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MICROSCOPIC MODELING THE DEMOGRAPHIC CHANGES

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We have adapted the Penna ageing model to simulate the profound changes in the age structures of populations caused by the better life style, medical care and decrease in birth rate. In Poland, after the political transformations in the last decade of the twentieth century, the increase in the expected lifespan has been accompanied by very deep decrease in birthrate, much below the minimum necessary for keeping the constant size of the population. Our microscopic model describes the changes in the age structure which have already happened and predicts the future, assuming that our attitudes in respect to life style and social relations will not change.

Keywords: Ageing; mutation accumulation; demography.

1. Introduction

The dynamics of the contemporary human populations are very complicated and different when comparing ethnic groups, nations, "developed" countries or countries during profound political and social transformations. Predicting changes in such populations is difficult and risky. There are many approaches used to predict the future age distribution and populations' sizes — extrapolations of trends found in analyses of life tables,[1] phenomenological analyses[2] or computer simulations using microscopic models[7] or formal descriptions of these microscopic models.[13] Microscopic models can incorporate some biologically justified parameters which help to understand the processes underlying the population dynamics and would also facilitate the formal description of these processes. In this paper we would like to show that a microscopic model can be a good source of data for comparative analyses and could help to predict some future phenomena.

The reproduction potential of all populations has to be high enough to replace all dying organisms by the young ones. If the replacement is not complete, the population will shrink and if such a situation persists for a longer period, population eventually dies out. On the other hand, too high reproduction rate leads to overcrowding the environment and the risk of starvation. In fact, stable populations keep their size in more or less constant values which depend on the capacity of the environment. Nevertheless, to fill up the environment, the population should have a higher reproduction potential than the minimum necessary just to keep the constant size, because such a situation would be too risky — in case of even temporary increase in mortality the population would be extinct. In the nineteenth century, Verhulst[6] proposed a mathematic formula, called logistic equation, which connects the size of the population with the capacity of the environment. In the modeling experiments, to keep the constant size of populations, the idea of Verhulst is implemented by introducing the factor $V = 1 - N_t/N_{\max}$. In this equation V describes the probability of survival of an individual living in the population of size N_t while the maximum capacity is $N_{\max}$. In some models the Verhulst factor describes the survival probability of each organism, independently of its age. In other models the Verhulst factor is implemented to control only the probability of survival of the newborns. In the latter case it is just an additional parameter controlling the birth rate. It seems that such implementation of the Verhulst factor is better biologically justified (lower evolutionary costs) and often used in the reproduction strategy by Nature. Populations which evolved under such conditions are characterized by better structure of the genetic pool — lower fraction of defective genes in the genomes when compared with populations whose sizes were controlled by the Verhulst factor determining the survival probability of all organisms independently of their age.[5]

It seems that in Nature, the main parameters determining the capacity of the environment are availability abundance of food and space. In the context of natural populations, the behavior of human populations, particularly native populations of Western Europe countries, is strange — there are at least two features distinguishing the human populations from other natural ones. The first one — very profound changes of the age distributions in the human populations during the last 150 years with almost doubled average life expectancy. The second feature — during the same time, in all so called developed countries, the birth rate dropped significantly, especially during the last decades. Both processes lead to the increase in fractions of older people in the populations which raises serious social problems in many countries.

Using the Penna ageing model we have analyzed changes in the populations' structure and we would like to show the future changes assuming that nothing will change in our attitudes and social behavior which could influence the development of our populations.

2. Model

We have used the Penna diploid model of ageing (for details on the Penna model see reviews Refs. 1 and 16). In the model, each individual is represented by two bit strings 640 bits long. Each bit corresponds to one gene. If its value is 0, it corresponds to the correct gene, if it is 1 it corresponds to the defective gene. Genes are switched on chronologically, in the first Monte Carlo step (MCS) — two genes in the first position (locus) are switched on, in the second MCS — both genes in the second locus and so on. The defect is expressed only if both genes in the same locus are defective, which means that all defective genes have recessive character. If the number of expressed defects reaches the threshold value T, the individual dies. If the individual reaches the minimum reproduction age R it produces gametes. During the gamete production, one cross-over between two parental bitstrings occurs in a randomly chosen point and into the recombined bitstring one mutation, in a randomly chosen locus is introduced. A mutation changes the value of the bit from 0 to 1, if the chosen bit is already 1 it stays 1, which means that there are no reversions. During reproduction, the female produces one gamete and then a randomly chosen male partner at reproduction age, produces the second gamete. Both gametes form a new organism, its sex is established with equal probability for male or female and its survival probability is checked with the Verhulst factor. In the next MCS its age will be 1 and its first locus will be switched on.

For comparing the results of simulations with the life tables, the proper rescaling of Monte Carlo steps for years can be done.[7]

3. Results and Discussion

As it has been mentioned in the Introduction section, one of the phenomena of the development of the human populations during the last 150 years was an increase in the expected lifespan of people, especially those living in the developed countries. For instance, for American people, the chance to survive until 80 years old increased fourfold during the last century. It is impossible to reach such an effect by rebuilding the genetic pool of populations during the period of a few generations. It is rather the effect of the changing relations between the human population and the environment — medical care, diet, hygiene and more healthy style of life. In the Penna model it is parameter T which describes these relations. In the previous papers,[14,15] it has been shown that by changing only this one parameter it is possible to follow the changes of the mortality and age structure of human populations during the last century with the accompanying growing fraction of retired people.[7] In these published studies, the authors assumed that the size of the population was controlled by Verhulst factor. Thus, the age distribution was determined only by the genetic structure and the relation with the environment and the sizes of populations were practically constant.

Here we have considered another phenomenon, following or associated with the growing expected lifespan, the decrease of the birth rate much below the value necessary to compensate natural mortality.

The effect of increasing T is shown in Fig. 1. If the size of the population is controlled by the Verhulst factor operating at birth, the main effect of increasing T is the "rectangularization" of the curve of the age distribution — lower mortality of the youngsters, more people surviving until the more advanced age and relatively low increase in the maximum lifespan. The results of simulations shown in Fig. 1

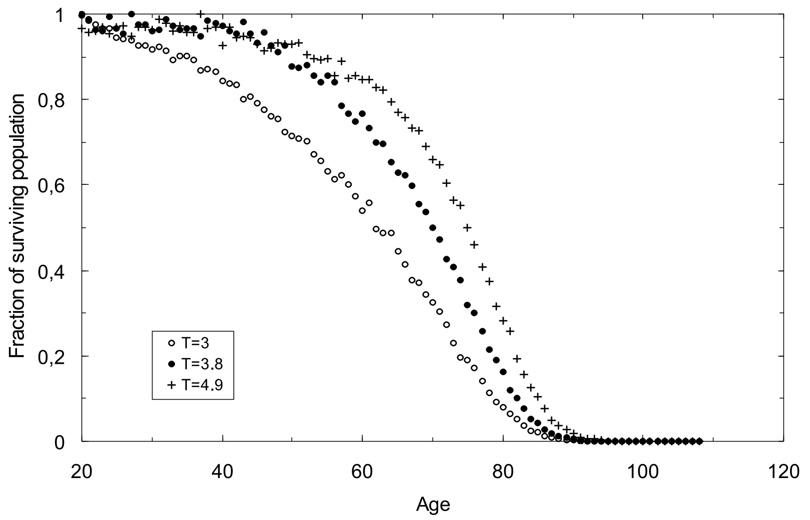


Fig. 1. Age distribution of populations in equilibrium with increasing value of the threshold T, corresponding to the better medical care, without any changes in the genetic pool of these populations.

corresponds to the dynamics of Swedish population from 1870 to 1990. In this scenario, the fraction of the "retired" grows (Fig. 1 and the earliest period in Fig. 5).

In many European countries, this period was accompanied or followed by the period of decreasing birth rate. It is easy to estimate the minimum birth rate which is necessary to keep the population in the metastable, very risky state. At such a point, implementing the Verhulst factor into the model is dispensable. In our model, like in European populations, this value of the fecundity is close to 2.07 offspring per female, on average (it depends on the fraction of women surviving until the reproduction age). Decrease in this value of birth rate results in extinction of the population. In Poland and in Germany the value of the fecundity was estimated at 1.37 and 1.38 respectively for[8,9] 2000 while in 2003 in Poland it was already[8] 1.22. It is much below the minimum, thus it is obvious that if the situation persists, it will lead to extinction of these populations. But before the extinction, the age structure of populations will change also. In Fig. 2. we plotted the fecundity and the life expectancy at birth for Polish population during the second half of the last century.[8] After 1990, significant decrease of fecundity with simultaneous increase of the life expectancy is seen.

In Fig. 3 we showed how the age distribution is changing under stabilized T which means no further increase in life expectancy (here corresponding to the value characteristic for years 1980–1990) and the linear decreasing birth rate from the level which is sufficient to keep the population at the metastable state to the level of nowadays birth rate and approximations for the next few generations.

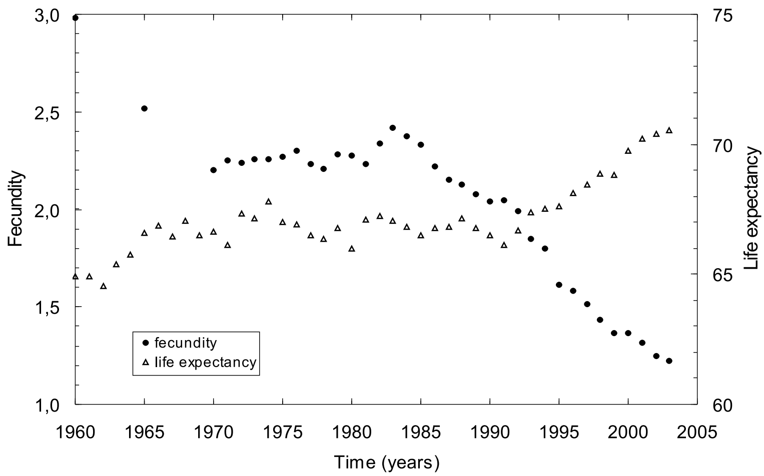


Fig. 2. Changes in the fecundity and in the life expectancy at birth in the Polish population during the last half century.

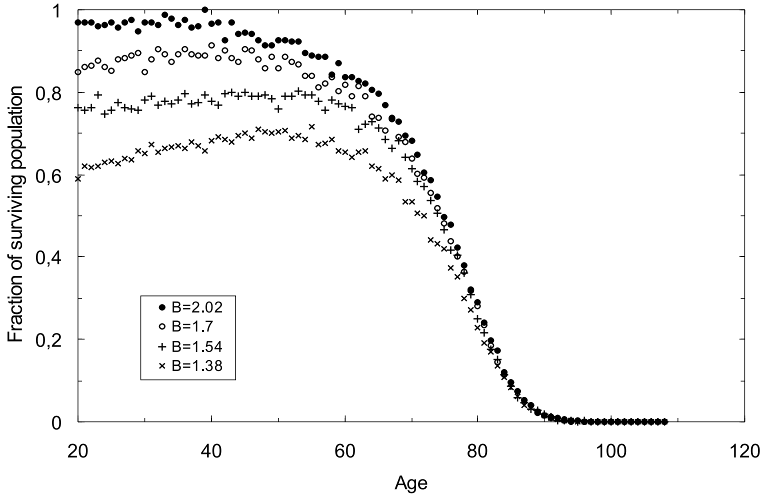


Fig. 3. Changes in the age distribution of the population during the period of decreasing the value of fecundity from the minimum securing the population stability to the value corresponding to that in Poland in 2000. Constant value of the threshold T was assumed. The shift in the maximum age is not observed.

In Fig. 4, we showed the situation which corresponds to what happened in Poland during the last decades — amelioration the life style (increasing T) and simultaneous fast decrease in the birth rate. Note the shift of the maximum life expectancy, observed also for French population by Yashin *et al.*[17]

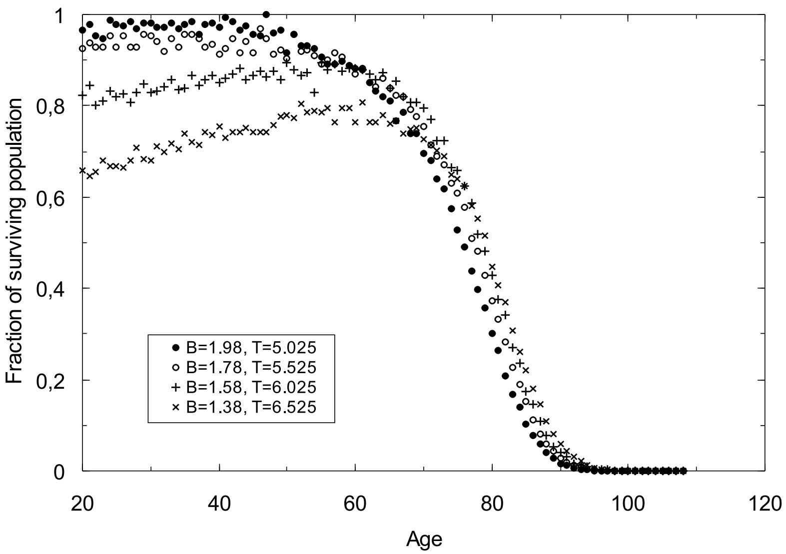
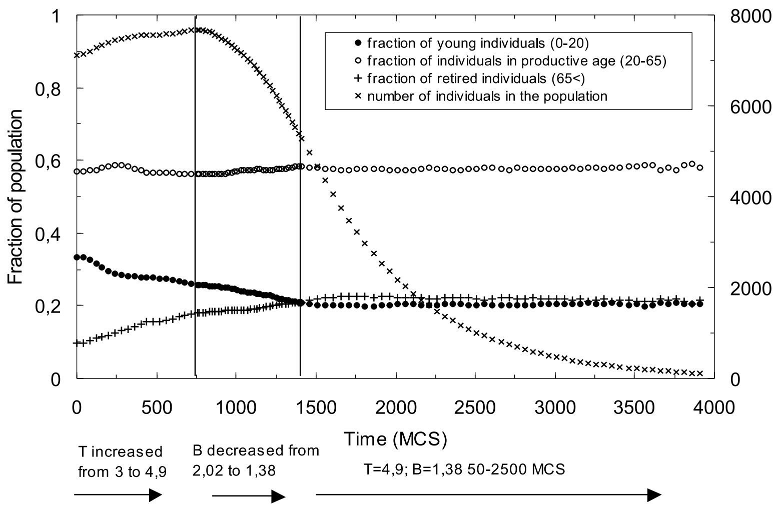


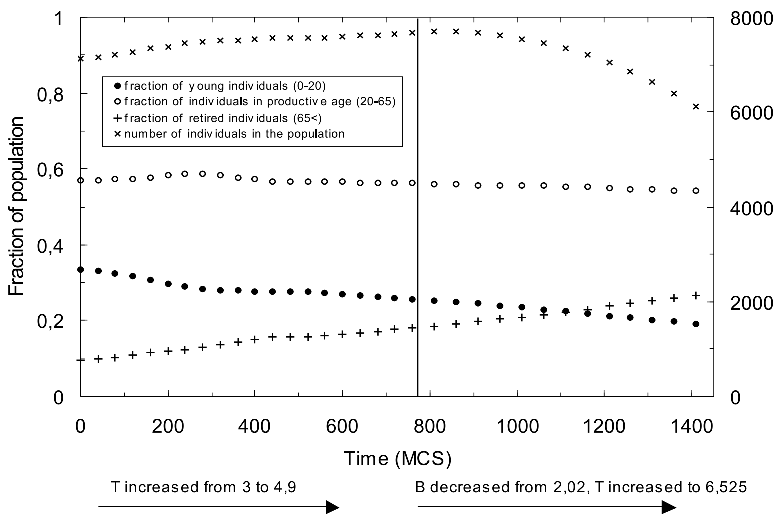
Fig. 4. The same as in Fig. 3, but the decrease in total value of woman fertility is accompanied by the simultaneous increase in the threshold T. Note the shift in the curves to the right.

In Figs. 5(a) and 5(b) we collected the data shown in the previous figures, showing the fraction of the youngest individuals, the fraction of people in the productive age and retired people and the rate of the changes in the populations' sizes. The most pessimistic conclusion from the results is the very fast decay of the whole population. The changes are very deep — increase in the fraction of retired people, decrease in the fraction of the youngest during the periods when the parameters of population dynamics are changing (T and/or birth rate). When these parameters stabilize, the age distribution also stabilizes but the population is shrinking and its size drops very fast. One could say that it is not so pessimistic for the economy because the increase in the fraction of the oldest is compensated by the decrease of the youngest, both demanding investment from the working part of the population. But in fact, it is estimated that costs of medical care only during the last six months of life are higher than the money spent on medical care during the whole life before.[12]

The situation described here, as the results of the microscopic model agree with the results of macroscopic model describing the dynamics of human populations[1] or some predictions shown in demographic databases.[11] All these results are rather pessimistic and we hope that the human attitudes will change in the near future and the results could not be considered as a prediction. We have not shown here the predictions concerning competition in the same environment with other populations, which could take place in the future (see Ref. 11).



(a)



(b)

Fig. 5. Relations between fractions of populations: the youngest individuals (below 20 years old), individuals in the productive age (20–65 years old) and retired individuals (above 65 years old); (a) the decrease in the birth rate follows the increase of T, (b) the first period of the threshold T increase is followed by further increase in T up to 6.525 accompanied by the decrease in the birth rate.

4. Conclusions

The situation in human populations could be considered unnatural, if we assume that humans have alienated themselves from the Nature. But, it is also unnatural, because in fact the capacity of our environment has been enlarged during the last century due to technological development — we are overproducing food, we can also live in very densely populated regions, leaving a lot of free space, showing that there is no problem with space, either. It seems that the capacity of the environment is shrinking only in our mental projections — we need larger houses, bigger cars, more brilliant professional careers and many other goods — all this negatively correlated with the fecundity. Additionally, our social systems offer the alternative choice how to secure our senescence — higher retirement rate or more children. People of the ancient times had probably more proper attitude to these problems. About 2400 years ago, Socrates, looking at the goods presented in the market place said: Oh, how many goods are here which I do not need![10]

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