoglobin genotype AA compared to those of genotype AS (Allison, 1964; Fleming et al., 1980). When malaria is eliminated, the frequency of allele S appears to decline. Consequently, the death rate due to SS genotypes also declines, while the susceptibility of the population, if malaria should become re-established, increases.

The neat methods of genetics will not easily account fully for the effects of disease on mortality. "Those who volunteer for screening (in a voluntary health screening program in the United States) appear to have better prognoses than those who do not. Shapiro and colleagues demonstrated that compared to others, women who responded to invitations to come to a mammography clinic had lower mortality for several major diseases for which they were neither screened nor treated" (Sackett, 1980, p. 1803).

The health of mothers affects the mortality experienced by their offspring. At Aberdeen Maternity Hospital, obstetricians graded the health and physique of women bearing their first pregnancy at the women's first visit to an antenatal clinic. Per 100 births, the number of perinatal deaths (deaths from 28 weeks of gestation to 7 days of life) increased from 27 for mothers judged to be in very good health to 63 for mothers judged to be in poor to very poor health. Among these mothers, 10 per cent of the women in very good health were under 5 feet 1 inch tall, while 48 per cent of the women in poor or very poor health were under 5 feet 1 inch tall (Baird, 1965). Thus an indicator of health as crude as height is associated with the mortality of offspring. Of course,

assessed health and height, as well as mortality of offspring, may have been effects of a common antecedent cause such as nutrition.

3.3. Fertility

Disease affects fertility in both developing and developed countries.

When first introduced from the New World, venereal syphilis killed many Europeans and reduced the fertility of many of the survivors (Crosby, 1972). In developing countries still, "the depressant effect on fertility of venereal disease and malaria is documented" (Taylor and Hall, 1967, p. 652, who provide references). For recent studies of the effects of venereal disease on fertility, see the essays of Gray, Belsey and Retel-Laurentin in Leridon and Menken (1979).

In St. Lucia, a Caribbean island with a high prevalence of schistosomiasis, Weisbrod et al. (1973) study the relationships among demographic, economic and disease variables. They use an interactive model that considers the effect on the birth rate of combinations of parasitic infections, and an additive model that assumes that the effect of several parasitic infections is the sum of the effects of the infections individually.

The interactive model gives no evidence for a negative effect of parasitic diseases on the birth rate. "In the Cul-de-Sac valley [one of the two valleys studied], for example, schistosomiasis was found to have a significant *positive* association with births. (The interpretation that the disease *causes* an increased birth rate is one that may not seem plausible; however, it is possible that persons who suffer from disease may turn more to sexual gratification)."(Weisbrod et al., 1973, p. 65).

The additive model gives "no evidence that schistosomiasis or the *Trichuris* or hookworm parasites exert a significant negative impact on the birth rate ... *Strongyloides*, however, was shown to have a significant and negative impact on births in both valleys, and *Ascaris* again was found to be associated with a significant *positive* impact on the birth rate in one valley ... Since certain types of schistosomiasis-control programmes (e.g., latrine construction) are likely to reduce the prevalence of other parasitic diseases, including that caused by *Strongyloides*, the impact of these other parasites is important in evaluating control programs for schistosomiasis ...

"Elimination of *Strongyloides* is estimated to increase the birth rate for those mothers infected with the disease by about 240 per cent. On the other hand, since only a small fraction of the total female population (about 10 per cent) was infected with *Strongyloides* parasites, the impact of the disease's elimination would result in a much smaller, though still substantial, increase in the aggregate birth rate – about 16 per cent" (p. 66-67).

In developed countries, non-fatal morbidity sometimes affects fertility. In British Columbia, for example (Newcombe, 1965, his Table 11), couples who bore a child with Down's syndrome subsequently had 28 per cent more children born and surviving to the end of a four-year study period than the general population. Reproductive compensation followed deaths from asphyxia, but not stillbirths or deaths from erythroblastosis (a consequence of blood group incompatibility) or from hemorrhagic disease.

Another example of the effect of morbidity on fertility comes from France. Leridon (1973) demonstrates a significant negative association between mortality from influenza in the winter months and the number of births 9 months later. Instead of the actual number of births, Leridon uses the residual after removing a straight-line time trend from

1946 to 1963 and a seasonal periodicity. Influenza mortality in January and February explains more than half of the variation in the number of births 9 months later. The same association appears between the general rate of mortality (expressed as a residual from its straight line trend) in the winter months and the (residual) number of births 9 months later. As Leridon points out, the variations in mortality are indicators of transient bad conditions of health in the surviving population. Leridon (1973, p. 46) cites several earlier studies on the same theme.

The examples of schizophrenia (Erlenmeyer-Kimling and Paradowski, 1966) and cystic fibrosis (Knudson et al., 1967) described above may be interpreted as effects of diseases on fertility, since in both cases differential fertility is associated with the disease. It seems more likely to me, however, that if the alleged fertility differences are real, they are caused by underlying factors common to the diseases and the fertility differences. The notion of a causal link in either direction between a disease and fertility is not appropriate if both are effects of a common antecedent.

3.4. Migration

Disease has been a reason for migration since long before the rise of scientific medicine.

The cult of Asclepius was the foremost healing cult of the Greek world, spreading as far as Rome in 201 B.c. (Sigerist, 1943, p. 135). Epidauros, the centre and origin of the cult, was the goal of pilgrimages for generations of Greek and Roman patients. A large hostel still visible in the ruins of Epidauros accommodated the pilgrims.

In the 14th and 15th centuries, plague drove a large fraction of the population of Italian towns into the countryside. It was primarily the wealthy who could afford to flee and did. At the same time, plague and famine in the countryside drove peasants into the cities in search of food. These mass migrations sometimes contributed to the further spread of infection (Livi-Bacci, 1978, pp. 95 - 100).

Even in the era of would-be rational medicine, disease has been a reason for migration. Before there were specific remedies for tuberculosis, affected patients of sufficient wealth sometimes moved to sanatoria at high altitudes, as described by Thomas Mann in *The Magic Mountain*. The Sun Belt of the United States has attracted many elderly individuals for reasons of health among others.

3.5. Work

Taylor and Hall (1967) have reviewed the interactions among health, population and economic development. Their economic argument for improving workers' health rests on the claim, which they illustrate with examples, that healthy workers work better.

"For maximum contribution to economic development, particular attention should be paid to conserving the health of economically active age groups. Increased productivity of the labor force augments returns on other investiments" (p. 652). "Whereas lowered morbidity is usually most evident in the increased productivity of working adults, the concomitant lowered mortality effect is more apparent in infants. There is no common standard of measurement which permits comparison of the essentially qualitative morbidity effects with the more quantitative mortality effects, from which a cost-benefit ratio may be derived ... In programs such as those against malaria, schistosomiasis, hook-

worm, malnutrition, yaws, trachoma, leprosy, tuberculosis, filariasis, and onchocerciasis, the net economic impact of lowered morbidity – through potential increase in productivity – almost certainly outweighs the demographic impact of reduced mortality ... The economic value of reductions in morbidity depends mainly on ... the extent to which expanding economic opportunities put to use the increased productive capacity of workers ... In postwar Ceylon, for example, the opening up of fertile areas for cultivation, in combination with increases in manpower resulting from decreased morbidity more than balanced any negative effect of population increase" (p. 653).

The detailed study by Weisbrod et al. (1973) attempts to make "the essentially qualitative morbidity effect" described by Taylor and Hall (1967) more quantitative. Weisbrod et al. investigate workers in a rural banana plantation and in an urban factory. Their "rural and urban labor-productivity results are consistent with the view that only one parasite, namely *Strongyloides*, adversely affects actual labor productivity – and then only for the female group working in agriculture. Not only are weekly earnings lower for females who have this disease but daily earnings and average number of days worked per week are also lower for this group. As far as schistosomiasis is concerned, the evidence supports the hypothesis that the daily productivity of male plantation workers, especially those working on day jobs [jobs that are paid by the day, rather than by piece rate], is decreased as a result of the infection. However, the *weekly* wages of male workers who have the infection are not lower than those who are not infected, because the infected group is absent less from the job" (p. 77). In sum, the effects of schistosomiasis on worker productivity are less than dramatic in this study.

In developed countries, attempts to evaluate the consequences of improvements in the health of workers are found even in countries with planned economies like the Soviet Union (Balatskii, 1976), complete with discount rates ("normative coefficients of effectiveness") and present value calculations.

4. METHODS FOR LEARNING MORE OF DEMOGRAPHY AND MORBIDITY

The basic strategy for learning more of the relations between demography and morbidity remains intelligent observation, coupled with vivacity of mind, tenacity of spirit, and veracity of report (Pickles, 1939). Some important techniques to guide observations and to increase their scope and interpretability are randomized controlled experiments, record linkage and sample surveys, clinical epidemiology, and modelling and simulation. These techniques are not mutually exclusive.

Randomized controlled experiments are a first step in the rational administrative evaluation of a proposed medical or public health intervention (Sackett, 1980, p. 1805): "The key criterion for evaluating the efficacy of a preventive procedure or regimen is the clinical outcome among recipients and non-recipients in a randomized trial. Only through the performance and interpretation of such trials can we determine the efficacy of these or any other health maneuvers".

The experimental procedure provides data that are of scientific value when it is used to answer a question of scientific interest. For example, Wiesbrod et al. (1973) study the effects of parasitic infection on fertility and the productivity of labour by statistical analysis of observational data. An experiment could have approached the same question by using communities or valleys as the units of randomization and controlling infection in some units but not in others. As Mack Lipkin, Jr. has pointed out, in classical clinical

trials, the treatment of individual patients was randomized; but greater creativity in the choice of unit is possible.

Certain problems cannot be approached by controlled randomized experiments. Newcombe (1955) could not have performed and experiment to determine whether mothers who bear children with Down's syndrome subsequently have elevated fertility. The linkage of records or a prospective study are alternatives. Where the necessary information exists in records routinely collected for administrative purposes, there may be substantial economies in record linkage compared to special-purpose studies. Record linkage for genetic and medical studies is advocated by Cavalli-Sforza and Bodmer (1971, p. 329) and Acheson (1967), who gives examples of biomedical discoveries resulting from record linkage. Record linkage on a small scale is familiar to historical demographers since the work of Henry (1956) and Gautier and Henry (1958).

Some national sample surveys yield morbidity data, for example on cancer (Krueger and Feldman, 1980).

Clinical epidemiology means the use of information arising from ordinary clinical practices to establish the conditions under which diseases arise and to evaluate the effectiveness of clinical procedures. (This is only one of several current definitions; see White and Bullock, 1980). An example of clinical epidemiology is a thoughtful evaluation (Brook and Whitehead, 1980) of a therapeutic community for adolescent Canadian amphetamine abusers. There was little possibility of performing a randomized controlled experiment, as Sackett (1980) recommends. Brook and Whitehead find that the level of functioning, four years after release, of individuals who were in the therapeutic community is not related to the individual's durations of stay in the community, over a range of durations from a few hours to more than a year. Those in the community very briefly serve as a kind of control for those present longer. Even this weak control lends force to the conclusion of Brook and Whitehead that no effect of treatment on function could be demonstrated.

A central problem in clinical epidemiology is "the denominator problem". Any epidemiological or demographic rate is a ratio: the number of events (such as births, deaths, or illnesses) divided by the population at risk of experiencing the event. This population at risk is the denominator. The denominator problem is to estimate the denominator when the numerator, or number of events, is derived from clinical information about physicians' practices. If a physician sees two cases of pneumonia, what inference can be made about the risk of pneumonia in some well-defined population ? Initial efforts to attack this problem have fitted standard mathematical frequency distributions (such as the zero-truncated negative binomial distribution) to observed frequency distributions, for example, of episodes of illness with new problems, in order to try to estimate the number of people who do not appear in the doctor's office at all (Kilpatrick and Brennan, 1980; Krogh-Jensen and Kilpatrick, 1980). Here is an opportunity for demographers and statisticians to contribute their expertise in one of the most basic problems of demography: estimating the size of a relevant population.

One good use of clinical epidemiological data may be as part of a larger programme of record linkage. Equally obviously, clinical data may be used to determine outcomes in randomized controlled experiments.

Modelling and simulation can aid the planning of observations and the interpretation of data. Simulation is a kind of modelling in which the consequences of assumptions are explored by machine computations instead of by analytical mathematics. I will use modelling to refer to both analytical and computational activities. The relation between

modelling and the interpretation of data is like the relation between health professionals and the health of a population: the largest benefits per unit of effort derive from preventive action, but the demands for services are most insistent after problems already exist.

Here is an example of the pay-off from developing a model concurrently with the *planning* of a large field trial. In the Gardi study of malarial epidemiology and control (Molineaux and Gramiccia, 1980), conducted by the Government of Nigeria and the World Health Organization in northern Nigeria, parasitological surveys of the population of some five thousand people had to be carried out at regular intervals. One option for the interval was five weeks; another was ten weeks. Preliminary modelling, using data then available, indicated that little additional information would be gained by surveying every five weeks. The result was a substantial saving in the costs of the study. Modelling and simulation may be most helpful if intelligently exploited at the inception of an empirical study.

Thus randomized controlled experiments, record linkage and sample surveys, clinical epidemiology, and modelling are mutually supporting approaches.

This review of the relations between demography and disease has emphasized examples rather than grand generalizations because, in my opinion, the field is still at an early stage of natural history. There are many opportunities for modelling, theory-building in the small, and for new methods of acquiring and interpreting data.

ACKNOWLEDGMENTS

I am very grateful to Ron Gray, Henri Leridon, Mack Lipkin, Jr., Massimo Livi-Bacci, William W. Lowrance, Jerry Nedelman, Burton H. Singer and Kerr L. White for helpful comments on earlier drafts and many important references. Jean Hernandez typed the manuscript. My work has been partially supported by U.S. National Science Foundation grant DEB 80-11026.

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