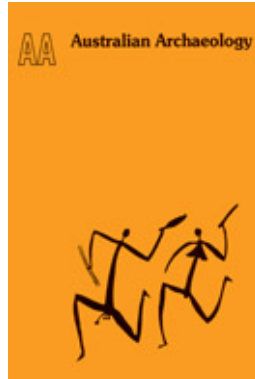


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COMPUTER SIMULATIONS OF SMALL POPULATIONS

The September number of the *Journal of the Polynesian Society*, 1976, will contain a report by Norma McArthur (Research School of Pacific Studies, ANU), I.W. Saunders and R.L. Tweedie (Division of Mathematics and Statistics, CSIRO) on their first series of computer simulations of very small populations. Some preliminary results of these experiments were presented at an ANU Prehistory seminar in April 1975, and a more mathematical treatment of the project was published in the first volume of CSIRO's *The Mathematical Scientist*, 1976.

The simulations are essentially projections forward in time from initial groups of males and females of specified ages under given rates of mortality and fertility at each age. While the logic underlying the evolution of a population is the same whatever the size of the population, the conventional demographic techniques which were designed for the projection of large populations are not appropriate for small groups, because there the demographic fate of each individual is of greater significance in the fate of the group as a whole than it would be in a large population.

This smallness also creates wide random fluctuations about the 'expected' mortality and fertility rates. If, for example, the probability of a man aged 50 dying within a year is 0.10, and there are 100 such men in a population, one could expect that the number of deaths which would occur among them in a year would lie within the range of 4 to 16. If there are only two men aged 50, and each has the same probability of dying - 0.10 - perhaps neither will die, perhaps either or both will, so that the mortality rate observed in a year for them would be either zero, 0.5 or 1.0 instead of within the range of 0.04 to 0.16 as in the group of 100, or an even narrower range if there were more than 100 men aged 50 years.

This problem can be met in a computer by programming it to generate, for each man, a random number between zero and 1.0, and if that number falls at or below the 'expected' mortality rate of 0.10 that man dies; if the random number exceeds 0.10 the man survives. In this way the 'expected' rates are 'stochasticised' and the computer keeps tabs on each individual from year to year, rather than on a group of the same age and sex which is the unit in the conventional method of demographic projections. Initially the storage capacity of the computer imposed restrictions on the length of time a population might be followed as it evolved, and the maximum time span for any of the populations generated in this series was 500 years. There was also a restriction on the size in that the storage 'overflowed' if either the total number of males or the total number of females who had ever lived exceeded 500.

At the start of each 'year' the computer scanned each individual alive in the population, subjecting each of them to the fertility and mortality rates (in that order) appropriate to

their age and sex before advancing the age of the survivors by one year to create the population alive at the start of the next 'year'. The sex of each child born in the course of a 'year' was allocated randomly, with equal probabilities of its being male or female. Marriages were performed where necessary, and in this series there were two sets of marriage rules, one in which monogamy was the only restriction and the other in which monogamous marriages between siblings and between parents and offspring were prohibited. In both cases marriages were terminated only by the death of a spouse.

The initial or founding groups consisted of equal numbers of unrelated males and females who were already married but without children. The simulations were run for groups of 3, 5 and 7 couples, and for each of these groups there were four different age brackets for both men and women, with the women two years younger than their husbands. Twenty populations were generated stochastically for each founding population of stipulated size and age composition, all under the same schedules of fertility and mortality which, in combination, had a growth potential of 1.78 per cent per year.

However, not all of the population were viable and the likelihood of extinction was greatest for the smallest group, with the increase from 3 to 5 couples giving relatively greater chances of success than the increase from 5 to 7 couples. Whatever the size of the initial group, the populations founded by the youngest males and females had significantly lower probabilities of extinction than did those begun by the oldest couples. For groups of 3 married couples with monogamy the only restriction on marriage, at least 52 (\pm 6) per cent of those where the founding wives were aged 18, 19 and 20 years became extinct, and 77 (\pm 5) per cent of those begun by women aged 27, 28 and 29 years. The parallel range for 5 couples of the same average ages was from 18 (\pm 6) to 55 (\pm 11) per cent, and for 7 couples from 15 (\pm 8) to 40 (\pm 11) per cent.

These are minimum probabilities of extinction for each group, and there was considerable diversity among the populations which became extinct in the maximum size attained, the time taken to reach that maximum and the time each persisted after attaining its maximum size. None of this variability was diminished by increasing the number of runs from 20 to 60, and the only generalisation possible was that the populations which attained the larger maximum sizes from each initial group tended to take longer to reach their maximum. Amongst those which attained the same maximum size, some were already headed for extinction before others had reached their maximum; and whatever the maximum size attained, there was no correlation whatsoever between the time taken to attain it and the time from there to non-viability. One population begun by the 3 youngest couples, for example, never exceeded 11, but it took as long to become extinct as another of the same set which increased to 26 in the same period of time.

The populations which were viable were divided into two categories - those presumed successful because they attained their maximum size either at the completion of the 500-year period or just as the constraint on the number of males or females who had ever lived was reached; and those which had passed their maximum size before any one of the constraints operated were classed as doubtful. Neither of these categories is as clear-cut as the first, in which all surviving members of a population were of one sex, and further reproduction was therefore impossible. Had the time limit exceeded 500 years some of the doubtful populations would also have become extinct, as might some of the presumed successes.

Certainly the times needed by these latter populations to attain some specified size were as variable and unpredictable as were the times that those which failed to survive persisted before eventually heading for extinction. More than 90 per cent had average growth rates over the whole period of observation within the range of 0.50 to 1.49 per cent per year, with more than half within the range 0.75 to 1.24 per cent, and more with annual rates below 0.50 per cent than above 1.75 per cent. The failure to match the expected growth potential was due partly to the rule of monogamy and the restriction of child-bearing to married women only, partly to a systematic downward bias in the growth rate caused by random fluctuations in the sex ratio at birth.

The random allocation of sex to the children born into the populations, reinforced by the randomisation of mortality and fertility rates each year, is the key to the diversity exhibited by the populations, whatever their ultimate fate. When 20 populations generated from 3 married couples in which the wives were aged 21, 22 and 23 years, with monogamy the only restriction on marriage, were printed out at 5-year intervals in the course of their evolution to a maximum of 300 years, 9 became extinct, 3 were doubtful and 8 could be presumed to be successful. None of the trajectories (six of which are reproduced in Fig.1) showed uniformly smooth growth at all stages of development, and the slowing-down or reversal of growth was almost invariably traceable to distortions in the sex ratios, either because of the predominance of one sex among the births that occurred, or the failure of some who were born to survive to marry and reproduce.

It is impossible to gauge how large a population needs to be before the random predominance of one sex at certain ages ceases to affect the pattern of growth, because this depends on the level and pattern of mortality as well as on the number of births that might occur within some time interval. The probabilities of extinction or otherwise proved very sensitive to different hypotheses about births and deaths, even when the initial groups were enlarged to 10 couples. Two of the four combinations chosen had the same growth potential but the probabilities of extinction were different, as were the sizes - and more especially, the composition - of the populations generated.

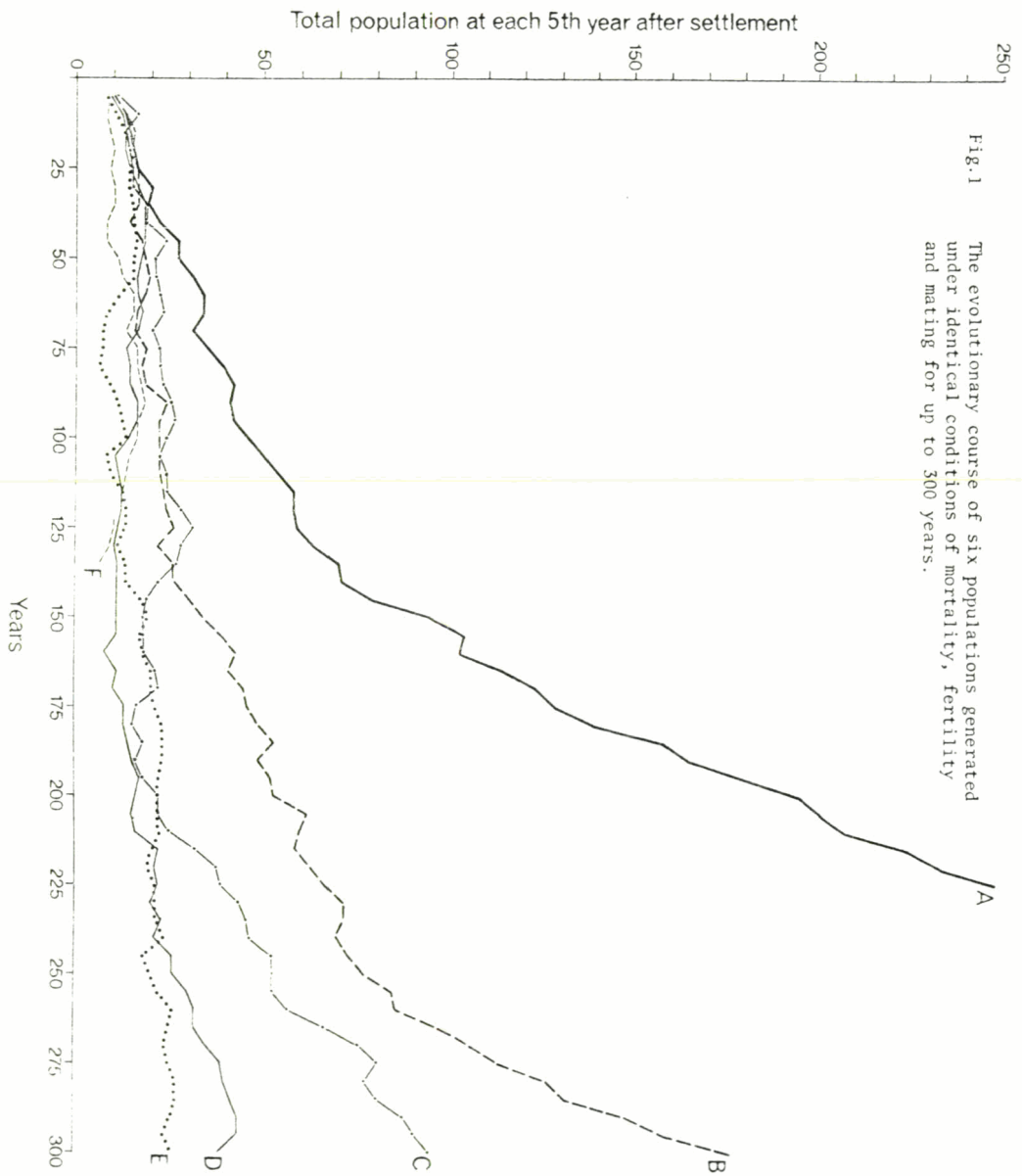


Fig. 1
 The evolutionary course of six populations generated under identical conditions of mortality, fertility and mating for up to 300 years.

The composition of the population is important to archaeologists because virtually all of their evidence relates to the activities of the adult segment of the population being studied, and adults do not constitute the same proportion of all populations of a given size, even if they increase at the same rate. A population with a high proportion of adults - such as would occur if mortality and effective fertility were low - would be likely to create more artifactual evidence than a population of the same size which may be increasing at the same rate but which, because of high fertility combined with high mortality, would contain fewer adults. And the same rate of growth might be achieved by an almost infinite number of combinations of mortality and fertility.

While in archaeological terms a time-span of 500 years may be fleeting, in human terms it represents many generations and it is unrealistic to suppose - as was done in these experiments - that there would be no demographic or social changes in even an isolated population during such a period. Changes in marriage or mating patterns would affect fertility, and even without outside contacts, new diseases might arise or the people develop a degree of immunity to old ones so that the mortality rates would be altered. If either or both of these occurred, the subsequent fate of such a population would be no more predictable than it proved for those created by the computer. Hence, extrapolation backwards from some particular number to try to establish either the size of the initial group, or the time-depth of settlement, is clearly futile.

Two other common misconceptions are also challenged. The first is that there is some universal 'critical' level of infanticide which cannot be exceeded if a population is not to diminish in size. On the contrary, the amount of infanticide that can be tolerated by any population will be determined by the mortality and fertility rates which it experiences. A population with low mortality can tolerate more infanticide than another which has the same fertility as the first but patterns of disease or life-style which cause high mortality. For similar reasons the concept of a universal 'minimum' population size is also patently absurd except in a very specific and limited context.

By now the original programme has been revised so that the artificial constraints on the numbers of persons who had ever lived and the maximum number of years exist no longer, and there is provision for greater flexibility in the mortality and fertility rates and other governing rules. These changes broaden the range of topics that can be investigated by computer simulation, and enhance the diagnostic power of the model.

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