Max-Planck-Institut für demografische Forschung

Max Planck Institute for Demographic Research

Konrad-Zuse-Strasse 1 ▪ D-18057 Rostock ▪ Germany ▪ Tel +49 (0) 3 81 20 81 - 0 ▪ Fax +49 (0) 3 81 20 81 - 202 ▪ www.demogr.mpg.de

MPIDR Technical Report TR 2018-005 I October 2018

An Educational Simulation Tool to Enhance the Understanding of Population Dynamics

Rainer Walke I walke@demogr.mpg.de
Daniel Ciganda I ciganda@demogr.mpg.de
Sebastian Klüsener

For additional material see www.demogr.mpg.de/tr/

This technical report has been approved for release by: Mathias Lerch (lerch@demogr.mpg.de), Deputy Head of the Laboratory of Fertility and Well-Being.

An Educational Simulation Tool to Enhance the Understanding of Population Dynamics

Rainer Walke[*], Daniel Ciganda[*], Sebastian Klüsener[*,**]
[*] Max-Planck-Institute for Demographic Research
[**]Federal Institute for Population Research, Vytautas Magnus University

Abstract
There is a dearth of software tools targeted at the general public that provide users with an intuitive understanding of population dynamics and the underlying demographic processes (fertility, mortality, and migration). This existing gap motivated us to implement such a tool in the software package NetLogo. In this technical working paper, we describe the technical specifications of the tool and provide access to the underlying NetLogo code. In addition, we outline the lessons users could learn from our educational tool.

Keywords: simulation, population age structure, population projections, population dynamics

Motivation

Population dynamics and their implications for the size and age structure of populations are of considerable relevance for public debates (e.g., Coulmas 2007, Elmendorf and Sheiner 2000, Greenhalgh 2013). High fertility can lead to youth bulges (Fuller 1995) and strong population growth if mortality and out-migration are low. Low fertility, on the other hand, is likely to lead to population aging and shrinking. Again, it is important to emphasize that population aging is driven not only by fertility levels, but also by mortality trends and migration dynamics. While there have been public debates about the direct demographic implications of these processes – such as about how these processes affect the size and age structure of particular populations in the short, medium, and long run – the main focus of public interest has been on the (potential) social and economic implications of these developments. For example, youth bulges might lead to instability due to high youth unemployment, while population aging could endanger the sustainability of welfare systems.

The educational simulation tool presented in this paper has been developed to provide non-scientific users with an intuitive understanding of how fertility, mortality, and migration processes interact in producing changes in the age structure and size of populations. By altering fertility, mortality, and migration levels, users are, for example, able to explore to what degree changes in fertility could be counterbalanced by changes in mortality and migration. Although other similar educational tools are available[1], to the best of our knowledge these tools focus exclusively on fertility and mortality patterns. By also taking simple migration dynamics into account, our simulation tool provides users with the opportunity to develop a better understanding of pressing contemporary issues, like the arrival of migrants and the effect this development has on the age structure and the evolution of a population as a whole.

In addition to allowing users to alter fertility, mortality, and migration rates in order to explore how these changes affect population development, the tool is designed to raise awareness among users about the pace of demographic change. This, we hope, will support users in developing a more skeptical scientific perspective on apocalyptic warnings about "population bombs" (Ehrlich 1978) or "demographic suicides" (Prichet and Viarengo 2013).

There are a wide range of software platforms on which such a simulation tool could be built. We decided to implement the tool with NetLogo simulation software (Wilensky 1999), because this platform makes it easy to implement sliders and buttons that allow users to easily change the parameter settings of the model. These changes are then immediately reflected in the model dynamics. Such features would, for example, be more difficult to implement in R, which we might have chosen if we had wanted to use such a simulation of population dynamics primarily for scientific purposes.

Data and specification of the tool

As the tool was initially developed for the German public, we use data for Germany in the code presented here. Included in these data are the female age-specific period fertility rates for 2013 (HFD 2018); the period mortality rates by single-year ages for Germany in the same year (HMD 2018); and the official statistical data on the balance of in- and out-migration counts from and to Germany by single-year ages, again in 2013 (Klüsener et al. 2018). Our use of period fertility rates raises the issue that these rates are artificially depressed due to the ongoing postponement process to higher ages at childbirth. For example, in Germany in 2012, the tempo-adjusted total fertility rate (Bongaarts and Feeney 1998) was 1.59, while the non-adjusted rate was 1.41 (HFD 2018). By keeping the level of

[1] https://www.ined.fr/en/everything_about_population/population-games/tomorrow-population/
https://www.learner.org/courses/envsci/interactives/demographics/demog.html

fertility constant at the period rates for 2013, the pace of population aging and shrinking in the simulations is, for example, likely to be overestimated. Thus, if users would like to freeze fertility at current cohort fertility levels, they would need to choose slightly higher fertility levels.

For the migration data, we decided to use counts instead of rates, as we believe that migration is less dependent on the population already living in the country. This choice is also in line with the assumptions about future migration in absolute numbers that are used by the German Federal Statistical Office for implementing population projections (Pötzsch and Rößger 2015). While we focus on Germany, data for other countries could be easily integrated as well.

The initial population structure represents Germany in 2013. The population age structure by single-year ages ("population pyramid") becomes visible in the so-called world window as soon as the [setup] button is pressed. Pressing [reset standard values] resets all sliders to the default values. Our fertility and mortality patterns by age are derived from the age-specific rates recorded in 2013. Sliders allow the users to modify these fertility and mortality rates. For reasons of simplicity, we have chosen to keep the age structure constant, so that all the age-specific fertility or mortality rates are multiplied by the same factor if users decide to adjust the fertility or mortality levels. The fertility slider allows users to select the number of children women will have at the end of their reproductive lives in the simulation (sum of age-specific rates). In contrast, the mortality factor denotes the annual reduction or gain in the mortality rates. For migration, we offer two different options. In the first option, users can apply the age-specific net migration rates as they were recorded in 2013. In the second option, it is possible to increase the cohort size at age 20 by 20% in response to an immigration wave. Thus, users are able to explore how singular in-migration waves affect population structures in the long run. By making multiple clicks, users can increase the cohort size multiple times. For convenience, both migration options have a switch for automatic annual reapplication.

In addition, users can specify a cohort they want to follow. This could, for example, be a user's own cohort. A yellow dot then appears in the center of the world window to indicate the position of this cohort in the population pyramid. This yellow dot moves upward as the cohort ages. Additional monitor windows provide information on the changes in the total population and the year that has been reached.

Discussion and Conclusion

The software tool has been tested by school classes and by visitors attending an open door day at the MPIDR. For testing purposes, a German language version of the tool was developed. While the overall feedback was positive, it became clear during the testing phase that it was helpful to have a person with demographic background knowledge around to provide initial assistance to the users. Once the users had a basic understanding of the tool, they were able to handle it independently. The dimension that generated the most interest among the participants in this phase was the potential effect of migration in slowing down the pace of population aging. We therefore believe that even though our tool presents only a rudimentary sketch of this process, it can help users to develop a more nuanced understanding of a hotly debated topic.

A number of extensions of this tool are possible. As well as including data for different countries that are facing different demographic challenges, we could add modifications that allow users to adjust the age-specific schedules of fertility, mortality, and migration. This would, for example, permit users to explore how fertility postponement or changes in the modal age or lifespan variation of mortality (Vaupel et al. 2011) affect population dynamics. It might also be interesting to implement the option to simulate (massive) emigration waves if the tool is used for countries that register substantial emigration. More sophisticated extensions might enable users to model trends separately for different educational groups (Kc et al. 2010). Such extensions would, however, require detailed data that are not easy to obtain for many countries, including for Germany. We would be very grateful if researchers built upon our work by implementing more sophisticated versions of our simulation tool, either in NetLogo or in other software packages.

References

Bongaarts, J., & Feeney, G. (1998). On the Quantum and Tempo of Fertility. Population and Development Review, 24(2), 271-291. doi:10.2307/2807974

Coulmas, F. (2007). Population Decline and Ageing in Japan: The Social Consequences. London: Routledge.

Ehrlich, P. R. (1978). The Population Bomb. New York: Ballantine.

Elmendorf, D. W., & Sheiner, L. M. (2000). Should America save for its old age? Fiscal policy, population aging, and national saving. Journal of Economic Perspectives, 14(3), 57–74.

Fuller, G. (1995). The demographic backdrop to ethnic conflict: A geographic overview. In: Central Intelligence Agency (ed.). The Challenge of Ethnic Conflict to National and International Order in the 1990s (pp.151 –156), Washington: Central Intelligence Agency.

Greenhalgh, S. (2013). Patriarchal demographics? China's sex ratio reconsidered. Population and Development Review, 38(supplement), 130–149.

Kc, S., Barakat, B., Goujon, A., Skirbekk, V., Sanderson, W., & Lutz, W. (2010). Projection of populations by level of educational attainment, age, and sex for 120 countries for 2005-2050. Demographic Research, 22(Art 15), 383–472.

Klüsener, S., Grigoriev, P., Scholz, R. D., & Jdanov, D. A. (2018). Adjusting inter-censal population estimates for Germany 1987-2011: Approaches and impact on demographic indicators. Comparative Population Studies, 43(2018): 31–64.

Pötzsch, O., & Rößger, F. (2015). Bevölkerung Deutschlands bis 2060. 13. koordinierte Bevölkerungsvorausberechnung. Wiesbaden: Statistisches Bundesamt.

Pritchett, L., & Viarengo, M. (2013). Why demographic suicide? The puzzles of European fertility. Population and Development Review, 38(supplement), 55–71.

Vaupel, J. W., Zhang, Z., & van Raalte, A. A. (2011). Life expectancy and disparity: An international comparison of life table data. BMJ open 1:e000128

Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.

Appendix 1: Model Code

```
;; pyramid
;; $Id: PopulationPyramidGER.nlogo 42 2018-10-04 06:41:32Z Walke $
;; Rainer Walke, Daniel Ciganda, Sebastian Klüsener MPIDR

globals [Year Age Female Male maxFemale maxMale baselineASFR mxFemale mxMale Total
MigInFemale MigOutFemale MigInMale MigOutMale]

patches-own [pAge pFemale pFemaleTemp pMale pMaleTemp pmxFemale pmxMale
pDeathFemale pDeathMale pASFR pChildren
  pMigInFemale pMigOutFemale pMigInMale pMigOutMale]

to setup
  clear-all

  set Year 2013

  ;; Germany 2013 Age
  set Age [ 0  1  2  3  4  5  6  7  8  9
    10  11  12  13  14  15  16  17  18  19
    20  21  22  23  24  25  26  27  28  29
    30  31  32  33  34  35  36  37  38  39
    40  41  42  43  44  45  46  47  48  49
```

```
  50  51  52  53  54  55  56  57  58  59
  60  61  62  63  64  65  66  67  68  69
  70  71  72  73  74  75  76  77  78  79
  80  81  82  83  84  85  86  87  88  89
  90  91  92  93  94  95  96  97  98  99
  100  101  102  103  104  105  106  107  108  109
  110  ]
;; Germany 2013 Female
set Female [
  328424  324398  333776  328157  338176
  337377  330494  336208  345307  345772
  351900  360084  377333  377762  386794
  399231  392199  380842  387726  405897
  418170  438410  485243  484370  499927
  492943  489744  475815  476747  481999
  495268  496479  499255  476648  470965
  467494  460737  447891  456664  461881
  501782  553128  574871  617164  647571
  667014  686405  688004  703098  698645
  679132  672380  650605  633395  599063
  587365  572893  558701  552881  537307
  536691  526007  525646  506993  461711
  435041  379811  336545  447193  452372
  437776  533179  560362  549981  507450
  469763  449952  427405  388458  305692
  296941  293235  297883  276704  258276
  230890  215518  196367  168348  146051
  129553  112803  90585  54449  26702
  19405  15771  14556  13315  8690
  5450  3252  1843  1014  574
  261  122  53  27  10
  6  ]

;; Germany 2013 Male
set Male [
  345987  341450  350534  345843  355497
  355946  349430  354047  363634  364094
  371262  380625  397086  398743  406763
  419850  413981  401881  409325  427173
  436659  457637  506959  504480  522826
  516186  508240  492650  493215  496340
  509069  503976  504384  482236  476846
  473924  464830  453873  459627  465095
  507509  562426  584257  632277  663538
  682713  704379  709241  722309  716393
  691967  680451  656755  639144  603042
  588349  569966  548968  533700  513489
  511566  500160  498521  482106  440203
  409528  354444  306329  407759  411093
  393870  469677  484252  465943  423782
  383067  356626  329803  291345  220938
  205791  194328  187993  166713  148968
  120209  98820  80844  59521  48213
  41270  33238  24614  13857  6500
  4316  3283  2863  2322  1473
  847  420  229  130  46
  23  6  3  2  1
  0  ]

;; Baseline Female ASFR - Germany 2013
set baselineASFR [
  0  0  0  0  0  0  0  0  0  0
  0  0  0  0.00003  0.00036
  0.00125  0.00304  0.00643  0.01166  0.01751
  0.02333  0.02884  0.03469  0.04152  0.05034
  0.06098  0.0711  0.0806  0.08955  0.09613
  0.10149  0.10329  0.09951  0.09351  0.08602
  0.07585  0.06433  0.05297  0.04152  0.0313
  0.02178  0.01366  0.00809  0.00449  0.00229
```

```
    0.00109  0.00056  0.00026  0.00013  0.00009
    0.00006  0.00004  0.00002  0.00001  0
    0  0  0  0  0  0  0  0  0  0
    0  0  0  0  0  0  0  0  0  0
    0  0  0  0  0  0  0  0  0  0
    0  0  0  0  0  0  0  0  0  0
    0  0  0  0  0  0  0  0  0  0
    0  0  0  0  0  0  ]

  ;; Germany 2013 mx Female
  set mxFemale [
    0.002972  0.000271  0.000112  0.000112  0.000078
    0.000094  0.000087  0.000066  0.000079  0.000058
    0.00006  0.000056  0.000087  0.000079  0.000115
    0.000138  0.000157  0.000166  0.000182  0.000203
    0.000209  0.000181  0.00016  0.000227  0.000216
    0.000226  0.000222  0.000226  0.000246  0.00029
    0.000292  0.000306  0.000355  0.00039  0.000391
    0.000446  0.000454  0.000533  0.000589  0.000646
    0.000747  0.000729  0.000864  0.000953  0.001068
    0.001161  0.001345  0.001529  0.001636  0.001825
    0.002018  0.002405  0.002601  0.002989  0.003104
    0.003545  0.003846  0.003962  0.004465  0.004884
    0.005115  0.005682  0.006171  0.006851  0.007653
    0.008121  0.009041  0.009195  0.010789  0.011371
    0.012127  0.013243  0.013784  0.01617  0.017622
    0.019949  0.02318  0.026469  0.031616  0.035494
    0.041041  0.047187  0.055744  0.064031  0.07416
    0.084419  0.098077  0.113474  0.130757  0.148093
    0.167352  0.191227  0.211485  0.25834  0.230578
    0.285676  0.330631  0.343762  0.410442  0.407152
    0.446375  0.487612  0.52139  0.559208  0.608025
    0.633877  0.633759  0.570523  0.821505  0.91607
    1.117037  ]

  ;; Germany 2013 mx Male
  set mxMale [
    0.003644  0.000307  0.000166  0.000135  0.000097
    0.000117  0.000077  0.000097  0.00008  0.000124
    0.000062  0.000061  0.00008  0.000095  0.000099
    0.00016  0.000238  0.000282  0.000443  0.000453
    0.000435  0.000446  0.000426  0.000467  0.000461
    0.000516  0.000544  0.000478  0.00057  0.000572
    0.000658  0.000641  0.000669  0.000704  0.000814
    0.000857  0.000836  0.000881  0.001014  0.001201
    0.001217  0.001306  0.001459  0.001688  0.001818
    0.002098  0.002403  0.002556  0.00293  0.00334
    0.003595  0.004281  0.004751  0.005344  0.005982
    0.00655  0.007056  0.007974  0.008871  0.009478
    0.01048  0.011193  0.011982  0.013041  0.014119
    0.015249  0.016663  0.017911  0.020125  0.021197
    0.022404  0.025119  0.026439  0.02989  0.032203
    0.035366  0.040286  0.044649  0.051918  0.056072
    0.063882  0.07311  0.084006  0.094824  0.106097
    0.117804  0.130485  0.148224  0.166583  0.185359
    0.204738  0.234709  0.254843  0.308031  0.259591
    0.344735  0.378649  0.392058  0.493306  0.475073
    0.602986  0.59679  0.507168  0.68606  0.689942
    1.087985  0.831354  0.495868  2.598477  2.554945
    6  ]

;; Germany 2013 MigIn Female
set MigInFemale [
 3126  6509  6181  5789  5546
 5341  4782  4469  4043  4056
 3857  3522  3470  3364  3101
 3223  3914  4007  7208  12636
 16914  19982  21212  22173  20902
 19594  17285  15876  14670  13471
```

```
 12627  12088  11086  10415  9607
 9374  8589  8270  7953  7568
 7160  7006  6585  6408  6381
 6187  5669  4854  4833  4604
 4542  4033  3876  3752  3403
 3226  2923  2550  2364  2127
 1872  1643  1526  1383  1256
 1155  965  804  623  622
 576  532  489  474  455
 380  350  324  308  250
 220  200  167  176  157
 122  94  89  58  50
 39  34  27  16  8
 6  4  4  4  3
 2  2  0  0  0
 0  0  0  0  0
 0  ]

;; Germany 2013 MigOut Female
set MigOutFemale [
 908  2645  2883  2833  2799
 2680  2872  2316  1908  1896
 1827  1648  1589  1531  1421
 1375  1702  1946  2893  5125
 7610  11331  12907  13063  12485
 12024  10703  9877  9093  8403
 8075  7549  7220  6690  6037
 5885  5538  5284  5174  4862
 4549  4558  4379  4236  4141
 4175  3920  3385  3439  3252
 3159  2965  2827  2777  2488
 2423  2244  2054  1912  1748
 1592  1536  1413  1435  1270
 1286  1179  907  794  716
 720  664  632  617  537
 497  494  420  360  329
 326  282  221  216  226
 177  134  124  95  95
 109  96  75  46  21
 17  13  13  13  8
 4  4  0  0  0
 0  0  0  0  0
 0  ]

;; Germany 2013 MigIn Male
set MigInMale [
 3416  6812  6403  6188  5815
 5523  5029  4637  4299  4251
 4109  3865  3659  3638  3569
 3758  4901  5044  9485  15338
 18448  22102  24716  27470  27530
 27678  26409  25667  24290  22962
 21796  21106  19889  19907  18597
 17682  17621  16654  16207  15568
 14132  14006  13413  13213  12585
 12266  11362  9932  9342  9078
 8314  7597  7111  6848  6036
 5508  4880  4388  3717  3139
 2609  2130  1912  1581  1385
 1357  1091  961  763  727
 631  644  606  552  461
 402  342  289  231  212
 170  131  107  109  89
 75  67  52  32  23
 29  24  17  9  5
 3  2  2  2  1
 1  0  0  0  0
 0  0  0  0  0
 0  ]
```

```
;; Germany 2013 MigOut Male
set MigOutMale [
 909  2829  3033  3061  2855
 2875  2981  2443  2153  2022
 1976  1806  1620  1618  1554
 1548  1836  2011  3102  5651
 8687  12211  14543  15774  16603
 16950  16657  16573  15820  15507
 15035  15027  14390  14210  13678
 13040  12977  12492  12187  11654
 10825  10648  10230  10234  9932
 9482  8941  8036  7579  7302
 6935  6186  5919  5679  5106
 4772  4233  3850  3372  2875
 2442  2064  1830  1749  1649
 1778  1562  1210  1062  974
 964  877  866  834  737
 637  591  488  393  336
 342  244  203  219  170
 132  117  88  72  60
 66  53  38  21  11
 6  4  4  4  2
 2  0  0  0  0
 0  0  0  0  0
 0  ]


  set maxFemale 800000
  set maxMale 800000


  ask patches [
    set pAge item pycor Age
    set pFemale item pycor Female
    set pMale item pycor Male
    set pASFR item pycor baselineASFR
    set pmxFemale item pycor mxFemale
    set pmxMale item pycor mxMale
    set pmxMale item pycor mxMale
    set pMigInFemale item pycor MigInFemale
    set pMigOutFemale item pycor MigOutFemale
    set pMigInMale item pycor MigInMale
    set pMigOutMale item pycor MigOutMale
  ]

  create-y-line-labels

  set Total round( sum [pFemale + pMale] of patches with [pxcor = 0] )

  ask patches with [pxcor = 0] [ set pcolor white - 2 ]
  reset-ticks

  ask patches with [pxcor = 0 and pycor = (Year + ticks - cohort) ] [ set pcolor
yellow ]

  ask patches with [pxcor < 0] [
    ifelse (( pMale / maxMale ) > ( pxcor / -50)) [ set pcolor 104 ] [set pcolor 0]
  ]

  ask patches with [pxcor > 0] [
    ifelse (( pFemale / maxFemale ) > ( pxcor / 50)) [ set pcolor 14 ] [ set pcolor
0]
  ]


  output-print Year + ticks
```

```
end

;; display y values
to create-y-line-labels
  ask patches with [pxcor = 2]
    [
      set plabel-color black
      if pycor = 0 [ set plabel 0 ]
      if pycor = 10 [ set plabel 10 ]
      if pycor = 20 [ set plabel 20 ]
      if pycor = 30 [ set plabel 30 ]
      if pycor = 40 [ set plabel 40 ]
      if pycor = 50 [ set plabel 50 ]
      if pycor = 60 [ set plabel 60 ]
      if pycor = 70 [ set plabel 70 ]
      if pycor = 80 [ set plabel 80 ]
      if pycor = 90 [ set plabel 90 ]
      if pycor = 100 [ set plabel 100 ]
      if pycor = 110 [ set plabel 110 ]
  ]
  ask patches with [pxcor = -2]
    [
      set plabel-color black
      if pycor = 5 [ set plabel 5 ]
      if pycor = 15 [ set plabel 15 ]
      if pycor = 25 [ set plabel 25 ]
      if pycor = 35 [ set plabel 35 ]
      if pycor = 45 [ set plabel 45 ]
      if pycor = 55 [ set plabel 55 ]
      if pycor = 65 [ set plabel 65 ]
      if pycor = 75 [ set plabel 75 ]
      if pycor = 85 [ set plabel 85 ]
      if pycor = 95 [ set plabel 95 ]
      if pycor = 105 [ set plabel 105 ]
  ]
end

to boost20
  ask patches with [pycor = 20] [
    set pFemale ( pFemale * 1.2)
    set pMale ( pMale * 1.2)
    ask patches with [pxcor < 0 and pycor = 20] [
      ifelse (( pMale / maxMale ) > ( pxcor / -50)) [ set pcolor 104 ] [set pcolor
0]
    ]

    ask patches with [pxcor > 0 and pycor = 20] [
      ifelse (( pFemale / maxFemale ) > ( pxcor / 50)) [ set pcolor 14 ] [ set
pcolor 0]
    ]
  ]
  set Total round( sum [pFemale + pMale] of patches with [pxcor = 0] )
end

to boost2013
  ask patches [
    set pFemale ( pFemale + pMigInFemale - pMigOutFemale)
    set pMale ( pMale  + pMigInMale - pMigOutMale)
  ]
  ask patches with [pxcor < 0] [
    ifelse (( pMale / maxMale ) > ( pxcor / -50)) [ set pcolor 104 ] [set pcolor 0]
  ]

  ask patches with [pxcor > 0] [
    ifelse (( pFemale / maxFemale ) > ( pxcor / 50)) [ set pcolor 14 ] [ set pcolor
0]
  ]
  set Total round( sum [pFemale + pMale] of patches with [pxcor = 0] )
end
```

```
to set1
  set yearly_increase_20 FALSE
  set yearly_increase FALSE
  set mortality 1.0
  set number_of_children 1.42
  set cohort 1969
end

to go-once
  go
end


to go

  if yearly_increase_20 [ boost20 ]

  if yearly_increase [boost2013]

  ;; modify fertility
  ask patches [
    set pASFR ( ( item pycor baselineASFR ) * number_of_children / sum
(baselineASFR) )
  ]

  ;; compute the number of newborn children depending on the number of women and
the ASFR
  ask patches [
    set pChildren round( pASFR * pFemale )
  ]

  ;; compute the number of death for each age
  ask patches [
    set pDeathFemale ceiling( pmxFemale * pFemale )
    set pDeathMale ceiling( pmxMale * pMale )
  ]
  ask patches [
    set pMale max (list 0  ( pMale - pDeathMale ) )
    set pFemale max ( list 0 ( pFemale - pDeathFemale ) )
  ]

  ask patches with [pycor > 0] [
    set pMaleTemp [pMale] of patch pxcor (pycor - 1)
    set pFemaleTemp [pFemale] of patch pxcor (pycor - 1)
  ]
  ask patches with [pycor = 0] [
    set pMaleTemp round(( sum [pChildren] of patches with [pxcor = 0] ) / 2)
    set pFemaleTemp round(( sum [pChildren] of patches with [pxcor = 0] ) / 2)
  ]

  ask patches [
    set pMale pMaleTemp
    set pFemale pFemaleTemp
  ]

  ask patches with [pxcor < 0] [
    ifelse (( pMale / maxMale ) > ( pxcor / -50)) [ set pcolor 104 ] [set pcolor 0]
  ]

  ask patches with [pxcor > 0] [
    ifelse (( pFemale / maxFemale ) > ( pxcor / 50)) [ set pcolor 14 ] [ set pcolor
0]
  ]
  tick

  ;; modify mortality
  ask patches [
```

```
    set pmxMale ( pmxMale * mortality )
    set pmxFemale ( pmxFemale * mortality )
  ]


  ask patches with [pxcor = 0 ] [ set pcolor white - 2 ]
  ask patches with [pxcor = 0 and pycor = (Year + ticks - cohort) ] [ set pcolor
yellow ]
  set Total round( sum [pFemale + pMale] of patches with [pxcor = 0] )

  output-print Year + ticks
end
```