**INTEGRATED POPULATION MODELING OF RED FOX POPULATIONS**

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# Integrated population model for the red fox population in Domagné France

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# Age structured, female-based model (2 age classes-1-year)

# Pre-breeding census

#

# Combination of:

# - Distance sampling census (2002-2010): --> state-space model

# - productivity for harvest data (2002-2006) --> Poisson regression

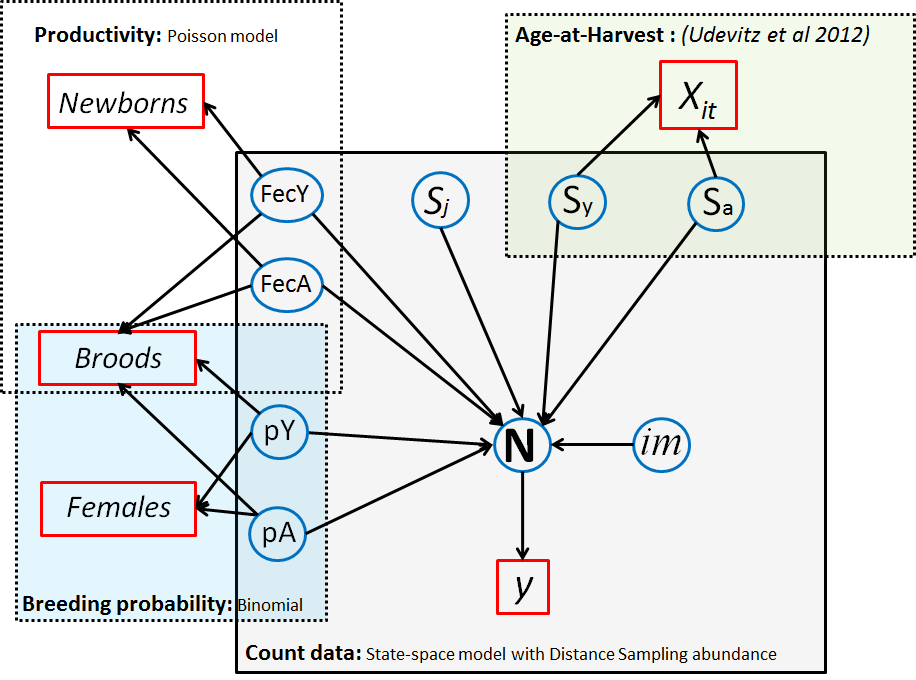
# - age-at-harvest data from trapping and hunting (2002-2006) --> yearling and adult survival:

# Model by Udevitz & Gonan (2012)

#

Previous estimation of red fox vital rates using age-at-harvest data with Udevitz and Gogan (2012) method highlight our inability to estimate juvenile survival from our data set (see “Vital rate .doc”). Moreover, preliminary perturbation analysis revealed the main importance of juvenile survival on red fox dynamics (see “Perturbation analysis.doc”). Then, Distance Sampling estimate of population size revealed that density were lower in the center of the GIC suggesting an important portion of immigrant after removals (see “Distance sampling estimate.doc”). Finally, our age-at-harvest data expends from 2002 to 2006 whereas spotlight counts continued until 2010; so, we would like to have estimated parameters for the overall period.

For all these reasons, we construct on integrated population model (IPM) using age-at-harvest data, uterus analysis of reproductive outputs and spotlight count survey. We adapt Schaub et al (2007) code for our purposes.



### IPM along the sampling period (2002 to 2006): RedFoxDIPM.R

**mean sd 2.5% 25% 50% 75% 97.5% Rhat n.eff**

**Sj[1] 0.510573 0.176451 0.092529 0.418375 0.525150 0.624525 0.830220 1.005447 2200**

Sj[2] 0.644763 0.215449 0.105695 0.533375 0.678500 0.799900 0.968810 1.025476 310

Sj[3] 0.382573 0.131117 0.073715 0.310700 0.391500 0.467300 0.624252 1.020046 890

Sj[4] 0.363293 0.130249 0.059945 0.293700 0.372450 0.447525 0.597600 1.011679 710

**Sy[1] 0.259618 0.043907 0.178700 0.229500 0.257800 0.288100 0.350252 1.001209 4900**

Sy[2] 0.335106 0.040997 0.258500 0.306700 0.334050 0.362600 0.417952 1.000978 7500

Sy[3] 0.234209 0.038558 0.163447 0.206300 0.233150 0.259900 0.312900 1.001311 3900

Sy[4] 0.333864 0.046088 0.249295 0.301400 0.332500 0.364500 0.427000 1.000806 7500

**Sa[1] 0.430453 0.060918 0.312342 0.389675 0.430300 0.471800 0.551205 1.000876 7500**

Sa[2] 0.523509 0.068937 0.388447 0.475600 0.522500 0.572725 0.655800 1.000809 7500

Sa[3] 0.566462 0.061212 0.444785 0.525475 0.567500 0.607200 0.685157 1.001097 6700

Sa[4] 0.543761 0.063793 0.419300 0.501300 0.544600 0.586825 0.667310 1.000867 7500

**im[1] 0.214352 0.322975 0.000003 0.007983 0.056415 0.284150 1.153050 1.001728 2200**

im[2] 0.210327 0.306513 0.000010 0.009089 0.061975 0.292625 1.093574 1.004348 990

im[3] 0.137814 0.210168 0.000003 0.005674 0.038790 0.177700 0.749152 1.001443 3100

im[4] 0.144068 0.220731 0.000005 0.005100 0.036950 0.187550 0.793854 1.006986 910

im[5] 0.195108 0.615243 0.000000 0.000001 0.001034 0.067765 1.944300 1.002263 7500

**pY[1] 0.466651 0.082347 0.308247 0.410975 0.465700 0.522725 0.630157 1.001892 1800**

pY[2] 0.593009 0.069774 0.453895 0.546000 0.593850 0.640525 0.727905 1.000967 7500

pY[3] 0.689011 0.081614 0.519547 0.635075 0.692600 0.748925 0.833952 1.001100 6600

pY[4] 0.607705 0.086375 0.434285 0.549675 0.608650 0.668725 0.771452 1.001185 5200

pY[5] 0.689518 0.084084 0.514847 0.632200 0.694500 0.749250 0.840052 1.000824 7500

**pA[1] 0.887176 0.052029 0.767100 0.856500 0.894400 0.925300 0.967452 1.000964 7500**

pA[2] 0.525947 0.023532 0.500700 0.507900 0.519100 0.537800 0.588152 1.001137 5900

pA[3] 0.694305 0.076231 0.538447 0.640875 0.697700 0.748500 0.835200 1.000847 7500

pA[4] 0.834648 0.067390 0.686395 0.793900 0.842600 0.884225 0.941352 1.000892 7500

pA[5] 0.965316 0.033330 0.878447 0.951300 0.975200 0.989825 0.999100 1.000987 7500

**FecY[1] 3.979072 0.496675 3.087000 3.628750 3.953500 4.299250 5.024525 1.000906 7500**

FecY[2] 2.951482 0.327474 2.348475 2.725750 2.940000 3.166000 3.631000 1.000806 7500

FecY[3] 3.887268 0.427212 3.106425 3.587750 3.868000 4.168250 4.783525 1.000868 7500

FecY[4] 4.150069 0.479771 3.276475 3.817000 4.129000 4.465000 5.125525 1.001075 7200

FecY[5] 2.848659 0.383049 2.147475 2.585000 2.825000 3.098000 3.645050 1.000894 7500

**FecA[1] 5.176473 0.409001 4.408000 4.893000 5.163000 5.447000 6.007149 1.000935 7500**

FecA[2] 3.729104 0.487927 2.817000 3.397000 3.708000 4.044000 4.735525 1.000825 7500

FecA[3] 4.704671 0.453654 3.851000 4.396000 4.685000 5.000000 5.660000 1.000872 7500

FecA[4] 4.750074 0.433503 3.940000 4.455750 4.733000 5.027250 5.633575 1.001028 7500

FecA[5] 4.296259 0.399225 3.552475 4.019000 4.288000 4.562000 5.094000 1.000941 7500

**Ntot[1] 173.711480 9.524531 155.600000 167.100000 173.500000 180.000000 193.000000 1.001127 6100**

Ntot[2] 202.781840 13.988832 176.100000 193.100000 202.400000 211.900000 231.000000 1.001239 4500

Ntot[3] 218.586693 14.455816 190.800000 208.600000 218.300000 228.300000 247.600000 1.000980 7500

Ntot[4] 215.166653 14.630753 186.700000 205.300000 215.000000 224.700000 244.500000 1.000851 7500

Ntot[5] 224.536587 15.073574 196.200000 214.100000 224.300000 234.400000 255.000000 1.001111 6400

**lambda[2] 1.170821 0.102829 0.983195 1.099000 1.167000 1.237250 1.387000 1.001208 4900**

lambda[3] 1.082838 0.100968 0.897347 1.012000 1.080000 1.150000 1.291000 1.001251 4400

lambda[4] 0.988595 0.093234 0.817200 0.924400 0.986000 1.048000 1.183525 1.000830 7500

lambda[5] 1.048360 0.100002 0.865347 0.978175 1.045000 1.113000 1.253000 1.001068 7400

**Ny[1] 109.485612 8.504856 93.114750 103.700000 109.400000 115.200000 126.052490 1.001777 2000**

Ny[2] 146.743693 16.836991 114.400000 135.200000 146.500000 158.000000 179.952493 1.000843 7500

Ny[3] 140.025053 17.758482 104.347488 128.400000 140.100000 152.200000 174.552493 1.001077 7200

Ny[4] 138.048575 18.151533 102.700000 125.600000 137.800000 150.300000 173.500000 1.000891 7500

Ny[5] 136.498496 18.955078 99.084750 123.900000 136.400000 149.324994 173.152493 1.000906 7500

**Na[1] 64.225600 8.539314 47.574248 58.260000 64.275000 70.052500 81.045250 1.001679 2300**

Na[2] 56.038133 9.269398 39.000000 50.000000 56.000000 62.000000 74.000000 1.001237 4600

Na[3] 78.561600 10.791435 59.000000 71.000000 78.000000 86.000000 101.000000 1.001338 3700

Na[4] 77.118000 11.088045 56.000000 69.000000 77.000000 85.000000 99.000000 1.001233 4600

Na[5] 88.038133 12.012535 65.000000 80.000000 88.000000 96.000000 112.000000 1.001021 7500

**R[2] 123.863333 37.334532 22.000000 110.000000 133.000000 149.000000 174.000000 1.003926 660**

R[3] 116.171200 36.319158 19.000000 102.000000 125.000000 141.000000 165.000000 1.011362 310

R[4] 117.469333 34.777900 23.000000 103.000000 125.000000 140.000000 167.000000 1.002785 1400

R[5] 115.389067 36.097556 19.000000 100.000000 123.000000 140.000000 168.000000 1.004498 670

**IM[2] 22.880413 34.057806 0.064796 0.873299 6.161000 30.719995 122.904959 1.002499 1200**

IM[3] 23.854075 34.033250 0.081929 1.138750 7.245000 32.862500 122.200000 1.004140 600

IM[4] 20.579320 31.073048 0.074238 0.849550 5.657498 26.512500 113.552489 1.001768 2100

IM[5] 21.109467 31.875325 0.066901 0.811250 5.474500 27.782500 114.100000 1.002765 1000

**H[1] 0.583177 0.032073 0.523300 0.561100 0.582100 0.604300 0.648952 1.001128 6100**

H[2] 0.455859 0.031603 0.398247 0.434175 0.454450 0.476400 0.522352 1.001240 4500

H[3] 0.448010 0.029824 0.393747 0.427100 0.446700 0.467500 0.511052 1.000980 7500

H[4] 0.413222 0.028272 0.361947 0.393800 0.411600 0.431200 0.474052 1.000851 7500

H[5] 0.371324 0.025046 0.325500 0.354100 0.370000 0.387700 0.423100 1.001112 6400

deviance 244.308067 8.043722 230.300000 238.600000 243.600000 249.500000 261.900000 1.000879 7500

For each parameter, n.eff is a crude measure of effective sample size,

and Rhat is the potential scale reduction factor (at convergence, Rhat=1).

DIC info (using the rule, pD = var(deviance)/2)

pD = 32.4 and DIC = 276.7





**Fig:** Posterior means (with 95% CRI) of the demographic parameters (Population size and age-specific survival) in a red fox population in NW France under a population model with random year effects for all demographic rates. Points show the mean and vertical segments the 95% CRI of the mean hyperparameters.





**Fig:** Posterior means (with 95% CRI) of the demographic parameters (age-specific Fecondity, immigration and growth rate) in a red fox population in NW France under a population model with random year effects for all demographic rates. Points show the mean and vertical segments the 95% CRI of the mean hyperparameters.

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**Fig.:** Estimates of annual demographic rates plotted against the estimates of interannual population growth. Black dots show posterior means and grey lines 95% CRI. Inset we print the posterior mode of the correlation coefficients (r, with 95% CRI and mean) and the probability of a positive correlation (P(r>0)).



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**Fig.:** Estimates of annual demographic rates plotted against the estimates of interannual population growth. Black dots show posterior means and grey lines 95% CRI. Inset we print the posterior mode of the correlation coefficients (r, with 95% CRI and mean) and the probability of a positive correlation (P(r>0)).

Interpretation

* All demographic estimates from the IPM are closed to those from independent analysis (as for Distance sampling and survival estimate). The uncertainty is slightly smaller with the IPM but can be interesting as for adult survival estimates.

Ex: survival estimate

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Udevitz method | | | | IPM | | | |
|  | mean | | standard deviation | | mean | | standard deviation | |
|  | Yearlings | Adults | Yearlings | Adults | Yearlings | Adults | Yearlings | Adults |
| 2002 | 0.2542176 | 0.4272268 | 0.05089288 | 0.08494112 | 0.259493 | 0.429590 | 0.045122 | 0.061489 |
| 2003 | 0.3324220 | 0.5241748 | 0.04787744 | 0.11488673 | 0.334877 | 0.522181 | 0.040611 | 0.066926 |
| 2004 | 0.2308483 | 0.5703311 | 0.04301927 | 0.10240191 | 0.234093 | 0.567783 | 0.038651 | 0.061101 |
| 2005 | 0.3301848 | 0.5447587 | 0.05429679 | 0.10477098 | 0.333077 | 0.545280 | 0.045777 | 0.064841 |

* IPM enables to analyze several parameters unestimated before: immigration rate, juvenile survival, age structure of the population but also the number of local and immigrant recruits! However, uncertainty is strongly larger for these estimates, as expected. But it may enable us to analysis some trends on these vital rates.
* During the length of the sampling period, the removal rate decreased regularly associated with the regular increase of the population size. The growth rate was more variable with a U from and remained higher than 1. The age structure stabilized at 60% of yearling.
* Juvenile survival seems to decrease as pop size increases and removal rate decreases. Whereas adult survival increases on the contrary. Female productivity is merely constant but proportion of breeding female among yearling is highly variable, increasing as pop size increase and removal decreases. Immigration rate seems to be constant at 20% of annual recruits.
* These trends are confirmed by descriptive correlation: interestingly, population growth rate increases with the removal intensity, and it is correlated with the increase of juvenile survival and immigration rate!

A higher growth rate is also linked with a slower adult survival and yearling probability of breeding.

Hypothesis

These first descriptive results indicate that removal intensity increases the population growth rate by decreasing adult survival and increasing juvenile survival and a yearling composition. It looks like as if density dependence existed in this species where adult density constraint juvenile survival. As a consequence, a major control of adult age class leads to a compensatory increase of the population growth.

However, this idea has to be complete by longer time series data, between population comparison and rigorous modelisation.

We start here by working on longer time scale, even if uncertainty increases when age-at-harvest data are missing.

### IPM along the overall period (2002 to 2010): TotalRedFoxDIPM.R

**mean sd 2.5% 25% 50% 75% 97.5% Rhat n.eff**

**Sj[1] 0.515611 0.170807 0.098890 0.427750 0.528650 0.625675 0.824952 1.010300 1000**

Sj[2] 0.646610 0.214573 0.107800 0.534175 0.677000 0.801900 0.968405 1.008878 570

Sj[3] 0.374402 0.134094 0.067050 0.300900 0.384000 0.462325 0.616810 1.006006 600

Sj[4] 0.361669 0.131998 0.066191 0.288400 0.370000 0.448325 0.608157 1.012462 580

Sj[5] 0.460130 0.190770 0.078244 0.329175 0.463700 0.594900 0.829452 1.002230 2000

Sj[6] 0.387395 0.257827 0.021959 0.176550 0.339200 0.571950 0.939052 1.003406 830

Sj[7] 0.544954 0.245900 0.076734 0.361200 0.542700 0.739300 0.970657 1.006053 590

Sj[8] 0.470234 0.254595 0.046678 0.264500 0.448050 0.663950 0.956510 1.010180 320

**Sy[1] 0.259505 0.044081 0.177200 0.228500 0.258200 0.288725 0.350252 1.000840 7500**

Sy[2] 0.335046 0.040860 0.257547 0.307300 0.334200 0.361900 0.417205 1.001112 6400

Sy[3] 0.234225 0.038710 0.163200 0.207475 0.232400 0.259600 0.314000 1.001046 7500

Sy[4] 0.331805 0.045521 0.245747 0.300200 0.331200 0.362600 0.422452 1.002123 1500

Sy[5] 0.376173 0.229579 0.016509 0.174600 0.370000 0.567125 0.774552 1.004301 780

Sy[6] 0.426063 0.223529 0.026644 0.241175 0.439900 0.617800 0.778052 1.006977 450

Sy[7] 0.424935 0.231353 0.022390 0.227200 0.438100 0.628775 0.784600 1.002147 1500

Sy[8] 0.435524 0.226907 0.026852 0.248075 0.453450 0.630725 0.783205 1.003685 830

**Sa[1] 0.429382 0.061330 0.311447 0.387200 0.429000 0.470825 0.548452 1.001100 6600**

Sa[2] 0.524098 0.068715 0.388800 0.477400 0.524600 0.572000 0.656752 1.000817 7500

Sa[3] 0.567543 0.060297 0.447947 0.527000 0.568200 0.609000 0.683600 1.001002 7500

Sa[4] 0.543067 0.065478 0.414347 0.498500 0.543200 0.587300 0.669300 1.001055 7500

Sa[5] 0.596601 0.230764 0.219100 0.394900 0.596450 0.795675 0.979700 1.000881 7500

Sa[6] 0.600331 0.221915 0.224447 0.414300 0.599350 0.786550 0.978610 1.003947 640

Sa[7] 0.637096 0.226025 0.230542 0.449125 0.654900 0.834425 0.982100 1.000853 7500

Sa[8] 0.618266 0.226386 0.222447 0.428475 0.627500 0.812400 0.980152 1.001348 3600

**im[1] 0.200312 0.307289 0.000005 0.007699 0.053450 0.259700 1.121000 1.002131 1800**

im[2] 0.207692 0.300895 0.000009 0.008732 0.064500 0.283800 1.079525 1.002742 1000

im[3] 0.147782 0.216562 0.000003 0.005726 0.042130 0.203100 0.784649 1.004914 720

im[4] 0.149100 0.222103 0.000003 0.005689 0.040465 0.206000 0.791792 1.001841 1900

im[5] 0.153471 0.233809 0.000003 0.005522 0.041985 0.201300 0.845572 1.002022 1600

im[6] 0.128063 0.234204 0.000002 0.005188 0.034235 0.149600 0.725357 1.004340 1200

im[7] 0.211740 0.348529 0.000007 0.007040 0.053995 0.274600 1.132525 1.017393 180

im[8] 0.156062 0.254127 0.000007 0.006247 0.044835 0.195925 0.905741 1.001676 2300

im[9] 0.196314 0.620920 0.000000 0.000001 0.001125 0.066010 1.922720 1.000827 7500

**pY[1] 0.467038 0.081806 0.308995 0.408800 0.467350 0.522925 0.628057 1.001350 3600**

pY[2] 0.594338 0.070047 0.456847 0.546200 0.595400 0.643500 0.726400 1.000803 7500

pY[3] 0.690268 0.079157 0.527647 0.637875 0.694400 0.746400 0.833800 1.000907 7500

pY[4] 0.605514 0.085622 0.429347 0.548700 0.608400 0.665825 0.767010 1.001694 4300

pY[5] 0.685603 0.084116 0.509947 0.629700 0.690050 0.745300 0.839952 1.000910 7500

pY[6] 0.427171 0.284260 0.016238 0.177075 0.393100 0.654625 0.959952 1.001212 4800

pY[7] 0.516790 0.282572 0.030824 0.279450 0.520450 0.760400 0.973300 1.001913 1800

pY[8] 0.470903 0.283586 0.024365 0.226000 0.451650 0.709925 0.968400 1.001382 5000

pY[9] 0.493089 0.288904 0.022854 0.243275 0.489200 0.738525 0.978062 1.002637 2900

**pA[1] 0.886552 0.052042 0.761500 0.855500 0.893550 0.925200 0.966652 1.000999 7500**

pA[2] 0.525702 0.023352 0.500700 0.508300 0.519000 0.536700 0.587500 1.000886 7500

pA[3] 0.694820 0.075722 0.540100 0.643500 0.696200 0.749200 0.835752 1.000851 7500

pA[4] 0.836120 0.066760 0.684847 0.796775 0.843800 0.885000 0.941000 1.000905 7500

pA[5] 0.964799 0.034133 0.872942 0.950700 0.975900 0.989700 0.999100 1.000864 7500

pA[6] 0.737133 0.144970 0.510900 0.609075 0.728950 0.863200 0.985652 1.000927 7500

pA[7] 0.749799 0.144357 0.512200 0.624975 0.747900 0.877500 0.987352 1.001750 2100

pA[8] 0.744656 0.143949 0.511447 0.619875 0.742600 0.869100 0.985200 1.001320 3800

pA[9] 0.750457 0.143450 0.513000 0.626075 0.750900 0.873450 0.986752 1.000805 7500

**muY[1] 1.372795 0.127054 1.114000 1.290000 1.374000 1.459000 1.617050 1.001096 6700**

muY[2] 1.079268 0.110266 0.860190 1.006000 1.081000 1.154000 1.294000 1.000908 7500

muY[3] 1.349269 0.109393 1.131475 1.278000 1.352000 1.422000 1.556000 1.001014 7500

muY[4] 1.414172 0.115461 1.184475 1.338000 1.415000 1.494000 1.633000 1.001017 7500

muY[5] 1.029562 0.136385 0.764637 0.935150 1.030000 1.123000 1.289525 1.000883 7500

muY[6] 0.927024 0.564309 0.046975 0.436800 0.892850 1.390000 1.934525 1.001615 2500

muY[7] 1.032841 0.565033 0.060272 0.554500 1.054500 1.522000 1.949000 1.001279 4200

muY[8] 0.965820 0.557796 0.047988 0.492075 0.961250 1.430250 1.932000 1.001497 2900

muY[9] 1.032619 0.569317 0.056065 0.551025 1.048000 1.531000 1.949000 1.000953 7500

**muA[1] 1.642019 0.078893 1.484000 1.588000 1.643000 1.696250 1.794000 1.001246 4500**

muA[2] 1.308188 0.133001 1.037475 1.218000 1.312000 1.401000 1.557000 1.000895 7500

muA[3] 1.543705 0.097427 1.347000 1.478750 1.545000 1.610000 1.733000 1.001471 3000

muA[4] 1.553240 0.092748 1.373000 1.492000 1.553000 1.616000 1.730000 1.001107 6500

muA[5] 1.448770 0.093144 1.265475 1.386000 1.449000 1.514000 1.626000 1.000815 7500

muA[6] 0.926509 0.555589 0.048770 0.446975 0.891900 1.376000 1.931525 1.001739 2100

muA[7] 1.072773 0.542872 0.082285 0.631950 1.103500 1.525000 1.948000 1.002173 1800

muA[8] 0.968021 0.551304 0.057568 0.500950 0.955150 1.424250 1.922525 1.001395 3400

muA[9] 1.053234 0.567063 0.063970 0.572700 1.074500 1.542250 1.951000 1.000864 7500

**Ntot[1] 173.882867 9.727436 155.400000 167.174994 173.900000 180.400000 193.400000 1.001020 7500**

Ntot[2] 202.727533 13.857768 176.347493 193.300000 202.400000 211.800000 231.000000 1.000962 7500

Ntot[3] 219.096587 14.559944 191.700000 209.200000 218.800000 228.500000 248.652495 1.001130 6000

Ntot[4] 214.930880 14.652819 186.800000 205.000000 214.500000 224.500000 245.500000 1.000985 7500

Ntot[5] 223.933360 14.843411 195.500000 213.700000 223.600000 234.100000 253.800000 1.000828 7500

Ntot[6] 271.502400 16.442975 241.100000 260.000000 271.300000 282.300000 305.352496 1.000953 7500

Ntot[7] 216.855027 14.528938 189.300000 207.100000 216.300000 226.300000 246.600000 1.001148 5700

Ntot[8] 265.139893 15.953813 234.600000 254.300000 264.800000 275.900000 297.000000 1.001039 7500

Ntot[9] 255.586693 15.934383 225.647494 244.500000 255.400000 266.200000 287.652496 1.001153 5700

**lambda[2] 1.169482 0.103046 0.983200 1.097000 1.165000 1.236000 1.391000 1.001178 5300**

lambda[3] 1.085528 0.100584 0.902195 1.015000 1.082000 1.152000 1.292000 1.001089 6900

lambda[4] 0.985319 0.094001 0.814900 0.920675 0.982000 1.044000 1.181525 1.000860 7500

lambda[5] 1.046707 0.099479 0.867195 0.977275 1.042000 1.111000 1.259000 1.000977 7500

lambda[6] 1.217705 0.108912 1.021000 1.142000 1.212000 1.286000 1.447000 1.000873 7500

lambda[7] 0.801644 0.072444 0.669647 0.751100 0.798750 0.847800 0.952357 1.001291 4100

lambda[8] 1.228131 0.110482 1.020000 1.151000 1.224000 1.299000 1.455000 1.001198 5000

lambda[9] 0.967428 0.083463 0.815937 0.908200 0.963750 1.022000 1.137525 1.001394 3400

**Ny[1] 109.627775 8.559265 92.884750 103.900000 109.500000 115.400000 126.400000 1.000931 7500**

Ny[2] 146.664324 16.831938 114.600000 135.100000 146.400000 157.800000 180.552493 1.001073 7300

Ny[3] 140.613823 17.724954 106.800000 128.700000 140.700000 152.600000 175.152493 1.001044 7500

Ny[4] 137.581905 18.164886 102.547488 125.300000 137.400000 149.700000 173.952493 1.000878 7500

Ny[5] 136.262927 19.055889 99.234750 123.200000 136.400000 149.300000 173.752493 1.001388 3400

Ny[6] 168.092716 42.289088 86.454750 137.874993 169.300000 199.100000 245.452495 1.001225 4700

Ny[7] 82.366284 42.158443 11.318460 50.637500 78.740000 111.224992 170.952493 1.015119 220

Ny[8] 143.002972 42.133206 64.528626 112.100000 142.500000 174.124995 222.300000 1.001250 4400

Ny[9] 117.028372 46.281736 33.452205 83.079998 115.449989 149.300000 208.552494 1.001819 2000

**Na[1] 64.256269 8.628521 47.900000 58.270000 64.100000 70.000000 81.410000 1.000968 7500**

Na[2] 56.063200 9.380064 38.000000 50.000000 56.000000 62.000000 75.000000 1.000980 7500

Na[3] 78.482800 10.840420 58.000000 71.000000 78.000000 86.000000 100.000000 1.000813 7500

Na[4] 77.348933 11.027320 56.472793 70.000000 77.000000 85.000000 99.000000 1.000819 7500

Na[5] 87.670400 12.037320 65.000000 79.000000 87.000000 96.000000 112.000000 1.001991 1700

Na[6] 103.409733 39.110557 34.000000 74.000000 102.000000 132.000000 180.000000 1.003965 1100

Na[7] 134.488667 41.259007 49.000000 107.000000 137.000000 165.000000 205.000000 1.008592 280

Na[8] 122.136800 38.995074 49.000000 93.000000 123.000000 152.000000 193.000000 1.001102 6600

Na[9] 138.558667 44.203703 50.000000 107.000000 141.000000 172.000000 218.000000 1.002221 1400

**R[2] 125.174133 35.754681 25.000000 112.000000 133.000000 149.000000 174.000000 1.003057 890**

R[3] 116.876933 36.039505 19.000000 102.000000 125.000000 141.000000 166.000000 1.007009 410

R[4] 115.349600 35.869296 20.000000 99.000000 123.000000 140.000000 167.000000 1.008084 320

R[5] 114.468400 36.271688 19.475000 99.000000 122.000000 139.000000 167.000000 1.005164 580

R[6] 140.980000 54.343419 24.000000 105.000000 145.000000 180.000000 234.000000 1.002821 990

R[7] 66.509067 41.360411 4.000000 34.000000 61.000000 94.000000 156.000000 1.006890 330

R[8] 115.475467 50.094122 15.000000 81.000000 117.000000 152.000000 208.000000 1.013335 160

R[9] 95.364133 48.906390 9.000000 59.000000 93.000000 129.000000 195.525000 1.003489 750

**IM[2] 21.490157 32.505915 0.071014 0.873600 5.859990 27.880000 119.352490 1.002764 1000**

IM[3] 23.736842 33.862656 0.079726 1.059249 7.340492 33.182477 122.904959 1.003614 710

IM[4] 22.232261 32.163540 0.074946 0.921599 6.443983 30.310000 116.852489 1.005300 450

IM[5] 21.794964 32.012298 0.067428 0.929225 5.840996 29.992500 115.600000 1.003048 890

IM[6] 27.112541 40.845202 0.073874 1.012750 7.278000 36.572500 150.257425 1.002529 1200

IM[7] 15.857106 24.208881 0.059455 0.747225 4.541000 20.694998 87.950998 1.001831 1900

IM[8] 27.527811 40.376175 0.075253 1.038249 7.667000 38.300000 145.104966 1.014374 150

IM[9] 21.664209 31.658674 0.079224 1.016000 6.762499 29.722500 114.400000 1.002387 1300

**H[1] 0.582673 0.032742 0.522347 0.560000 0.580700 0.604225 0.649800 1.001020 7500**

H[2] 0.455940 0.031299 0.398300 0.434375 0.454450 0.476000 0.521705 1.000961 7500

H[3] 0.446979 0.029765 0.392147 0.426700 0.445700 0.466100 0.508600 1.001130 6000

H[4] 0.413685 0.028373 0.360500 0.394275 0.412550 0.431700 0.473752 1.000984 7500

H[5] 0.372284 0.024827 0.327100 0.354600 0.371300 0.388400 0.424500 1.000828 7500

deviance 308.946253 8.569407 294.000000 302.900000 308.200000 314.300000 327.400000 1.001084 7000

For each parameter, n.eff is a crude measure of effective sample size,

and Rhat is the potential scale reduction factor (at convergence, Rhat=1).

DIC info (using the rule, pD = var(deviance)/2)

pD = 36.7 and DIC = 345.7

DIC is an estimate of expected predictive error (lower deviance is better).

**Fig:** Posterior means (with 95% CRI) of the demographic parameters (Population size and age-specific survival) in a red fox population in NW France under a population model with random year effects for all demographic rates. Points show the mean and vertical segments the 95% CRI of the mean hyperparameters.





**Fig:** Posterior means (with 95% CRI) of the demographic parameters (age-specific Fecondity, immigration and growth rate) in a red fox population in NW France under a population model with random year effects for all demographic rates. Points show the mean and vertical segments the 95% CRI of the mean hyperparameters.



**Fig.:** Estimates of annual demographic rates plotted against the estimates of interannual population growth. Black dots show posterior means and grey lines 95% CRI. Inset we print the posterior mode of the correlation coefficients (r, with 95% CRI) and the probability of a positive correlation (P(r>0)).



**Fig.:** Estimates of annual demographic rates plotted against the estimates of interannual population growth. Black dots show posterior means and grey lines 95% CRI. Inset we print the posterior mode of the correlation coefficients (r, with 95% CRI) and the probability of a positive correlation (P(r>0)). Above: analysis for overall period; below: analysis for 2002-2005

Interpretation

* All demographic estimates from the IPM are closed to those from independent analysis (as for Distance sampling and survival estimate). The uncertainty is too large between 2006 and 2010 as sampling finished. Estimates during the restrictive interval are the same.
* However, large uncertainty between 2006 and 2010 induce a larger noise on descriptive statistics. Previous observations are the same but statistical significance are less clear. It suggests combining different population to increase data point for analysis and confirms our hypothesis of compensatory growth linked to a release of density-dependance.

##########################################################################

# Integrated population model for the red fox population in Vendelais

#

# Age structured, female-based model (2 age classes-1-year)

# Pre-breeding census

#

# Combination of:

# - Distance sampling census (2003-2010): --> state-space model

# - productivity for harvest data (2003-2007) --> Poisson regression

# - age-at-harvest data from trapping and hunting (2003-2007) --> yearling and adult survival:

# Model by Udevitz & Gonan (2012)

#

### IPM along the overall period (2003 to 2010): TotalRedFoxDIPM.R

**mean sd 2.5% 25% 50% 75% 97.5% Rhat n.eff**

**Sj[1] 0.667535 0.209876 0.148282 0.548875 0.696150 0.826125 0.976452 1.001656 2300**

Sj[2] 0.550253 0.227302 0.090713 0.389250 0.546950 0.720425 0.958457 1.009959 640

Sj[3] 0.598825 0.227234 0.117990 0.442375 0.608800 0.777050 0.973900 1.008690 1100

Sj[4] 0.378492 0.182011 0.056792 0.251025 0.361950 0.490450 0.780920 1.001190 5100

Sj[5] 0.368983 0.186001 0.047531 0.236200 0.355300 0.484100 0.777820 1.000962 7500

Sj[6] 0.428766 0.260745 0.029187 0.212975 0.394950 0.625425 0.943720 1.007310 390

Sj[7] 0.489705 0.258709 0.049745 0.283100 0.470950 0.697200 0.963605 1.001062 7500

**Sy[1] 0.166611 0.066858 0.059499 0.117850 0.158700 0.207400 0.319967 1.000845 7500**

Sy[2] 0.276881 0.075049 0.142700 0.223400 0.272350 0.326225 0.433805 1.001433 3200

Sy[3] 0.467842 0.081321 0.311495 0.412200 0.466400 0.523000 0.627905 1.001079 7100

Sy[4] 0.378972 0.103639 0.189595 0.304500 0.375800 0.450200 0.590005 1.001790 2000

Sy[5] 0.394641 0.227907 0.020306 0.199575 0.392250 0.588000 0.779205 1.002195 5000

Sy[6] 0.399328 0.226520 0.019251 0.205175 0.402050 0.592200 0.775852 1.001572 2600

Sy[7] 0.425603 0.227006 0.022344 0.235375 0.441250 0.620100 0.781500 1.003711 1300

**Sa[1] 0.350504 0.102449 0.207700 0.269675 0.332900 0.414425 0.583167 1.001608 2500**

Sa[2] 0.515235 0.154815 0.234700 0.398300 0.510700 0.626825 0.814405 1.000816 7500

Sa[3] 0.312894 0.081051 0.205200 0.247600 0.297900 0.362600 0.500805 1.000962 7500

Sa[4] 0.326327 0.095142 0.204400 0.250400 0.307500 0.383425 0.554152 1.001770 2100

Sa[5] 0.588736 0.230819 0.217547 0.386200 0.583000 0.789125 0.979052 1.001821 2000

Sa[6] 0.596167 0.226210 0.222495 0.403825 0.593250 0.787800 0.977800 1.002011 1700

Sa[7] 0.621703 0.226771 0.225647 0.429400 0.633550 0.815450 0.981352 1.001187 5200

**im[1] 0.226485 0.323592 0.000005 0.010010 0.074745 0.315625 1.162000 1.002806 1000**

im[2] 0.278392 0.433213 0.000009 0.012767 0.083270 0.362225 1.513000 1.002267 6600

im[3] 0.312232 0.468482 0.000010 0.013935 0.102750 0.420250 1.674525 1.002261 1400

im[4] 0.115347 0.170641 0.000004 0.005597 0.037935 0.155225 0.616497 1.001260 6200

im[5] 0.166146 0.244563 0.000003 0.007749 0.053545 0.222950 0.881302 1.001342 3700

im[6] 0.147259 0.256482 0.000002 0.006653 0.042890 0.175350 0.854620 1.010570 1300

im[7] 0.199119 0.301376 0.000007 0.009889 0.066575 0.268425 1.063000 1.003332 7500

im[8] 0.195231 0.619727 0.000000 0.000001 0.001077 0.068062 1.874000 1.001132 6000

**pY[1] 0.667874 0.106275 0.446347 0.597575 0.673400 0.746325 0.859257 1.000864 7500**

pY[2] 0.311539 0.136087 0.092908 0.210600 0.295500 0.397425 0.617152 1.000900 7500

pY[3] 0.240668 0.184842 0.009731 0.091120 0.200550 0.353250 0.684857 1.001066 7500

pY[4] 0.733215 0.125897 0.455447 0.653500 0.747000 0.828000 0.936467 1.001092 6800

pY[5] 0.865625 0.117052 0.566790 0.810375 0.897150 0.954300 0.996152 1.000853 7500

pY[6] 0.460865 0.285626 0.021395 0.215000 0.430600 0.702200 0.966752 1.001367 3500

pY[7] 0.492568 0.283964 0.025640 0.248975 0.487750 0.733075 0.972605 1.000805 7500

pY[8] 0.503519 0.288487 0.025349 0.251875 0.506750 0.750425 0.976852 1.001305 7500

**pA[1] 0.544815 0.040169 0.501200 0.513600 0.533700 0.564200 0.647657 1.000839 7500**

pA[2] 0.650015 0.098306 0.506900 0.568775 0.637300 0.718300 0.860300 1.001052 7500

pA[3] 0.804908 0.136208 0.526847 0.703800 0.824600 0.923525 0.993100 1.000951 7500

pA[4] 0.610246 0.079322 0.504500 0.545175 0.596100 0.661825 0.789910 1.000858 7500

pA[5] 0.597527 0.077367 0.503500 0.535500 0.580150 0.641925 0.787957 1.000891 7500

pA[6] 0.739172 0.145135 0.509547 0.613300 0.733200 0.862825 0.985852 1.000971 7500

pA[7] 0.746897 0.143617 0.512900 0.620875 0.749050 0.871000 0.985752 1.000980 7500

pA[8] 0.752627 0.143778 0.513800 0.627675 0.754700 0.877200 0.987552 1.000805 7500

**muY[1] 1.143742 0.166471 0.806600 1.034000 1.146000 1.259000 1.459000 1.001539 2700**

muY[2] 1.684758 0.214660 1.195000 1.556000 1.719000 1.854000 1.983000 1.001000 7500

muY[3] 1.012459 0.563503 0.061971 0.536375 1.021000 1.487250 1.946000 1.000950 7500

muY[4] 1.248931 0.187762 0.861685 1.126000 1.256000 1.383000 1.590000 1.000964 7500

muY[5] 1.207575 0.218112 0.757332 1.066000 1.213000 1.356250 1.612000 1.000851 7500

muY[6] 0.970585 0.563897 0.057602 0.488625 0.956750 1.448000 1.941000 1.001121 6200

muY[7] 0.982586 0.564141 0.051017 0.501800 0.974400 1.457250 1.943000 1.000909 7500

muY[8] 1.020366 0.568806 0.056815 0.539775 1.023000 1.503250 1.955525 1.002561 3500

**muA[1] 1.297311 0.249308 0.775722 1.139000 1.309000 1.473000 1.757525 1.001229 4700**

muA[2] 1.463204 0.233593 0.981442 1.307000 1.475000 1.632000 1.882000 1.000866 7500

muA[3] 1.708089 0.200983 1.239000 1.585000 1.742000 1.865000 1.985000 1.001049 7500

muA[4] 0.912610 0.272317 0.360542 0.736350 0.923700 1.103000 1.418000 1.001163 5500

muA[5] 1.685310 0.222647 1.162000 1.553000 1.724000 1.861000 1.984000 1.000836 7500

muA[6] 0.946297 0.556670 0.051944 0.464025 0.926050 1.407000 1.937000 1.000857 7500

muA[7] 0.980034 0.547473 0.062113 0.522850 0.977350 1.421000 1.936000 1.004776 790

muA[8] 1.028011 0.569589 0.056124 0.549675 1.030000 1.511250 1.958000 1.001382 7500

**Ntot[1] 126.735863 8.685559 110.200000 120.800000 126.600000 132.600000 144.300000 1.000864 7500**

Ntot[2] 135.122403 10.976511 114.100000 127.500000 134.800000 142.500000 157.300000 1.001565 2600

Ntot[3] 125.184840 10.945968 104.600000 117.600000 124.800000 132.400000 147.652492 1.000871 7500

Ntot[4] 141.071653 11.746501 119.000000 133.000000 140.600000 148.900000 165.000000 1.001037 7500

Ntot[5] 116.289621 10.583965 96.468998 108.900000 116.100000 123.200000 138.000000 1.001030 7500

Ntot[6] 132.453492 11.341053 111.400000 124.700000 132.100000 139.700000 156.000000 1.000965 7500

Ntot[7] 113.664053 10.257192 93.914249 106.600000 113.400000 120.400000 134.500000 1.000914 7500

Ntot[8] 121.164961 10.826951 101.100000 113.500000 120.800000 128.400000 142.900000 1.001615 2500

**lambda[2] 1.070972 0.111656 0.865095 0.993275 1.067000 1.145000 1.303000 1.001490 2900**

lambda[3] 0.932482 0.110783 0.734495 0.854975 0.926550 1.002000 1.170000 1.001147 5700

lambda[4] 1.135308 0.135663 0.893895 1.040000 1.128000 1.222000 1.421525 1.000892 7500

lambda[5] 0.830037 0.102599 0.648047 0.757400 0.824200 0.894750 1.048525 1.000858 7500

lambda[6] 1.148321 0.142916 0.894500 1.048000 1.139000 1.236000 1.450525 1.001102 6600

lambda[7] 0.864240 0.106084 0.670695 0.790600 0.859500 0.929825 1.089000 1.000800 7500

lambda[8] 1.074566 0.135997 0.834947 0.977700 1.065000 1.159250 1.373000 1.001578 2600

**Ny[1] 75.714331 8.249433 59.520000 70.230000 75.690000 81.250000 91.725250 1.000824 7500**

Ny[2] 104.397057 13.862855 76.918997 95.227500 104.500000 113.600000 131.200000 1.001474 3000

Ny[3] 80.235568 15.333103 49.694248 69.950000 80.240000 90.630000 110.552489 1.001264 4300

Ny[4] 89.199128 15.584740 58.158997 79.137500 89.340000 99.440000 120.100000 1.000944 7500

Ny[5] 65.757093 16.450015 33.494750 54.620000 66.035000 77.140000 96.985250 1.001106 7500

Ny[6] 76.764266 23.119980 31.344750 60.917500 76.875000 93.092500 120.900000 1.002168 1500

Ny[7] 49.867252 23.121442 8.601494 32.494999 49.100000 66.342500 95.555749 1.003485 750

Ny[8] 59.493123 22.587966 17.864749 43.160000 58.915000 75.535000 103.852488 1.001164 5500

**Na[1] 51.020979 8.236268 35.080000 45.447500 51.000000 56.510000 67.455250 1.000973 7500**

Na[2] 30.725333 8.926813 15.000000 24.000000 30.000000 36.000000 50.000000 1.001124 6200

Na[3] 44.949600 10.869597 25.000000 37.000000 45.000000 52.000000 67.000000 1.001388 3400

Na[4] 51.872533 10.730438 33.000000 44.000000 51.000000 59.000000 75.000000 1.001168 5400

Na[5] 50.532667 12.709558 28.000000 42.000000 50.000000 59.000000 77.000000 1.001082 7100

Na[6] 55.689200 20.165658 19.000000 41.000000 55.000000 70.000000 95.000000 1.003200 840

Na[7] 63.796933 21.817815 22.000000 48.000000 64.000000 80.000000 104.000000 1.004539 540

Na[8] 61.671867 20.584581 23.000000 46.000000 62.000000 77.000000 100.000000 1.000812 7500

**R[2] 87.167867 25.720169 19.000000 76.000000 93.000000 105.000000 124.000000 1.003731 680**

R[3] 66.969733 22.357543 13.000000 55.000000 70.000000 82.000000 104.000000 1.002783 1100

R[4] 73.504800 24.341639 14.000000 60.000000 77.000000 90.000000 113.000000 1.004948 490

R[5] 54.933200 21.114764 8.000000 41.000000 56.000000 70.000000 92.000000 1.001385 3400

R[6] 62.710400 27.450772 8.000000 43.000000 64.000000 83.000000 114.000000 1.000880 7500

R[7] 40.246133 23.349778 3.000000 22.000000 38.000000 56.000000 89.000000 1.007527 300

R[8] 46.480800 23.876293 5.000000 29.000000 46.000000 63.000000 95.000000 1.001711 2200

**IM[2] 17.229126 24.010583 0.065179 0.853824 5.643999 24.122490 86.195250 1.004969 480**

IM[3] 13.265746 19.017090 0.060194 0.703075 4.189000 18.100000 68.933465 1.001438 3100

IM[4] 15.694334 21.542417 0.067057 0.817875 5.623993 22.254998 77.195749 1.002658 1100

IM[5] 10.823810 15.427514 0.057389 0.590575 3.697500 14.934997 55.355250 1.001238 4600

IM[6] 14.053574 20.258634 0.069505 0.708350 4.603000 19.240000 73.175748 1.001685 2300

IM[7] 9.621076 14.301035 0.053062 0.529600 3.083500 12.550000 52.273453 1.001661 2300

IM[8] 13.012464 17.883126 0.066818 0.755750 4.641000 18.917496 63.896245 1.001146 5800

**H[1] 0.257653 0.017768 0.225300 0.245175 0.256700 0.269025 0.294900 1.000865 7500**

H[2] 0.160176 0.013144 0.136700 0.150800 0.159500 0.168600 0.188452 1.001564 2600

H[3] 0.136846 0.012066 0.115147 0.128400 0.136200 0.144600 0.162552 1.000871 7500

H[4] 0.210573 0.017655 0.178747 0.198100 0.209800 0.221900 0.247952 1.001036 7500

H[5] 0.099717 0.009149 0.083335 0.093330 0.099070 0.105600 0.119200 1.001032 7500

deviance 236.384480 7.843285 222.800000 230.800000 235.700000 241.300000 253.700000 1.002081 1600

For each parameter, n.eff is a crude measure of effective sample size,

and Rhat is the potential scale reduction factor (at convergence, Rhat=1).

DIC info (using the rule, pD = var(deviance)/2)

pD = 30.7 and DIC = 267.1

DIC is an estimate of expected predictive error (lower deviance is better).

**Fig:** Posterior means (with 95% CRI) of the demographic parameters (Population size and age-specific survival) in a red fox population in NW France under a population model with random year effects for all demographic rates. Points show the mean and vertical segments the 95% CRI of the mean hyperparameters.





**Fig:** Posterior means (with 95% CRI) of the demographic parameters (age-specific Fecondity, immigration and growth rate) in a red fox population in NW France under a population model with random year effects for all demographic rates. Points show the mean and vertical segments the 95% CRI of the mean hyperparameters.



**Fig.:** Estimates of annual demographic rates plotted against the estimates of interannual population growth. Black dots show posterior means and grey lines 95% CRI. Inset we print the posterior mode of the correlation coefficients (r, with 95% CRI) and the probability of a positive correlation (P(r>0)).



**Fig.:** Estimates of annual demographic rates plotted against the estimates of interannual population growth. Black dots show posterior means and grey lines 95% CRI. Inset we print the posterior mode of the correlation coefficients (r, with 95% CRI) and the probability of a positive correlation (P(r>0)). Above: analysis for overall period; below: analysis for 2002-2005



Interpretation

##########################################################################

# Integrated population model for the red fox population in Fougères

#

# Age structured, female-based model (2 age classes-1-year)

# Pre-breeding census

#

# Combination of:

# - Distance sampling census (2003-2007+2010): --> state-space model

# - productivity for harvest data (2003-2007): --> Poisson regression

# - age-at-harvest data from trapping and hunting (2003-2007) --> yearling and adult survival:

# Model by Udevitz & Gonan (2012)

#

### IPM along the overall period (2003 to 2010): TotalRedFoxDIPM.R

**mean sd 2.5% 25% 50% 75% 97.5% Rhat n.eff**

**Sj[1] 0.536450 0.172580 0.119890 0.442800 0.547400 0.647100 0.851652 1.001128 6100**

Sj[2] 0.595178 0.182795 0.155400 0.493700 0.606100 0.717350 0.923452 1.000877 7500

Sj[3] 0.457601 0.171602 0.064445 0.363400 0.467200 0.570725 0.780252 1.022041 260

Sj[4] 0.439406 0.159262 0.062770 0.355575 0.460100 0.546150 0.708605 1.009278 620

Sj[5] 0.522588 0.263741 0.052149 0.312650 0.523800 0.742000 0.969300 1.011212 300

Sj[6] 0.469630 0.281861 0.029062 0.220200 0.458250 0.702775 0.965257 1.017067 150

Sj[7] 0.457728 0.281866 0.025324 0.212450 0.432750 0.690125 0.968310 1.011620 250

**Sy[1] 0.234104 0.045153 0.151000 0.202700 0.231700 0.263700 0.325900 1.000877 7500**

Sy[2] 0.223443 0.054118 0.125547 0.184800 0.221250 0.258000 0.335400 1.000861 7500

Sy[3] 0.249727 0.045267 0.166100 0.218200 0.247600 0.278800 0.344400 1.000964 7500

Sy[4] 0.357169 0.072783 0.223195 0.305700 0.355500 0.406300 0.502657 1.001173 5300

Sy[5] 0.404112 0.228589 0.021399 0.208975 0.406000 0.602125 0.779700 1.003168 7500

Sy[6] 0.406756 0.224229 0.024909 0.219075 0.404500 0.597000 0.780200 1.002634 1100

Sy[7] 0.389613 0.228089 0.018920 0.193050 0.387550 0.584725 0.775700 1.002883 980

**Sa[1] 0.451119 0.066390 0.319295 0.405400 0.451150 0.496000 0.582952 1.001215 4800**

Sa[2] 0.571126 0.091041 0.388400 0.508575 0.573750 0.634200 0.743452 1.000988 7500

Sa[3] 0.383555 0.078458 0.240500 0.326900 0.379650 0.436700 0.542952 1.001312 3900

Sa[4] 0.749347 0.100077 0.533827 0.685000 0.759900 0.820800 0.916105 1.000817 7500

Sa[5] 0.595304 0.228433 0.219000 0.400300 0.593200 0.789325 0.976457 1.005114 470

Sa[6] 0.606398 0.227286 0.221647 0.415500 0.609500 0.802625 0.979405 1.001305 4000

Sa[7] 0.608240 0.232451 0.222990 0.405000 0.613650 0.811900 0.981100 1.007662 290

**im[1] 0.156234 0.247962 0.000002 0.005097 0.039665 0.193450 0.898987 1.000869 7500**

im[2] 0.195064 0.306377 0.000003 0.006351 0.048765 0.246850 1.110525 1.002882 5800

im[3] 0.181344 0.284023 0.000005 0.005569 0.043365 0.221850 1.003525 1.010239 580

im[4] 0.140006 0.208796 0.000005 0.004459 0.034700 0.188725 0.734115 1.001081 7100

im[5] 0.269794 0.507650 0.000006 0.005644 0.054030 0.289275 1.934525 1.004794 990

im[6] 0.211592 0.425518 0.000004 0.004240 0.034825 0.212525 1.523099 1.002012 1700

im[7] 0.250601 0.524849 0.000003 0.004945 0.041870 0.236050 1.862148 1.005634 790

im[8] 0.184319 0.584693 0.000000 0.000001 0.001107 0.067522 1.778147 1.001411 7500

**pY[1] 0.579152 0.089483 0.399247 0.517800 0.581200 0.642425 0.747452 1.000869 7500**

pY[2] 0.530761 0.095670 0.344637 0.464575 0.531650 0.596950 0.717852 1.000832 7500

pY[3] 0.651775 0.119568 0.404990 0.569100 0.658850 0.739125 0.863605 1.001104 6500

pY[4] 0.957142 0.040682 0.847990 0.939500 0.969350 0.987300 0.998800 1.000913 7500

pY[5] 0.958363 0.040437 0.849947 0.942600 0.970800 0.987500 0.998900 1.000896 7500

pY[6] 0.476938 0.284827 0.024939 0.228650 0.465900 0.717750 0.969957 1.001412 3300

pY[7] 0.481288 0.287758 0.025084 0.226725 0.470800 0.729300 0.972700 1.002160 1500

pY[8] 0.496244 0.290658 0.024274 0.237200 0.497650 0.752650 0.973352 1.000978 7500

**pA[1] 0.592375 0.062264 0.504200 0.542500 0.583300 0.633400 0.732352 1.002231 1400**

pA[2] 0.592180 0.062626 0.504447 0.541800 0.582400 0.632925 0.735400 1.001102 6600

pA[3] 0.612174 0.078361 0.504300 0.548800 0.598650 0.664525 0.785852 1.001376 3500

pA[4] 0.616103 0.072461 0.506500 0.558600 0.607400 0.665600 0.772900 1.000943 7500

pA[5] 0.557044 0.046765 0.502200 0.519700 0.545050 0.583500 0.671705 1.000966 7500

pA[6] 0.747497 0.142806 0.512000 0.624400 0.747950 0.867225 0.985100 1.001010 7500

pA[7] 0.748725 0.145250 0.512547 0.624700 0.746600 0.874700 0.989700 1.001131 6000

pA[8] 0.751693 0.144691 0.512447 0.626575 0.749650 0.880200 0.987957 1.001267 4300

**muY[1] 1.178591 0.138859 0.900700 1.087000 1.180000 1.273000 1.442000 1.000816 7500**

muY[2] 1.428047 0.131750 1.166475 1.339000 1.429000 1.516000 1.682000 1.000928 7500

muY[3] 1.462749 0.161077 1.133475 1.355000 1.467000 1.572000 1.768525 1.000917 7500

muY[4] 1.097985 0.120453 0.856195 1.017000 1.100000 1.180000 1.325000 1.000904 7500

muY[5] 1.077449 0.123567 0.824442 0.996275 1.079000 1.162000 1.315000 1.001104 6500

muY[6] 0.999127 0.570370 0.053248 0.511000 1.007500 1.486000 1.945000 1.001165 5500

muY[7] 1.008042 0.567235 0.054079 0.527575 1.012000 1.486250 1.944000 1.001202 5000

muY[8] 1.023873 0.564097 0.055065 0.560475 1.036000 1.507250 1.954000 1.001637 3500

**muA[1] 1.480550 0.122383 1.233000 1.400000 1.484000 1.564000 1.712000 1.000803 7500**

muA[2] 1.535283 0.126831 1.273475 1.449000 1.540000 1.623000 1.777000 1.001009 7500

muA[3] 1.496225 0.176539 1.131000 1.382000 1.501000 1.621000 1.824000 1.001220 4700

muA[4] 1.294885 0.144379 1.007000 1.199000 1.295000 1.393000 1.570000 1.001004 7500

muA[5] 1.122598 0.188037 0.735647 0.999000 1.126500 1.253000 1.476000 1.001039 7500

muA[6] 1.044212 0.562896 0.061780 0.569950 1.062000 1.525000 1.951000 1.000864 7500

muA[7] 1.014802 0.564924 0.063822 0.529775 1.024000 1.496000 1.943000 1.009898 260

muA[8] 1.043921 0.561601 0.059129 0.580750 1.062500 1.518000 1.949000 1.000910 7500

**Ntot[1] 268.459373 10.796955 247.500000 261.100000 268.400000 276.100000 289.100000 1.000871 7500**

Ntot[2] 264.123947 15.944713 233.747495 253.200000 264.000000 274.600000 296.052496 1.000896 7500

Ntot[3] 300.695640 17.269790 268.000000 288.900000 300.400000 312.100000 335.152496 1.000941 7500

Ntot[4] 307.291253 17.428309 274.247495 295.100000 307.100000 319.200000 342.152496 1.001025 7500

Ntot[5] 360.252587 18.959209 323.800000 347.300000 359.849997 373.200000 397.252497 1.001303 4000

Ntot[6] 475.104341 187.724940 197.137342 348.000000 451.349997 567.524998 948.016541 1.006977 330

Ntot[7] 451.368947 185.452577 185.294973 315.400000 422.300000 551.924998 903.072388 1.004579 600

Ntot[8] 413.292773 20.354300 374.347497 399.474998 413.000000 426.900000 453.452497 1.000994 7500

**lambda[2] 0.985446 0.071623 0.853400 0.936375 0.981700 1.032000 1.133525 1.000829 7500**

lambda[3] 1.142653 0.095818 0.967542 1.076000 1.139000 1.204000 1.343000 1.000914 7500

lambda[4] 1.025297 0.082738 0.872895 0.967100 1.022000 1.080000 1.196525 1.000918 7500

lambda[5] 1.176078 0.090541 1.010000 1.113000 1.172000 1.234000 1.361525 1.000831 7500

lambda[6] 1.319581 0.518364 0.546047 0.969300 1.260000 1.573000 2.670525 1.007294 310

lambda[7] 1.032360 0.460170 0.398595 0.715300 0.936450 1.252250 2.152000 1.014295 150

lambda[8] 1.079102 0.471635 0.457500 0.751100 0.977200 1.308000 2.215574 1.004653 630

**Ny[1] 159.378107 8.831968 141.900000 153.500000 159.400000 165.400000 176.400000 1.000833 7500**

Ny[2] 177.765800 20.772702 137.500000 163.800000 177.900000 191.600000 219.000000 1.000809 7500

Ny[3] 211.549507 22.909594 166.700000 196.300000 211.600000 226.800000 256.352495 1.000829 7500

Ny[4] 220.402973 23.025775 174.900000 204.700000 220.300000 236.200000 265.200000 1.000895 7500

Ny[5] 216.453653 28.569661 159.900000 197.300000 216.849994 236.200000 271.652495 1.000886 7500

Ny[6] 302.289437 184.644923 40.348489 176.249979 276.649995 389.500000 782.663923 1.008223 310

Ny[7] 229.598025 170.827484 18.519453 104.674991 189.149993 316.349988 651.319877 1.002595 1100

Ny[8] 198.480938 86.780530 30.293740 134.000000 203.300000 265.124996 351.604986 1.016450 220

**Na[1] 109.081421 8.897046 91.670000 103.200000 109.100000 115.100000 126.552490 1.000871 7500**

Na[2] 86.358133 13.409250 61.000000 77.000000 86.000000 95.000000 113.000000 1.000981 7500

Na[3] 89.146133 15.513996 60.000000 78.000000 89.000000 100.000000 121.000000 1.000947 7500

Na[4] 86.888267 14.879354 59.000000 77.000000 86.000000 96.000000 118.000000 1.001557 2600

Na[5] 143.798933 21.699584 103.000000 129.000000 143.000000 158.000000 188.000000 1.000859 7500

Na[6] 172.815867 60.537915 61.000000 129.000000 172.000000 217.000000 289.000000 1.003294 1500

Na[7] 221.770800 99.293175 65.473097 150.000000 208.000000 284.000000 448.524722 1.003161 850

Na[8] 214.812000 86.359930 67.000000 148.000000 209.000000 280.000000 383.000000 1.012435 180

**R[2] 153.532933 41.941582 36.000000 138.000000 163.000000 181.000000 212.000000 1.001032 7500**

R[3] 183.854933 47.307378 52.000000 167.000000 194.000000 215.000000 247.000000 1.000958 7500

R[4] 186.108933 56.854165 26.000000 168.000000 202.000000 223.000000 257.000000 1.019502 190

R[5] 179.653733 59.290210 26.000000 155.000000 193.000000 220.000000 263.000000 1.006065 810

R[6] 225.218400 118.833628 21.000000 133.000000 220.000000 315.000000 457.000000 1.005281 450

R[7] 182.798400 145.756447 9.000000 72.000000 146.000000 253.000000 555.000000 1.013393 260

R[8] 154.066000 87.135826 10.000000 84.000000 149.000000 219.000000 325.000000 1.001311 3900

**IM[2] 24.232660 37.809530 0.066041 0.866000 6.110999 30.302500 141.752491 1.001001 7500**

IM[3] 27.695046 42.864508 0.058655 0.937700 7.071998 35.782500 158.509874 1.000878 7500

IM[4] 34.293846 52.833544 0.083658 1.111500 8.086000 42.612463 189.452493 1.005273 450

IM[5] 36.800027 54.493084 0.081408 1.220750 9.342500 50.220000 192.857442 1.001152 5700

IM[6] 77.071401 144.638224 0.091791 1.600000 15.579997 82.242500 547.053897 1.004465 550

IM[7] 46.799612 90.572798 0.075983 1.073500 8.265500 51.069997 298.300000 1.003086 880

IM[8] 44.414659 68.771574 0.075229 1.365750 10.894999 56.834999 250.509920 1.003986 630

**H[1] 0.212668 0.008585 0.197100 0.206500 0.212300 0.218300 0.230300 1.000870 7500**

H[2] 0.258397 0.015651 0.229647 0.247675 0.257600 0.268600 0.290952 1.000896 7500

H[3] 0.156821 0.009031 0.140247 0.150600 0.156500 0.162700 0.175400 1.000939 7500

H[4] 0.200782 0.011426 0.179700 0.192700 0.200200 0.208400 0.224252 1.001025 7500

H[5] 0.090466 0.004785 0.081810 0.087090 0.090320 0.093580 0.100400 1.001302 4000

deviance 256.483067 8.013329 242.500000 250.700000 255.900000 261.500000 273.800000 1.001094 6800

For each parameter, n.eff is a crude measure of effective sample size,

and Rhat is the potential scale reduction factor (at convergence, Rhat=1).

DIC info (using the rule, pD = var(deviance)/2)

pD = 32.1 and DIC = 288.6

DIC is an estimate of expected predictive error (lower deviance is better).

**Fig:** Posterior means (with 95% CRI) of the demographic parameters (Population size and age-specific survival) in a red fox population in NW France under a population model with random year effects for all demographic rates. Points show the mean and vertical segments the 95% CRI of the mean hyperparameters.





**Fig:** Posterior means (with 95% CRI) of the demographic parameters (age-specific Fecondity, immigration and growth rate) in a red fox population in NW France under a population model with random year effects for all demographic rates. Points show the mean and vertical segments the 95% CRI of the mean hyperparameters.



**Fig.:** Estimates of annual demographic rates plotted against the estimates of interannual population growth. Black dots show posterior means and grey lines 95% CRI. Inset we print the posterior mode of the correlation coefficients (r, with 95% CRI) and the probability of a positive correlation (P(r>0)).



**Fig.:** Estimates of annual demographic rates plotted against the estimates of interannual population growth. Black dots show posterior means and grey lines 95% CRI. Inset we print the posterior mode of the correlation coefficients (r, with 95% CRI) and the probability of a positive correlation (P(r>0)). Above: analysis for overall period; below: analysis for 2002-2005



Summary table

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **GIC** | **Year** | **Sj** | **Sy** | **Sa** | **im** | **pY** | **pA** | **fecY** | **fecA** |
| **D** | **2002** | **0.4636125** | **0.2521610** | **0.4164802** | **0.2143891** | **0.4706595** | **0.8873801** | **3.939299** | **5.186680** |
| D | 2003 | 0.6606178 | 0.3264566 | 0.5104152 | 0.1699829 | 0.5884767 | 0.5252595 | 2.947509 | 3.684343 |
| D | 2004 | 0.4047206 | 0.2415956 | 0.5897623 | 0.1402177 | 0.6883787 | 0.6928755 | 3.875806 | 4.665356 |
| D | 2005 | 0.3571696 | 0.3309688 | 0.5364291 | 0.1388282 | 0.6107920 | 0.8341139 | 4.125142 | 4.734238 |
| D | 2006 | NA | NA | NA | 0.1400929 | 0.6888630 | 0.9662345 | 2.787931 | 4.223617 |
| **V** | **2003** | **0.6252266** | **0.1633241** | **0.3473483** | **0.2535801** | **0.6695817** | **0.5480490** | **3.117371** | **3.640461** |
| V | 2004 | 0.5436523 | 0.2742462 | 0.5121695 | 0.2379391 | 0.3191625 | 0.6421712 | 5.453035 | 4.391900 |
| V | 2005 | 0.6244030 | 0.4892750 | 0.3201555 | 0.2563167 | 0.2277672 | 0.8175980 | 2.755122 | 5.525240 |
| V | 2006 | 0.3678522 | 0.3674505 | 0.3195948 | 0.1296423 | 0.7270453 | 0.6055420 | 3.479449 | 2.538592 |
| V | 2007 | NA | NA | NA | 0.1449328 | 0.8599263 | 0.5966357 | 3.337410 | 5.474942 |
| **F** | **2003** | **0.4856728** | **0.2372073** | **0.4568778** | **0.1346870** | **0.5821712** | **0.5912368** | **3.221863** | **4.419206** |
| F | 2004 | 0.6115053 | 0.2264062 | 0.5820457 | 0.1517302 | 0.5394387 | 0.5900650 | 4.185669 | 4.633125 |
| F | 2005 | 0.4570452 | 0.2552852 | 0.3918928 | 0.1810821 | 0.6539492 | 0.6065415 | 4.357939 | 4.468970 |
| F | 2006 | 0.4383263 | 0.3467158 | 0.7354677 | 0.1090562 | 0.9564667 | 0.6170313 | 3.002548 | 3.643258 |
| F | 2007 | NA | NA | NA | 0.1253061 | 0.9580478 | 0.5588045 | 2.923550 | 3.047383 |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **GIC** | **Year** | **Ntot** | **lambda** | **Ny** | **Na** | **R** | **IM** | **H** |
| **D** | **2002** | **164.62730** | **1.0884774** | **105.29583** | **59.33132** | **NA** | **NA** | **0.6156350** |
| D | 2003 | 178.58777 | 1.0573484 | 127.42377 | 51.16415 | 103.07873 | 17.19199 | 0.5178065 |
| D | 2004 | 187.88459 | 1.0297782 | 120.27111 | 67.61307 | 105.98325 | 17.66278 | 0.5212951 |
| D | 2005 | 192.60536 | 1.0295054 | 123.64533 | 68.95980 | 101.45729 | 18.05279 | 0.4618898 |
| D | 2006 | 197.26064 | 1.2559085 | 119.51015 | 77.75042 | 132.48911 | 21.92336 | 0.4228188 |
| **V** | **2003** | **110.03233** | **1.0372143** | **65.01743** | **45.01393** | **NA** | **NA** | **0.2953782** |
| V | 2004 | 114.12263 | 0.9194735 | 87.81885 | 26.30500 | 56.39167 | 9.91120 | 0.1900205 |
| V | 2005 | 104.00762 | 1.1737332 | 66.30285 | 37.70500 | 65.07333 | 10.67361 | 0.1650705 |
| V | 2006 | 120.88663 | 0.8169568 | 75.74730 | 45.14000 | 45.58500 | 10.28663 | 0.2457822 |
| V | 2007 | 98.05192 | 1.1834093 | 55.87178 | 42.18000 | 56.93667 | 10.49733 | 0.1182879 |
| **F** | **2003** | **252.48617** | **0.9222670** | **151.62000** | **100.86450** | **NA** | **NA** | **0.2261518** |
| F | 2004 | 232.45417 | 1.1693548 | 150.94077 | 81.51333 | 169.32833 | 19.23394 | 0.2935802 |
| F | 2005 | 270.80283 | 1.0344130 | 188.56117 | 82.24167 | 168.07667 | 30.93477 | 0.1741738 |
| F | 2006 | 279.12233 | 1.1352660 | 199.01067 | 80.11167 | 161.78000 | 26.16153 | 0.2210355 |
| F | 2007 | 315.80050 | 1.1073337 | 187.94050 | 127.86000 | 170.19167 | 31.47375 | 0.1032381 |