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 was originally 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 presented here is a revised model of the model 'Batavian Demography and Army Recruitment' (http://modelingcommons.org/browse/one_model/4678), that was presented as an appendix to Verhagen et al. (2016). This earlier model showed 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.

This models is now extended with options to include more sophisticated marriage rules and the effects of mortality crises on population growth and decline (Verhagen 2019). It shows that the effects of marriage strategies and birth control on population growth are considerable, thus suggesting that ancient populations had plenty of options available to control population growth. Mortality crises, while clearly felt on the short term, will only have a long-term negative effect when they have a short return period.

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, fertility 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 biological sex ('natural sex ratio' of 105:100 M:F - see Bagnall and Frier 1994:95) 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 (set by the user) are coupled to a male that is a minimum age difference (set by the user) older, 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), which can be modified by setting the fertility rate modifier to mimic the effects of longer birth spacings. Stopping behaviour can be set by the user to maximize the number of children per household.

If a female gives birth, a new human of age 0 will be hatched with biological sex male or female 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. Mortality can be modified by introducing mortality crises (named disease mortality and disease recurrence in the interface, but they could be due to other causes as well).

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 first-marriage-age or older will look for an unmarried male that is older by marriage-age-difference or more years. The marriage time scale factor can be used to reduce marriage probability depending on age, following Coale (1971) - not all females will get married at the same age. 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 ten user inputs:

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- selection of the model life table to be used (drop-down menu)
- recruitment rate (slider)
- disease mortality (slider)
- disease recurrence (slider)
- allow remarriage (switch)
- first marriage age (slider)
- marriage time scale factor (slider)
- marriage age difference (slider)
- fertility rate modifier (slider)
- stopping behaviour (slider)

</list>

Other inputs (like initial population size, age limitations etc.) can be set in the code section if so desired.

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

<list>

- 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
- number of widow(er)s

</list>

The minor plots show the annual population growth (upper center), the number of recruits in the army (middle centre), the number of children per female (lower center), the annual mortality rate (upper right), unmarried rate (centre right) and male-female ratio (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 has ten options for the user to play with. 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).

The mortality modifier used to simulate the mortality crises is extremely simple and could be extended to include differential mortality among age groups, and to simulate varying recurrence and mortality rates in order to mimic the effects of specific catastrophic events.

Reproduction

<i>More realistic reproduction models</i>

More realistic reproduction models could take into account more realistic 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 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.

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 do not consider 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 2019: 'Modelling the dynamics of demography in the Dutch limes zone' in Verhagen P, J Joyce & MR Groenhuijzen (ed), Finding the limits of the limes. Modelling economy, demography and transport on the edge of the Roman Empire'. Springer, New York.</i>

The first version of the model was described in:

<i>Verhagen P, Joyce J, Groenhuijzen MR 2016: Modelling the dynamics of demography in the Dutch limes zone, in Multi-, inter- and transdisciplinary research in landscape archaeology. Proceedings of LAC 2014 Conference, Rome, 19-20 September 2014. Vrije Universiteit Amsterdam, Amsterdam. doi:10.5463/lac.2014.62</i>

In these papers, 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>

Bagnall RS & BW Frier 1994: The demography of Roman Egypt. Cambridge University Press, Cambridge.

Coale AJ 1971: Age Patterns of Marriage. Population Studies 25(2):193-214.

Coale AJ & P Demeny 1966: Regional Model Life Tables and Stable Populations, Princeton University Press, Princeton.

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Danielisová A, K Olševičová, R Cimler & T Machálek 2015: Understanding the Iron Age Economy: Sustainability of Agricultural Practices under Stable Population Growth, in Wurzer G, K Kowarik & H Reschreiter (ed), Agent-based Modeling and Simulation in Archaeology, 205-241. Springer, Cham.

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

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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</i></list>

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