

WHAT IS IT?

This model is simulating the demographic development of a hypothetical human population. The main goal is to simulate and understand the mechanisms that influence population growth and decline, and to assess the effects of changing the relevant parameters. For this, a distinction can be made between 'natural' demographic factors (mortality and fertility), and 'social' factors (in particular marriage rules).

The model is applied in the context of recruitment practices of the Roman army in the Dutch limes zone. In the Early and Middle Roman period (15 BC - 275 AD), the Roman authorities levied soldiers from the local, Batavian population. The effects of this practice on demography and economy are poorly understood. The model is specifically intended to simulate what happens to the reproduction rate if a proportion of the male population is recruited, and taken from the marriage pool.

The model shows that, if the assumption of non-marriage of soldiers is correct, then the effects of recruitment on population growth will be considerable. The model results indicate that there is an 'optimal' recruitment that will leave the population stationary, and will guarantee the steady supply of recruits. This optimal level depends on the natural population growth. With higher levels of recruitment, the populations will quickly go in decline. Very low levels of recruitment on the other hand will require very large populations to supply sufficient recruits.

HOW IT WORKS

The model has two entities, humans and households. The households are collectives, composed of a limited number of humans (usually a couple with a number of children, but grandparents might be part of a household as well).

The basic principle of the model is to let a starting population reproduce and die under various regimes of mortality and recruitment. From this, demographic characteristics will emerge that may be relevant to the economic sphere as well, like the number of people available for labour.

The female agents only have one objective: to find a spouse, so that they can reproduce. The agents don't have any adaptive behaviours, there is no learning involved, and they don't interact. All patterns emerging from the model are therefore governed by external factors (in this case, recruitment rate and mortality regime). Stochasticity is involved in determining mortality, fertility and recruitment rate. All are defined as probabilities, and the chances of dying, reproducing and being recruited are determined by comparison of these probabilities to a random number.

The following procedures are part of the model: dying, reproducing, recruiting and marrying. Each is executed consecutively at each time step. Each time step represents one year.

Initialization

The starting population is composed of 200 humans. Each is attributed a gender (50/50 split male/female) and an age (based on one of three model life tables selected by the user). Furthermore, it will be registered whether the humans are widowed, recruited (only for males), how many children they have, and what household they belong to.

Next, females of marriageable age (18 years and older) are coupled to a male that is 7 to 15 years older (reflecting assumed age differences between spouses in the

Roman Empire), and together they will form a household. The remaining humans are distributed randomly over the households. This is not a realistic assumption, but suffices for the initialization phase of the model.

Submodels

<i>Reproducing</i>

In this procedure, it will be determined which females will give birth this year. The probability of reproducing is determined on the basis of the fertility rates suggested by Coale and Trussell (1978). If a female gives birth, a new human of age 0 will be hatched with gender male or female (probability 0.5 for each gender), and it will be added to the households of its parents.

<i>Dying</i>

In this procedure, it will be determined which humans will die this year. The probability of dying is determined on the basis of one of three model life tables select by the user (named West 3 Female, Pre-industrial standard, and Woods 2007 South 25). All three have been suggested as plausible mortality regimes for the Roman period. For females who die, it will be registered how many children they have had.

<i>Recruiting</i>

In this procedure, a number of males of age 18-25 will be 'recruited' for the army. The probability of recruitment is pre-set by the user, and can vary between 0 and 0.2 with steps of 0.01. Upon recruitment, the male will stay in the army for the next 25 years. During this time, he will not be available as a spouse. Recruitment will only start after 100 ticks, in order to give the model sufficient time to stabilize.

<i>Marrying</i>

In this procedure, any unmarried female of age 18 and older will look for an unmarried male that is older than 25 years. There are no further restrictions on the selection of a husband. Only after marriage a female will have the opportunity to reproduce.

HOW TO USE IT

The model has two user inputs: the selection of the model life table to be used (drop-down menu), and the recruitment rate (slider). Other inputs (like initial population size, age limitations etc.) can be set in the code section if so desired.

The model produces four plots. The main plot shows the following demographic characteristics of the population:

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- population size
- annual number of deaths
- annual number of births
- number of elderly (50 years and older)
- number adults (18 years and older)
- number of children (under 18 years old)
- the number of unmarried females (of 18 years and older)
- the number of males between 18 and 25 years old
- the number of married couples

</list>

The minor plots show the annual population growth (upper right), the number of

recruits in the army (middle right) and the number of children per female (lower right).

THINGS TO NOTICE

After initialization, the model should be run for 100 ticks in order to stabilize before collecting output statistics. There are no specific rules for collecting outputs, only the plots will be updated.

The model will stop after 200 ticks, but could be run longer if so desired. However, with high population growth rates, execution could then become very slow because of the large number of agents.

The model has no spatial component, so the World View is minimized.

THINGS TO TRY

The model interface only has two options for the user to play with: selecting the model life table used for determining mortality, and setting the recruitment rate. These options can be used to run various scenarios using the BehaviorSpace add-on, the results of which are reported in the paper accompanying the model.

EXTENDING THE MODEL

A number of possible improvements to the model are suggested here:

Mortality

Mortality rates are now given per 5-year age cohort, these could be recalculated to reflect mortality rates per year (as was done by Danielisová et al. 2015).

For future experimentation, it would be interesting to include catastrophic events like famine, war and disease in the model, and to estimate their effects on demographic growth.

Furthermore, no attention is paid here to the effect of carrying capacity on population size.

Reproduction

<i>More realistic reproduction models</i>

More realistic reproduction models could take into account the effects of the time lag between giving birth and the next pregnancy. This would however make the model much harder to handle, since the time steps would have to be much smaller (in the order of months; see e.g. White 2014 for an attempt at such an approach).

<i>Twins</i>

A more realistic model of household demographics should also include the possibility to give birth to twins. While the chances of twins being born are not very high (approx. 3%), it could slightly change the behaviour of the model. The fertility rates applied here are averages per five years for females over their whole reproductive period, that can be used to estimate the number of children born in this period, but without any indication about when these will be born. For obtaining general figures of demographic development, this will be good enough - but it will not be good enough if we want to zoom in to the level of the individual household.

<i>Recruitment</i>

A possible extension to the recruitment procedure could include the option for

recruits
to marry (for which some evidence is found in historical sources).

The effect of a shorter service term (20 instead of 25 years) can easily be implemented, but was not experimented with in this model.

In the current model, recruitment rates are set as proportions. It may be that the Roman authorities did not bother about this, but just demanded a fixed number of soldiers per year. This can be implemented quite easily as well. Furthermore, recruitment requirements might have been more dynamic, and fluctuating through time depending on the needs of the army. Again, this could be implemented quite easily.

Also note that the mortality of recruits is equal to the mortality of those who stayed at home. This may not be fully realistic, but it is assumed that during peace time mortality will not have been different for the soldier population.

Marriage

The marriage rules applied here are very simple, where females will just marry any male over 25 that happens to be available. The estimates of marriage age are based on 'educated guesses' cited in various publications. However, there is no consideration of more complex factors involved, such as geographical distance and economic and social position of the partners. This could be a rich field of experimentation for future models, since the influence of these factors on reproduction is generally not very well understood.

NETLOGO FEATURES

There are no particular NetLogo features used that need to be addressed here.

RELATED MODELS

White's ForagerNet model (2014), coded in Repast, deals with a number of similar issues.

<i>White, Andrew A. (2014, February 13). "ForagerNet3_Demography_V2" (Version 1). CoMSES Computational Model Library. Retrieved from: <https://www.openabm.org/model/4087/version/1></i>

CREDITS AND REFERENCES

This model comes as an appendix to the following paper:

<i>Verhagen P, J Joyce & M Groenhuizen 2015: Modelling the dynamics of demography in the Dutch limes zone, in Proceedings of LAC2014 Conference, Rome, 19-20 September 2014</i>

In this paper, the archaeological background and assumptions used for this model are described in more detail.

The following references were used for setting up the mortality and fertility estimates:

<list><i>Coale AJ & P Demeny 1966: Regional Model Life Tables and Stable Populations, Princeton University Press, Princeton.
Coale AJ & TJ Trussell 1974: Model Fertility Schedules: Variations in The Age Structure of Childbearing in Human Populations, Population Index 40, 185-258.
Danielisová A, K Olševičová, R Cimler & T Machálek 2015: Understanding the Iron Age

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Hin S 2013: The Demography of Roman Italy. Population Dynamics in an Ancient Conquest Society 201 BCE-14 CE, Cambridge University Press, Cambridge.

Séguy I & L Buchet 2013: Handbook of Palaeodemography, Springer, Cham.

Woods R 2007: Ancient and early modern mortality: experience and understanding, The Economic History Review 60, 373-399.

White AA 2014: Mortality, Fertility, and the OY Ratio in a Model Hunter-Gatherer System, American Journal of Physical Anthropology 154, 222-231. <http://onlinelibrary.wiley.com/doi/10.1002/ajpa.22495/abstract>

Thanks go to Tom Brughmans (University of Konstanz) for reviewing an earlier version of this model. All errors remain the responsibility of the author.