Demographic Measurement: Nuptiality, Mortality, Migration, and Growth

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Abstract

This is the second of two articles on demographic measurement, the first article being entitled *Demographic Measurement: General Issues and Measures of Fertility*. This second article presents the principal ways in which nuptiality, mortality, migration, and population growth are currently measured in demography. The section on nuptiality covers indices of both level and timing of marriage, divorce, and cohabitation. Crude and specific rates are presented along with synthetic or hypothetical cohort measures. The definitions of the main types of nuptiality and mortality measures are given in tabular form.

Introduction

In the article *Demographic Measurement: General Issues and Measures of Fertility*, we saw that demographic measures are required for comparisons through time and space, and between subpopulations. Well-specified measures are needed because the rate of demographic events varies both with age and with other dimensions of personal time, and because populations vary in size and in composition with respect to age and other factors influencing demographic event rates. Type 1 and type 2 rates were distinguished. In type 1, or occurrence-exposure, rates the denominator is confined to people who are at risk of the event in question. In type 2 rates, no such restriction is placed on the denominator. Synthetic or hypothetical cohort measures were introduced, their purpose being to summarize an array of specific rates pertaining to a period and to estimate the hypothetical lifetime consequences of the set of rates obtaining in a calendar period. Some demographic indicators measure 'flow' – the movement into and out of the population or into particular states – whereas others measure the 'stock,' or cross-sectional state of the population at a given time. Some further types of demographic behavior are considered in this article.

Marriage, Cohabitation, and Union Disruption/Divorce

Indicators of marriage and divorce are much less numerous than those of fertility. Measures of both level and timing are considered here.

Level

The most basic of the 'flow' indicators are the crude marriage rate, defined as the number of marriages per 1000 population, and the general marriage rate, defined as the number of marriages per 1000 population of marriageable age, usually 15 years of age and above, but the legally allowable minimum age at marriage varies between countries (Table 1). These rates are influenced both (a) by the structure of a population by age and sex, since marriage rates vary by age and sex, and (b) by the proportions currently married, since those already married are not at risk of a further marriage (though would be so if they were to divorce). To deal with the second of these, a general marriage rate may be defined per 1000 unmarried persons. Age–sex variation in rates is handled in the conventional way by defining marriage rates specific by age and sex. Age–sex specific marriage rates may be refined by restricting the denominator to the unmarried. Further detail may also be introduced by calculating marriage rates specific by order of marriage. Thus, in an occurrence-exposure rate of first marriage (type 1), the numerator of the age–sex specific first marriage rate is confined to first marriages and the denominator is restricted to people who are single (i.e., never married). A type 2 rate of first marriage has the same numerator as the type 1 rate, but the denominator includes all persons in the age–sex group in question. Remarriage rates are generally of type 1, i.e., they express the number of remarriages, by age and sex, per 1000 divorced and widowed persons, but they too can be calculated in type 2 form – remarriages per 1000 persons in an age–sex group, irrespective of marital status. All rates may be calculated on either a period or a cohort basis. The crude and general marriage rates can be standardized for age, using conventional standardization methods.

As an adjunct to, or sometimes in place of, period or cohort marriage rates, the cross-sectional distribution of marital status by age and sex may be used to depict the nuptiality of a population. These are 'stock' figures and have the advantage that they can be obtained from any census or survey in which individuals' current marital status is recorded and so do not require vital registration information or annual population estimates by age and sex. They reflect the prevalence of marriage, divorce, and widow(er)hood resulting from past rates of marriage and marital dissolution, and so do not represent marriage rates, etc., in the population concerned. However, marriage rates in preceding years can be reconstructed from cross-sectional surveys if information on retrospective marriage histories is collected.

Measuring the frequency of nonmarital cohabitation and of other types of informal partnerships is in principle similar to marriage but less straightforward. This is both because vital registration data are not available and because cohabitation and marriage behavior may need to be considered jointly, for a full picture (see Murphy, 2000 for a discussion of some methodological issues). Because informal partnerships are not recorded in vital registration systems, and that population estimates by *de facto* marital status are not usually available, the traditional approaches to measuring marriage often cannot be adopted. Current status data and retrospective questions in

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Table 1 Selected measures of marriage

Measure and time reference[a]	*Definition*	*Notes*[b,c]
Level		
Crude marriage rate		
Period	$\frac{M}{P} \times 1000$	$M =$ number of marriages during a specified year or period. $P =$ total person-years lived.
General marriage rate		
Period	$\frac{M}{P_{15+}} \times 1000$	$P_{15+} =$ person-years lived at ages 15 and above
Age–sex specific marriage rate (type 2)		
Period; cohort	$N_x^f = \frac{M_x^f}{P_x^f} \times 1000$	$M_x^f =$ women marrying at age x or in age-group x. $P_x^f =$ woman-years lived at age x or in age-group x. Analogous definition for men.
Age–sex specific first marriage rate (type 2)		
Period; cohort	$\frac{M_{x,1}^f}{P_x^f} \times 1000$	$M_{x,1}^f =$ single women marrying aged x or in age-group x. Analogous definition for men.
Age–sex specific first marriage rate (type 1)		
Period; cohort	$\frac{M_{x,1}^f}{P_{x,u}^f} \times 1000$	$P_{x,u}^f =$ woman-years lived while single and aged x or in age-group x Analogous definition for men.
Total marriage rate		
Period	$\sum_{15+} \frac{M_x^f}{P_x^f}$	Where age is in 5-year groups, the sum is multiplied by five. Analogous definition for men.
Total first marriage rate		
Period	$\sum_{15+} \frac{M_{x,1}^f}{P_x^f}$	Where age is in 5-year groups, the sum is multiplied by five. Analogous definition for men.
Gross nuptiality		
Period; cohort	$1 - \prod_{x=15+} (1 - q_x^f)$	$q_x^f =$ probability that a single woman aged x exactly will marry before $(x+1)$th birthday. Age range used may vary. Analogous definition for men.
Net nuptiality		
Period; cohort	Cumulative proportions ever marrying in a double-decrement life table with marriage and mortality as decrements	Age range used may vary. Defined for males and for females.
Timing		
Mean age at marriage (crude)		
Period; cohort	$\frac{\sum_{15+} xM_x^f}{\sum M_x^f} + 0.5$	Analogous definition for men.
Mean age at marriage (standardized)		
Period	$\frac{\sum xN_x^f}{\sum N_x^f} + 0.5$	Analogous definition for men.
Singulate mean age at marriage		
Period	$15 + \frac{\sum_{15}^{49} S_x^f - 35S_{50}^f}{1 - S_{50}^f}$ Assuming no marriage before age 15	$S_x^f =$ the proportion of women aged x who are single. S_{50}^f can be estimated by the mean of the proportions single in age-groups 45-49 and 50-54. Where 5-year age-groups are used, the first term in the numerator is multiplied by 5. Analogous definition for men.

[a]All measures given here relate either to a calendar year, time period, or cohort. For clarity, subscripts denoting the time reference are omitted.
[b]In the specification of demographic rates, person-years lived is the true denominator. Where the rate relates to a year or period, events and person-years lived are those occurring during the year or period in question, at age x where specified. A cohort rate is based on events experienced and person-years lived by the cohort concerned, at age x where specified. Person-years lived are normally estimated by the mid-year population.
[c]Throughout the table, age x denotes age x in completed years or, equivalently, age x at last birthday.

cross-sectional censuses and surveys are therefore a primary source of information. The absence of good quality information on informal unions limits assessment of levels and trends in *de facto* unions particularly in developed nations, where the prevalence of cohabitation has increased substantially since the 1970s, and in some countries of the Caribbean and Latin America, where visiting or consensual unions have long been common (Fussell and Palloni, 2004). Among the indicators used to evaluate the frequency of informal unions are: the proportion currently cohabiting, the proportion who have ever cohabited, the proportion cohabiting with their marriage partner prior to marriage, and the proportion of current unions that are cohabiting unions. The frequency of informal unions evaluated by all of these indicators tends to vary with age, and social differentials can vary both with age and the measure used (Ni Bhrolchain and Beaujouan, 2013).

The crude divorce rate is analogous to other crude rates, being defined as the number of divorces per 1000 persons in a population. It is influenced in a compositional sense by the proportions married by age and sex, and by the distribution of marriages by duration, since divorce rates are closely tied to duration of marriage. Where data are available, a slightly more detailed measure is preferable: divorces per 1000 existing marriages in a population. As with other events, divorce rates are more informative if specific by age and sex: divorces in an age–sex group per 1000 married persons in that age–sex group. However, divorce rates specific by duration of marriage are usually preferred to age-specific rates since divorce risk varies substantially by marriage duration. Divorce rates specific by both age at and duration of marriage, as well as by sex, are especially informative since the risk of divorce is strongly related to age at marriage, being higher among those marrying at younger ages. The divorce rate is sometimes expressed, mistakenly, as the number of divorces in a year per 1000 marriages in that year. This is erroneous because the divorces in a given year stem from marriages that took place in preceding years, and so divorces should be related in some way to the stock of marriages that are at risk of divorce, that is past marriages rather than those of the current year. Divorce rates expressed per 1000 married population are a crude way of achieving this, and rates by marriage cohort or duration of marriage improve on this. A further method is given in the section on synthetic indicators. It is separation rather than divorce that marks the end of informal unions, and measures such as the proportion of cohabitations separating within, e.g., 5 or 10 years are used instead. For many practical purposes, separation is also of greater interest as marking the *de facto* end of a marriage. Information on separation is obtained from retrospective histories of partnership collected in demographic surveys.

Where birth cohort information is available, the cumulative proportions ever having married by specified ages are useful indicators of both the level and the pattern of marriage within and across generations. Birth cohort proportions ever having divorced or ever having remarried can be obtained for the same purpose, though in this case the figures may be influenced by the cohort proportions ever having married or ever having divorced, respectively. The proportion ever having divorced or separated calculated by year of marriage or partnership, specific by duration of marriage/union, overcomes this issue. Similarly, the proportions ever having remarried may be calculated for divorce cohorts, or alternatively the proportions in a new partnership by duration since separation.

Synthetic or Hypothetical Cohort Measures

The total marriage rate is often used to summarize the overall level of marriage for each sex in a population. It is obtained by adding the (type 2) age–sex specific marriage rates and represents the hypothetical average number of marriages in a cohort of women or men if they experienced the age–sex specific marriage rates of a particular year throughout their lifetime. The total first marriage rate is defined similarly as the sum of the age–sex specific (type 2) first marriage rates and represents the proportion of women or men who would eventually marry, if they were subject through their lifetime to the age–sex specific first marriage rates of a given period. Both of these summary measures have the same strengths and weaknesses as the analogous conventional total fertility rate (TFR; *see* Demographic Measurement: General Issues and Measures of Fertility). On the one hand, they are standardized for age and so are an improvement on the crude marriage rate. However, like the conventional TFR they are influenced by timing changes and they do not take account of past history, since they are not standardized for marital status. As a result, a period-specific total first marriage rate can, and has been observed to, exceed one first marriage per person – an impossible result that could not apply in a real cohort. Like the TFR, however, the total marriage rate can be considered as a simple indicator of the level of marriage in a period; like the TFR, it is deficient as a summary indicator whenever change in marriage rates differs between age-groups.

As in the case of fertility, multiplicative summary indicators are available to overcome some of the deficiencies of additive measures: gross nuptiality and net nuptiality. Gross nuptiality is so called because it assumes that all survive to the latest age considered – usually to age 50. It is obtained, for each sex, by combining the age-specific first marriage probabilities of the unmarried (type 1) multiplicatively and computing the proportions ever marrying by 50 years of age (*see* Life Table). Net nuptiality, on the other hand, takes into account that death may intervene before marriage and is obtained by constructing a double-decrement life table, with marriage as one source of decrement and death while single as a second source of decrement (*see* Life Table). Gross nuptiality may be interpreted as the proportion of a cohort who would marry at a given period's age-specific rates if there were no mortality before 50 years of age, and net nuptiality as the proportion who would marry by 50 years of age, at a given period's age-specific marriage and mortality rates. Both gross and net nuptiality require more detailed information than is needed to obtain the total marriage rate – namely first marriages by age and sex together with population estimates by age, sex, and marital status in the case of gross nuptiality, and additionally, mortality rates by sex, age, and marital status in the case of net nuptiality. As with life table quantities in general, they are standardized for age structure.

The level of divorce in a population may also be summarized from period rates using hypothetical cohort indicators. Analogous to the total marriage rate is the male or female total divorce rate, defined as the sum of age–sex specific type 2 divorce rates and representing the average number of divorces per person if the age–sex specific divorce rates of the period in question were to be experienced throughout a person's lifetime. As before, a multiplicative life table-based indicator is preferable to the additive measure. The most common indicator used for the purpose is a life table estimate of the proportions who would divorce by a specified duration of marriage, at current duration-specific rates. As with analogous multiplicative indicators, this not only standardizes for the distribution by marriage duration but also takes some account of past history. It is probably the best available summary measure of the divorce propensity implied by current divorce rates, but is also subject to tempo effects. If successive marriage cohorts are moving to an earlier pattern of divorce, the high divorce rates of early divorcing couples may be combined with the high divorce rates of later-divorcing couples who had lower divorce rates at early durations, to produce an overall hypothetical proportion ever divorcing that is higher than that of any real cohort. Again, the measure can be specified ignoring mortality or incorporating mortality as a competing risk (Wilson and Smallwood, 2008).

Timing

Age at marriage may be calculated from period data in either crude or standardized form, though sources do not always indicate which measure is presented and, as with births, the terms 'crude' and 'standardized' are not in universal use in this context. The crude mean age at marriage is simply the mean age of those marrying in a period. The standardized mean age at marriage is analogous to the standardized mean age at birth and is the mean of the schedule of age-specific marriage rates (type 2). A crude and standardized median age at marriage may also be obtained. It is often useful to distinguish marriage age by the order of the marriage since the proportion of remarriages among all marriages can vary substantially through time or cross-nationally. Thus, we have the mean or median age at first marriage or at remarriage, either crude or standardized. Cohort mean ages at marriage can also be calculated and, as before, do not need to be standardized. Analogous indicators can be obtained for informal unions; the most useful are the mean age at first cohabitation and the mean age at first union. Mean and median ages at marriage can also be obtained from either gross or net nuptiality tables. Care is needed since the e_x column of a nuptiality table does not give the expected age at or years to marriage. Rather the column gives the expected number of years lived while single at and after age x. Since some never marry, this is not the same as the expected number of years to marriage among those who marry (*see* Life Table).

Where direct data are not available, an indirect procedure developed by Hajnal (1953) can be used to estimate the average age at marriage from cross-sectional proportions single (never married) by age. It gives what is termed the singulate mean age at marriage. Based on the hypothetical cohort principle, the procedure is appropriate where marriage rates by age have been reasonably stable and assumes that neither migration nor mortality rates are associated with marital status. Should the proportions single be found to increase over any part of the age range, this indicates that one or more of the assumptions does not hold and so the calculation is not valid. Brief details are given in **Table 1**; see also Preston et al. (2001: Section 4.6).

Mean and median ages at divorce may be calculated. Of particular interest in relation to divorce is the mean/median, etc., duration of marriage at which the divorce occurs. A distinction should be made between the duration of marriages in general – those terminated by either divorce or death – and the duration of those marriages that end in divorce. Crude or standardized versions of these indicators may be obtained; for most purposes, standardized indicators are to be preferred.

Mortality

Table 2 sets out selected mortality measures. These require data on deaths and population estimates. Where such data are not available, indirect methods for estimating mortality are available (*see* Demographic Techniques: Indirect Estimation).

The crude death rate (CDR) – deaths per 1000 population – is widely used as a basic measure of the level of mortality. It is strongly influenced by the age composition of a population because of the wide variation in death rates by age. Age-specific mortality rates – deaths at a particular age per 1000 population of that age – are at the next level of detail, usually specific by sex. Age is usually in 5-year groups and for refined analysis, in single year of age rates. Rates specific by single years of age are of particular importance at the younger and older parts of the age range, since in these age ranges differences in rates between adjacent single years of age may be sizable. Age may be grouped in a variety of ways. However, even where quinary age-groups are used, ages 0 and 1–4 are often distinguished, because of the relatively high death rate of infants, even in low-mortality countries.

The measurement of mortality is simplified somewhat by the fact that death occurs ultimately to all and occurs only once. These two together mean that crude and age-specific death rates are necessarily of type 1 (*see* Demographic Measurement: General Issues and Measures of Fertility). Death rates are so closely and systematically associated with age, and to a lesser extent sex, that specificity by age and sex is adequate for many demographic purposes. Other dimensions of personal time are sometimes used: e.g., duration since diagnosis, or since treatment, in epidemiological studies. Mortality rates may also be specific by social class, race/ethnicity, income, area of residence, marital status, and other socioeconomic characteristics. Analysis by such factors is of interest in examining social and economic variations in health and for actuarial and public health purposes.

The infant mortality rate (IMR) is reported and published extensively, partly as a demographic indicator but also as a proxy for socioeconomic development. It is defined as the number of deaths of infants (children under 1 year of age) per 1000 births in a given year. As the denominator is not an estimate of the person-years at risk of the event, it is, strictly, not a true rate. It has a correctly specified counterpart in the infant death rate, the number of deaths less than 1 year of age per 1000 person-years lived under age 1. The IMR is a convenient measure since it can be obtained from simple counts of vital events and does not require population estimates by age. But it

Table 2 Selected mortality measures

Measure and time reference[a]	*Definition*	*Notes*[b,c]
Crude death rate		
Period; cohort also possible but rare	$\frac{D}{P}$	D = the number of deaths occurring during a particular year/period. P = person-years lived.
Age-specific death rate[d]		
Period; cohort	$M_x = \frac{D_x}{P_x}$	D_x = deaths at age x. P_x = person-years lived at age x or in age-group x.
Infant mortality rate		
Period; cohort	$\frac{D_0}{B}$	D_0 = deaths of infants under 12 months. B = births.
Infant death rate		
Period; cohort	$\frac{D_0}{P_0}$	P_0 = person-years lived aged under 1 year.
Maternal mortality ratio (sometimes referred to as the maternal mortality rate)		
Period; cohort	$\frac{D_m}{B}$	D_m = maternal deaths.
Maternal mortality rate		
Period; cohort	$\frac{D_m}{P^f_{15-49}}$	P^f_{15-49} = woman-years lived at ages 15 – 49 (age limits may vary).
Directly standardized death rate[e]		
Period	$\sum_x M^i_x c^s_x$	M^i_x = age-specific death rate in index population i. c^s_x is the proportion of the standard population who are aged x.
Standardized mortality ratio[e] *(SMR)*		
Period	$\text{SMR}^i = \frac{D^i}{\sum_x n^i_x M^s_x}$ or equivalently $\text{SMR}^i = \frac{CDR^i}{\sum_x c^i_x M^s_x}$	D^i = total deaths in index population. n^i_x = numbers aged x in the index population. M^s_x = the age-specific death rate in the standard population. CDR^i = crude death rate in the index population. c^i_x = proportion who are aged x in index population. The SMR is often multiplied by 100.
Indirectly standardized death rate[e]		
Period	$\text{SMR}^i \times \text{CDR}^s$	CDR^s is the crude death rate in the standard population used in obtaining the SMR.

[a]All measures given here relate either to a calendar year, time period, or cohort. For clarity, subscripts denoting the time reference are omitted.
[b]For person-years lived, see **Table 1**, note 2.
[c]Throughout the table, age x denotes age x in completed years or, equivalently, age x at last birthday.
[d]Age-specific death rates, and associated mortality measures such as life expectancy, are generally also specific by sex, as mortality rates differ between the sexes.
[e]Each of these standardized indices can be compared meaningfully only with the standard population or with others standardized on the same standard population.

will approximate less well to the infant death rate when births are appreciably seasonal or that there are sizable year-on-year fluctuations in births. Several mortality rates are distinguished during the first year of life, both because of the steep decline in death rates over the first 12 months of life and because of the changing role of endogenous (genetic, intrauterine, perinatal) and exogenous (environmental, external) causes of death. Endogenous causes predominate in the earliest postpartum period, with exogenous factors growing in importance thereafter. The perinatal mortality rate is defined as the number of late fetal deaths plus the number of deaths within 1 week of birth per 1000 total late fetal deaths plus live births. The neonatal mortality rate is defined as the number of deaths within 1 month (28 days) of birth per 1000 live births, and the postneonatal mortality rate as deaths between 28 days of birth and 1 year of age per 1000 live births. The probability of dying between birth and the fifth birthday is widely referred to in the current demographic literature as the child mortality rate, though the latter is more correctly defined as the number of deaths of children under 5 years of age per 1000 person-years in the age-group. The probability definition (also sometimes termed child mortality risk) has become widespread because under-five mortality is of particular interest in high-mortality, less-developed societies, for which the indirect methods used to evaluate child mortality estimate a cohort probability rather than a rate (*see* Demographic Techniques: Indirect Estimation). High-mortality societies do not usually have good vital registration statistics and it can be difficult to formulate accurate assumptions about the average number of years lived by those who die, and thus to obtain an estimate of person-years lived.

Maternal deaths are those that occur during pregnancy or within 42 days of the end of the pregnancy, due to a cause related to the pregnancy or a condition aggravated by pregnancy, including abortion-related deaths. Maternal mortality is most often represented by the maternal mortality ratio: the number of maternal deaths per 100 000 live births in a period. This indicator is referred to by many authors and in many sources as the maternal mortality rate, although it is not in fact a true rate. Strictly, the maternal mortality rate is the number of maternal deaths per 100 000 women of reproductive age in a period, and some authors employ the term in this sense. It should be clear from the context which definition is in use. Indirect methods are available to estimate maternal mortality.

Mortality specific by cause of death, of which maternal mortality is an instance, is the principal way in which mortality indicators are disaggregated beyond age and sex. The International Classification of Disease, produced and revised from time to time by the World Health Organization, is the standard scheme by which cause of death is classified. Measures of mortality by cause of death are of two kinds. Cause-specific mortality rates refer to the number of deaths from a particular cause during a period per 100 000 population, and may be specific also by age and/or sex. A multiplier larger than 1000 is normally used for the purpose, since deaths from any one cause will usually be relatively small in number. Cause-specific mortality ratios, on the other hand, relate to the percentage of all deaths that result from a particular cause, either overall or by age and sex, and are of value where information on population denominators is inaccurate or unavailable. Proportional mortality analysis is used particularly in the study of occupational mortality.

Age Standardization

Because of the substantial variation in death rates by age, and in age structure across time and place, cross-national, areal, or time comparisons of the level of mortality require that death rates are standardized for age. The objective is to remove the effect of age structure from the comparison. Direct standardization, in which a standard age distribution is employed, yields a directly standardized death rate. Indirect standardization, based on a standard set of age-specific mortality rates, yields two indicators: the standardized mortality ratio (SMR) and the indirectly standardized death rate. The SMR gives an index figure expressing the level of mortality in the index population relative to that of the standard population, set to 1 or to 100: it is simply the ratio of observed to expected deaths in the index population, with expected deaths based on the standard population's age-specific rates. Multiplying the SMR of the index population by the CDR in the standard population gives the indirectly standardized death rate in the index population. Direct standardization requires that the age-specific mortality rates are known and precisely estimated in the populations to be standardized. Where the age-specific rates are either unknown or subject to sizable errors, the indirect method must be used. Statistical theory singles out a version of indirect standardization as optimal when a multiplicative model holds for the force of mortality.

Life Expectancy and Life Tables

Life expectancy at birth, e_0, is a summary of the overall level of mortality in a population. Because death occurs universally and removes an individual permanently from the population, any increase in death rates at any age is necessarily reflected in a shorter life expectancy, while a decline in death rates at any age is necessarily accompanied by an increase in life expectancy, all else equal. The expectation of life is influenced both by the level of mortality in a population and by the pattern of mortality by age. As a result, two populations with the same overall life expectancy may differ in their patterns of age-specific death rates. Life expectancy is calculated from a life table (*see* Life Table), and so is an age-standardized measure that can be compared fairly between populations and time periods. Life tables are more commonly based on period mortality rates, but are also compiled for birth cohorts. Where based on a period life table, the expectation of life and other life table functions are synthetic cohort measures and do not, strictly, represent the experience of any particular birth cohort. In practice, however, where mortality improvement is gradual, as in developed countries such as the US and Sweden, period life expectancy has been found to approximate to that of the cohort born about 40–50 years before (Goldstein and Wachter, 2006). That mortality change tends to be steady and unidirectional distinguishes it from period fertility, for which an approximate empirical correspondence between lagged synthetic period and ultimate cohort parameters cannot be established. Adjustment of period life expectancy for changing tempo has been proposed and has been subject to much debate (see especially Barbi et al., 2008).

The life table is fairly demanding of data since it requires information on age-specific death rates and hence on both deaths and population estimates by age. Because detailed data of this kind are often unavailable for historical populations and for less-developed nations, sets of empirically based model life tables have been developed corresponding to varying levels and patterns of mortality (Murray et al., n.d.). Such compilations allow estimates of the level and/or age pattern of mortality to be made from information that is insufficient in itself to determine these (*see* Demographic Techniques: Indirect Estimation). For further details of the measurement of mortality see Preston et al. (2001), Rowland (2003), and Siegel (2012).

Migration

Along with births and deaths, migration is the final component of population change. Migration is classified according to whether it is into an area (in-migration) or out of an area (out-migration). The sum of in- and out-migration is termed gross migration and the difference between them, in-migration minus out-migration, is known as net migration. For many purposes it is the absolute values of these quantities that are of interest. Crude and specific rates are also used. The crude in-migration (or immigration) rate is the number of in-migrants per 1000 population and the crude out-migration (or emigration) rate the number of out-migrants per 1000 population. The crude gross migration rate is the sum of these and the crude net migration rate is the difference between them.

There are, however, difficulties with these indicators. In particular, in-migrants are from populations outside the destination area, and a rate of in-migration per 1000 population in the destination area clearly does not link in-migrants with the true population at risk of such migration; it is therefore not a true rate. In addition, net migration is somewhat contested as a category. There is no such thing as a 'net migrant,' and looking for the influences on net migration rather than on the component in-flows and out-flows may be misconceived (Rogers, 1990). On the other hand, it is argued that net migration is useful where information on gross flows is lacking (Smith and Swanson, 1998).

Further indicators based on transition data – having changed residence between specified two time points – are in use. Cumulative migration experience can be represented by whether a person has ever migrated from his or her place of birth or during a specified time, e.g., the last year, the last 5 years. Synthetic summary indicators of lifetime migration experience are also in use, analogous to the fertility equivalent – the gross migraproduction rate, which ignores mortality, and migration expectancy or the net migraproduction rate, which takes mortality into account. Like other demographic events, migration is patterned by age and measures standardized for age can be constructed. For a detailed exposition and discussion of migration measurement, see Bell et al. (2002).

Population Growth

The difference between the crude birth rate (CBR) and CDR is known as the crude rate of natural increase and represents the rate at which a population is growing or declining in a year purely as a result of vital events. Since migration also influences population growth, the overall, crude population growth rate is CBR $-$ CDR $\pm$ the crude net migration rate. Where annual crude rates are not available, the population growth rate can be inferred from population size at two time points, say t years apart. If we assume that the population has been growing continuously at a fixed rate over that period, this implies an exponential model of growth, in which $P_t = P_0\ e^{rt}$, where P_0 is the initial population and P_t is population size t years later, and r is the annual growth rate. Under these assumptions, the annual growth rate can be estimated as $r = \ln(P_t/P_0)/t$. Note that the exponential model of growth does not necessarily represent, as is often assumed, extremely rapid growth. Whether exponential growth is rapid depends on the growth rate. For example, after 50 years a population growing exponentially at the rate of 1% per annum would have increased by 65% but the increase would be just 5% if it was growing exponentially at 0.1% per annum.

The growth rate of a stable population – one with a fixed set of age-specific mortality and fertility rates, and closed to migration – is known as the intrinsic rate of natural increase. It is a theoretical quantity. It can be calculated from the fertility and mortality rates of an empirical population. It should be interpreted with care since it is the hypothetical growth rate that would apply in a theoretical stable population with the vital rates assumed, and not the growth rate of the real population from which the vital rates are drawn. Further indicators relevant to the theoretical analysis of population growth are outlined in the article Demographic Measurement: General Issues and Measures of Fertility: the gross and net reproduction rates (GRR and NRR). While the GRR and NRR may be calculated for real populations, the same proviso must be borne in mind: the NRR reflects growth prospects only under strict hypothetical conditions. The same caution is necessary in relation to the TFR: in low-mortality countries, a TFR of 2.1 is widely referred to as 'replacement level fertility,' that is, the level of fertility necessary for population replacement in the long run. But this is potentially misleading. Low-mortality populations with a TFR of below 2.1 can and do continue to grow because of in-migration, declines in mortality, changing fertility, and/or population momentum. Equally, low-mortality populations with a TFR of 2.1 or more can and do decline because of out-migration, changes in fertility and/or mortality, and/or population momentum.

See also: Adult Mortality in Developing Countries; Adult Mortality in Industrialized Societies; Demographic Techniques: Indirect Estimation; Infant and Child Mortality in Industrialized Countries; Infant and Child Mortality in the Less Developed World; Internal Migration in Industrialized Countries; Internal Migration: Developing Countries; International Migration; Life Table; Partnership Formation and Dissolution in Western Societies.

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