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PROPORTION OF DYING CHILDREN IN PALEODEMOGRAPHICAL STUDIES: ESTIMATION BY GUESS OR BY METHODICAL APPROACH *

INTRODUCTION

In paleodemographical studies aiming at description of structure and dynamics of human groups usually introduction of some assumptions is necessary because of scarce data. In most of those studies the principal, if not sole, source of information is the mortality structure, or more exactly — distribution of deaths by age. Sometimes it is possible to estimate number of childbirths per women from examination of pelves [Putschar 1931, Stewart 1957, Angel 1969, Acsádi and Nemeskéri 1970, Houghton 1974, Ullrich 1975]. Still less frequently there arise possibility to estimate directly rate of natural increase from archeological data (eg. by comparing size of settlements in successive periods or increase in their number on a given area). Anyway it is impossible to obtain full information as to the structure and dynamics of a prehistoric population from direct examination of finds.

Introduction of assumptions into paleodemographical analyses usually is not entirely arbitrary but is based on the principles of moderate actualism (or uniformism). Use of these principles is made in two ways: firstly, by projecting into the past some numerical information obtained from data on modern populations, and secondly by assuming that in prehistoric groups interrelations between phenomena determining reproduction of populations were the same as in modern times. It seems that the last approach is more fruitful, so it is useful to show interactions between separate phenomena concerning mortality, fertility and net reproduction in a way most appropriate for obtaining maximum information from existing paleodemographical sources.

Some questions concerning interrelations between prehistoric mortality structures and possibilities for reproduction were dealt with in ear-

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lier papers [Weiss 1973, Henneberg 1975 a, 1975 b, 1976]. It was shown that from mortality structure and some common for non-Malthusian populations regularities of procreation, fertility, net reproductive rate and consequently rate of natural increase can be estimated when we are dealing with groups sufficiently close to the stable population model. A basis for all such estimations is constituted by mortality schedule, so it was assumed that data from cemeteries are complete in this respect. However, it is well known to paleodemographers that even with very accurate and careful archeological methods it is often impossible to obtain sufficient information on a number of deceased children, especially the youngest of them (newborns+infants). In such a situation some authors (eg. Acsádi and Nemeskéri [1970], Piasecki [1975], Nemeskéri [1976]) postulate that this number must be estimated on the basis of present-day mortality in underdeveloped societies of historical information, and respective data from cemeteries corrected by adding thus estimated numbers of subadults to the uncovered samples of adults. It seems, however, that such use of actualism principle may distort our knowledge on prehistoric mortality, and would lead to results which will not inform about the past but simply reflect assumptions introduced at the beginning of the analysis.

The aim of this paper is to show how proportion of deceased children can be estimated from known mortality schedule of adults and regularities of reproduction when one deals with a group sufficiently close to the stable population model with given net reproductive rate (or what is the same information — intrinsic rate of natural increase).

METHODICAL CONSIDERATIONS

When dealing with a skeletal sample we usually have at our disposal material originating from a period of at least one hundred years. Since it is practicaly impossible to obtain direct information on fluctuations in mortality and fertility schedules within the period in which given cemetery was used it is advisable to treat all buried individuals as a random sample from the stable population. Such approach is moreover founded by considering that minor fluctuations of fertility and mortality within the period are "smoothed up" when we treat the material as a single sample.

Disregarding migrations we may say that structure and dynamics of populations is determined by their reproduction, i.e. net result of interaction between mortality and fertility. Reproductive behavior of a stable population in most general form can be expressed by a following formula:

$$e^{rT} = R_0 = \sum_{x=0}^{\omega} l_x b_x \tag{1}$$

where: r — rate of natural increase, T — length of a generation in years, R_0 — net reproductive rate, ω — maximum attainable age, l_x — proportion surviving to the age x, b_x — age-specific birth rate.

It is well known trasformation of Lotka's fundamental equation. The rows of l_x and b_x values describing effects of mortality and fertility can be broken down into sets of other values expressing impact of various mortality and fertility components or "parts" on general schedules. Values of l_x depend on death frequencies of individuals in various ages which are described by d_x values. Fertility, as expressed by b_x values, can be divided into two components. One of them — intensity of births, may be defined simply as a total number of children born during lifetime of parents surviving to the physiologicaly determined end of reproductive period — U_c. The second component is a distribution of births within reproductive period, or as Weiss [1973] calls it — the shape of the fertility function. This distribution can be described either by Weiss' [1973] k_i coefficients or by s_x coefficients of the author [Henneberg 1975 a, 1975 b, 1976]. Both coefficients give similar information, but from differences in their definitions it follows that s_x values are more suitable for further analytical treatment in paleodemography. s_x is defined by following relation:

$$1-s_x=\frac{U_x}{U_c}$$

where U_x — cumulative number of births attained by adult up to the age x.

As has been shown previously [Henneberg 1975a, 1975b] sets of s_x values for various non-Malthusian populations, differing seriously in number of births (U_c), are almost identical, so one set called "archetype of fertility" can be used for paleodemographical studies.

Having at our disposal d_x values for adults and respective s_x row it is possible to compute the so called "potential gross reproductive rate" — R_{pot}:

$$R_{pot}=1-\sum_{x=15}^{\omega} d_x s_x \qquad (2)$$

where d_x is computed as a fraction of a total number of adults living at the beginning of reproductive period. R_{pot} multiplied by half of U_c value gives gross reproductive rate if sex ratio is 1 : 1. Furthermore, multiplying R (gross reproductive rate) by $1-d_{0-14}$ (fraction survinig to adulthood) net reproductive rate can be computed. Net reproductive rate divided by half U_c gives Biological State Index — I_{bs} expressing reproductive possibilities of a population. Use of this index in human biology is explained in another paper [Henneberg and Piontek 1975].

From above considerations it follows that death frequency of subadults (d_{0-14}) can be treated as a separate factor determining population dynamics. Hence, within fertility and mortality phenomena we may distinguish following set of variables suitable for elaboration of paleodemographic data: 1. mortality schedule of adults, 2. the shape of the fertility function, 3. U_c, 4. frequency of subadult deaths, 5. net reproductive rate. With present-day methods for sex and age determination in skeletal material we may admit that information on adult mortality schedule obtained from most of cemeteries is sufficiently accurate and reliable. The shape of the fertility function for non-Malthusian populations is in fact uniform and known to us [Henneberg 1975b, 1976; Ward and Weiss 1976]. Number of births can be sometimes estimated from pelves, though in the majority of situations is practicaly unknown. As has been pointed out in the introduction in certain cases it is possible to estimate rate of increase, otherwise it can be sufficient enough for some type of a study to assume stationary state of population. Hence from the five variables in many paleodemographical analyses at least three are known, and as to the remaining two we have usually some idea only. Although in equations given below we will have often two variables unknown, or rather "almost unknown", it seems reasonable to use these formulas instead of performing a sort of guessing-game in estimating reproductive behavior of a population by changing freely number of deaths in various age classes.

Equation relating all the five variables may be written in a form:

$$d_{0-14} = 1 - \frac{R_0 2}{R_{\text{pot}} U_c} \tag{3}$$

or, because $R_0/0.5\ U_c = I_{\text{bs}}$

$$d_{0-14} = 1 - \frac{I_{\text{bs}}}{R_{\text{pot}}} \tag{3a}$$

In a similar way we may arrive at equations enabling estimation of number of children deceased up to any age below fourteen years when we have complete data concerning mortality of persons above this age. It will be presented equation for computing proportion of newborn and infant deaths as this proportion is of great interest for paleodemographers and be of some use in historical demography where frequently number of deaths in the first year of life is underregistered. It suffices to compute a value similar mathematicaly to R_{pot}:

$$R'_{\text{pot}} = 1 - \sum_{x=1}^{\omega} d_x s_x \tag{4}$$

(where d_x is a fraction of surviving through the first year of life and s_x for $x = 1, 2, \ldots, 14$ is 1 because no births occur from individuals of these ages) and introduce it instead R_{pot} into formula (3). In order to construct complete mortality schedule (i.e. row of d_x values from $x=0$ to ω) previously computed values for $15 - \omega$ or $1 - \omega$ have to be multiplied by $1 - d_{0-14}$ or $1 - d_{0-1}$ respectively.

When we are dealing with a stationary population d_x values correspond directly to fractions of persons deceased in ages x among all deaths. In the case of stable population with non-zero growth rate, fractions of deaths in respective age groups cannot be computed directly from distribution of deaths by age alone, there should be made corrections for the rate of increase with use of routine demographical procedures (eg. Pressat [1961], Keyfitz [1968]).

APPLICATION OF THE METHOD

In a way of illustration the method outlined above was applied to the data from parish registers of a Polish rural community [Henneberg 1977]. The data are complete enough to allow for estimation of natural increase (in the years 1828 - 1854 $r=-0.005$ per year), completed fertility ($U_c=6.3$) and construction of the life table (tab. 1). The rate of natural increase corresponds approximately to $R_0=0.9$ and calculated $R_{pot}=0.76$. Assuming stationary population state and $U_c=6$ a value of d_{0-14} calculated from the equation (3) is 0.561 and d_{0-1} is 0.167. After assuming

Table 1. Selected parameters of the life tables computed with assumed stable population state from parish registers (Szczepanowo) and skeletal material uncovered at Słaboszewo cemetery with proportion of children uncorrected and corrected as explained in the text

Age (x)	Szczepanowo 1828 - 54 $r=-0.005$		Słaboszewo cemetery 1350 - 1650 $r=+0.004$			
			uncorrected		corrected	
	l_x	e_x^0	l_x	e_x^0	l_x	e_x^0
0	100.0	20.1	100.0	31.8	100.0	23.7
1	75.2	25.6	90.8	34.0	75.3	30.3
15	39.5	30.8	64.6	31.6	47.1	31.5
20	36.1	28.4	60.9	28.3	44.5	28.3
40	23.5	18.4	38.4	18.7	28.0	18.7
60	10.2	9.5	15.6	11.5	11.4	11.5

stationary state and $U_c=7$ respective values are 0.624 and 0.286. Actual values in the life table are 0.605 and 0.249. Obviously, with $R_0=0.9$ and $U_c=6$ the results are almost identical with those from the life table. From the same territory for which we have parish registers originates skeletal material dated at 1350 - 1650 A.D. comprising about 500 skeletons [Piontek 1977]. Selected functions of the life table computed for this material with stable population model and $r=+0.004$, which was known from the literature [The Population of Poland 1975] as being probable for the region, are presented in table 1. Comparison with parish registers data clearly shows that proportion of children at the cemetery is too low. After assuming $U_c=6$ and computing proportion of deaths for first two age classes separately the life table for the cemetery has become similar to that for parish registers (tab. 1).

In the majority of cases, however, the data at our disposal are more scarce than those presented above and in such situations it is advisable to perform a sort of cross-checking, computing firstly U_c with mortality of children as it is in a skeletal material, and secondly with assumed U_c to estimate proportions of subadult deaths at various rates of increase. For most of prehistoric populations, but not for them all, it suffices to assume stationary population state. With not too numerous material, resulting in considerable standard errors of life table parameters, values

Table 2. Completed number of births (U_c), mean interval between births (BI) and fertility rate (f) when stationary population state is assumed, as estimated from I_{bs} values computed on the basis of mortality data given by various authors. BI and f are calculated for 25 years long reproductive life span of persons surviving at least to the age of 50 years. In the last line actual data on fertility in Poland are given for comparison

Group	I_{bs}	U_c	BI (years)	f (per 1000 per year)	Source of mortality data
Neandertal	.32	6.3	4.0	250	Vallois [1937]
Upper Paleolithic	.30	6,7	3,8	267	,,
Maghreb type (Epipaleolithic)	.35	5,7	4.4	229	Acsádi&Nemeskéri [1970]
Mesolithic	.30	6.7	3.8	267	Vallois [1937]
Nea Nikomedeia (Early Neolithic)	.23	8.7	2.9	348	Angel [1969]
Volni (Neolithic)	.44	4.5	5.5	182	Acsádi&Neméskeri [1970]
Germany, Neolithic	.48	4.2	6.0	167	Ullrich [1972]
Nordhausen (Neolithic)	.38	5.3	4.7	213	,,
Niederbösa (Neolithic)	.32	6.2	4.0	248	,,
Alsonemedi (Copper Age)	.51	3.9	6.4	157	Acsádi&Nemeskéri [1970]
Tisapolgár-Basatanya (Copper Age)	.61	3.3	7.7	130	,,
Grossbrembach (Early Bronze Age)	.32	6.3	4.0	250	Ullrich [1972]
Lerna (Middle Bronze Age)	.30	6.7	3.8	267	Angel [1969]
Sulęcin (Late Bronze Age)	.42	4.8	5.3	190	Piontek [1975]
Athens and Corinth (Classic)	.40	5.0	5.0	200	Angel [1969]
Intercisa and Brigetio (I - IV c.A.D.)	.43	4.7	5.4	186	Acsádi&Nemeskéri [1970]
Valachians (IV c.A.D.)	.40	5,0	5.0	200	Nicolaescu&Wolski [1972]
Keszthely-Dobogó (Late Roman Era)	.60	3.3	7.5	133	Acsádi&Nemeskéri [1970]
Sopronköhida (IX c.A.D.)	.50	4.0	6.3	160	,,
Ártánd (IX c.A.D.)	.58	3.4	7.2	138	Éry [1967]
Espenfeld (XI-XII c.A.D.)	.31	6.5	3.9	258	Bach&Dušek [1971]
Czarna Wielka (XI - XII c.A.D.)	.44	4.5	5.5	182	Modrzewska [1958]
Hungarian Model (X - XII c.A.D.)	.49	4.1	6.1	163	Acsádi&Nemeskéri [1970]
Reckahn (XII - XIV c.A.D.)	.47	4.3	5.9	170	Schott [1964]
Słaboszewo (XIV - XVII c.A.D.)	.47	4.3	5.9	170	Piontek [1977]
Poland 1960 - 1966	.94	2.1	11.8	85	Rocznik Demograficzny [1968]
Poland 1963 (direct data on fertility)		2.5	12.3	81	Rosset [1975]

Table 3. Proportion of deceased subadults in skeletal material and frequency of subadult deaths (in percentages) estimated on the basis of R_{pot}, R_0 and U_c from the equation (3)

Group	R_{pot}	d_{0-14} in skeletal material	d_{0-14} estimated when:			
			$R_0=1.0$		$R_0=1.3$	
			$U_c=6$	$U_c=8$	$U_c=6$	$U_c=8$
Neandertal	.56	38.5	40.5	55.4	22.7	42.0
Upper Paleolithic	.49	38.2	32.0	49.0	11.6	33.7
Maghreb type	.75	53.2	55.6	66.7	42.3	56.7
Mesolithic	.42	29.5	20.6	40.5	—	22.6
Nea Nikomedeia	.58	58	42.5	56.9	25.3	44.0
Volni	.69	35.6	51.7	63.8	37.2	52.9
Germany, Neolithic	.66	26.6	49.5	62.1	34.4	50.8
Nordhausen	.57	34.0	41.5	56.1	24.0	43.0
Niederbösa	.57	43.3	41.5	56.1	24.0	43.0
Alsonemedi	.76	35.9	56.1	67.1	43.0	57.2
Tisapolgár-Basatanya	.76	19.3	56.1	67.1	43.0	57.2
Grossbrembach	.53	41.5	37.1	52.8	18.3	38.7
Lerna	.66	56	49.5	62.1	34.4	50.8
Sulęcin	.64	34.4	47.9	60.9	32.3	49.2
Athens and Corinth	.76	47	56.1	67.1	43.0	57.2
Intercisa and Brigetio	.68	36.3	51.0	63.2	36.3	52.2
Valachians	.56	29.2	40.5	55.4	22.7	42.0
Keszthely-Dobogó	.81	28.3	58.8	69.1	46.5	59.9
Sopronköhida	.93	45.9	64.2	73.1	53.4	65.1
Artánd	.78	26.0	57.3	67.9	44.5	58.3
Espenfeld	.60	49.2	44.4	58.3	27.8	45.8
Czarna Wielka	.65	32.1	48.7	61.5	33.4	50.0
Hungarian Model	.80	39.4	58.3	68.8	45.9	59.4
Reckahn	.66	28.1	49.5	62.1	34.4	50.8
Słaboszewo	.78	39.3	57.3	67.9	44.5	58.3

obtained for assumed stationary state are valid (statisticaly insignificantly different) for wide range of natural increse rates [Henneberg and Strzałko 1975].

From the table 2 it follows that, if populations were stationary and data on children mortality accurate, in many prehistoric populations fertility would be unreasonably (for non-Malthusian situation) low — eg. birth spacing of six years. It would be noteworthy to mention in this context that in a previous paper [Henneberg 1975a] quite reasonable results concerning fertility in many of these populations were obtained with assumed $R_0=1.1$ and $d_{0-14}=0.600$.

Values d_{0-14} presented in table 3 do not give a clear picture. It may be seen that for some groups estimates quite closely correspond to proportions found in skeletal material, and sometimes when assumed rate of natural increase is about $+0.01$ ($R_0=1.3$) they are even lower than actual values. For these last groups it may be concluded that their net reproductive rate was lower than 1.3, if assumption of stable population state is valid. In many cases considered proportion of children found at a cemetery lies under the lowest estimate (for $U_c=6$ and $R_0=1.3$) and there is no value of this proportion higher than the highest estimate. It should be noted that, as was said at the end of the preceding chapter, proportion of subadult deaths among all deaths in a cemetery does not correspond mathematicaly to that computed with non-zero growth rate for a stable population. If natural increase were positive ($R_0>1$) proportion subadult deaths among all deaths should be higer than d_{0-14} value in life table for stable population given in last two columns of the table 3. Hence, it may be said that at the majority of cemeteries proportion of deceased children was underestimated. Range of his underestimation may be seen from the table 3.

CONCLUDING REMARKS

In order to obtain more accurate estimates of mortality schedule with use of the method presented here it is necessary to improve our ability for estimating number of births from skeletal material and rate of natural increase from archeological sources. Nevertheless even with present--day knowledge we may draw some conclusions concerning reproductive behavior of earlier human groups.

Aforementioned discrepancies between results for various cemeteries computed in the same way support our earlier conclusions about rather high variability of reproductive phenomena in the past obtained with use of Biological State Index [Henneberg and Piontek 1975]. Having at hand the equation relating five reproductive phenomena, even when values describing two of them are assumed *a priori*, it is clear that a change in one of the variables have to result in change concerning at least one another variable. Since human reproduction, be it mortality or fertility or both, creates opportunity for operation of natural selection we may conclude that natural selection in the past was strongly differentiated as to the intensity and mode of operation. Observation of reproductive phenomena is necessary if one wants to explain changes occuring in biological properties of past populations.

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METODA SZACOWANIA CZĘSTOŚCI ZGONÓW DZIECI W BADANIACH PALEODEMOGRAFICZNYCH

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W materiałach uzyskiwanych dla celów paleodemograficznych często brak odpowiedniej reprezentacji zmarłych dzieci, w związku z czym niektórzy autorzy sugerują, by częstość zgonów w wieku przedreprodukcyjnym doszacować na podstawie danych pochodzących z populacji nowożytnych, które nie przeszły jeszcze „rewolucji demograficznej". Wydaje się jednak, że dysponując danymi o strukturze wieku zmarłych dorosłych, przy istniejących obecnie możliwościach oceny liczby urodzeń na podstawie materiału szkieletowego i ewentualnie wnioskowania o tempie przyrostu naturalnego na podstawie źródeł archeologicznych, można uniknąć przenoszenia na stosunki panujące w przeszłości informacji dotyczących ostatnich kilkuset lat.

Częstość zgonów w wieku przedreprodukcyjnym jest jednym ze zjawisk determinujących sposób i tempo reprodukcji populacji — jej dynamikę ilościową. Korzystając z poprzednio wprowadzonych mierników opisujących reprodukcję w pracy niniejszej przedstawiono metodę pozwalającą obliczyć dla populacji ustabilizowanej częstość zgonów dzieci (d_{0-14}) z rozkładu wymieralności dorosłych, prawidłowości rozrodu opisywanej rozkładem względnej kumulatywnej liczby urodzeń w ciągu okresu aktywności rozrodczej (szereg wartości s_x), liczby urodzeń przypadających na osobnika dożywającego fizjologicznego kresu okresu zdolności rozrodczej (U_c) i tempa reprodukcji (współczynnik reprodukcji netto R_0 lub współczynnik przyrostu naturalnego r). Zależności funkcyjne pomiędzy wymienionymi zmiennymi przedstawiają równania (1) - (3). Szczegóły konstrukcji i interpretacji poszczególnych miar opisano w pracach: Henneberg [1975a, 1975b, 1976], Henneberg i Piontek [1975]. Z równania (3) lub (3a) można także odtwarzać proporcję zgonów noworodków i niemowląt w przypadku, gdy znana jest struktura wymieralności osobników powyżej pierwszego roku życia. Celem wykonania odpowiednich obliczeń należy do wzoru (3) podstawić wielkość R'_{pot} obliczoną według formuły (4).

W tabeli 1 przedstawiono wybrane parametry tablic wymieralności obliczonych z materiału szkieletowego pochodzącego z cmentarzyska w Słaboszewie [Piontek 1977] przed i po zastosowaniu odpowiednich poprawek dla częstości zgonów w pierwszych dwóch klasach wieku. Porównanie z tablicą wymieralności obliczoną z danych zawartych w księgach parafialnych z tego samego terenu (Szczepanowo) wskazuje iż po zastosowaniu poprawek oszacowanie wymieralności z materiału szkieletowego jest lepszym przybliżeniem sytuacji rzeczywistej. Tabela 2 przedstawia liczby urodzeń w rodzinach kompletnych (U_c), przeciętne odstępy intergenetyczne (BI) i współczynniki płodności (f) dla wybranych populacji wyliczone przy założeniu, że materiały szkieletowe dają prawidłową informację o wymieralności, a populacje badane były zastojowe. Przynajmniej w niektórych przypadkach obliczone wartości wymienionych parametrów wydają się co najmniej mało prawdopodobne dla populacji nie stosujących współczesnych metod kontroli urodzeń. W tabeli 3 przedstawiono oszacowania częstości zgonów osobników w wieku przedreprodukcyjnym wyliczone proponowaną metodą w zestawieniu z częstościami stwierdzonymi bezpośrednio w materiale szkieletowym (d_{0-14} w drugiej kolumnie). Z rozpatrzenia wartości d_{0-14} obliczonych przy różnych założeniach co do wielkości R_0 i U_c wynika, że w większości przypadków, szczególnie gdy badane populacje uznamy za zastojowe ($R_0 = 1$) liczba dzieci w materiale szkieletowym jest zbyt niska. Rozpatrując łącznie dane z tabel 2 i 3 można stwierdzić, że w populacjach pradziejowych istniało znaczne zróżnicowanie zjawisk reprodukcji co wpływało na międzypopulacyjne różnice w tempie i sposobie działania doboru naturalnego.