Dynamics Model Testing

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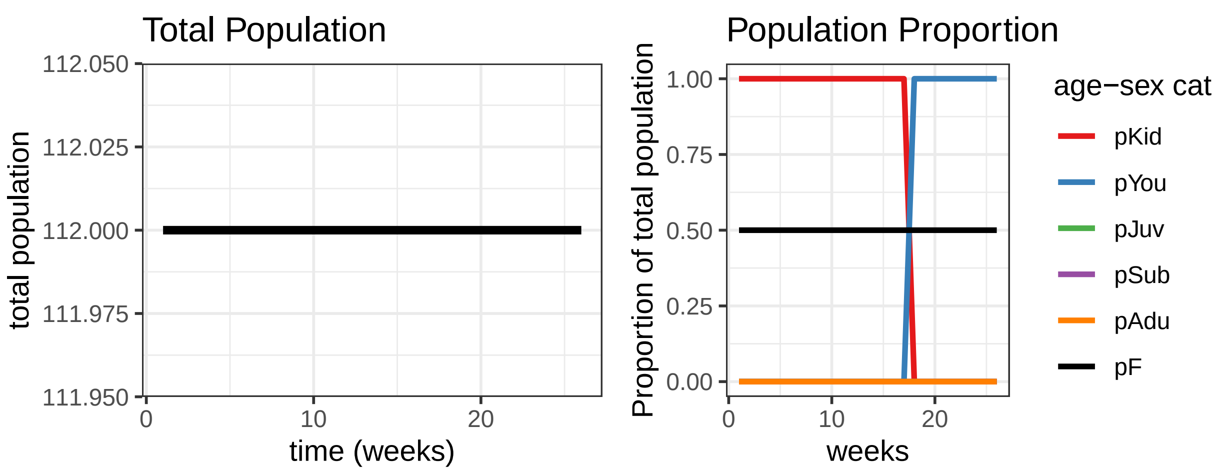
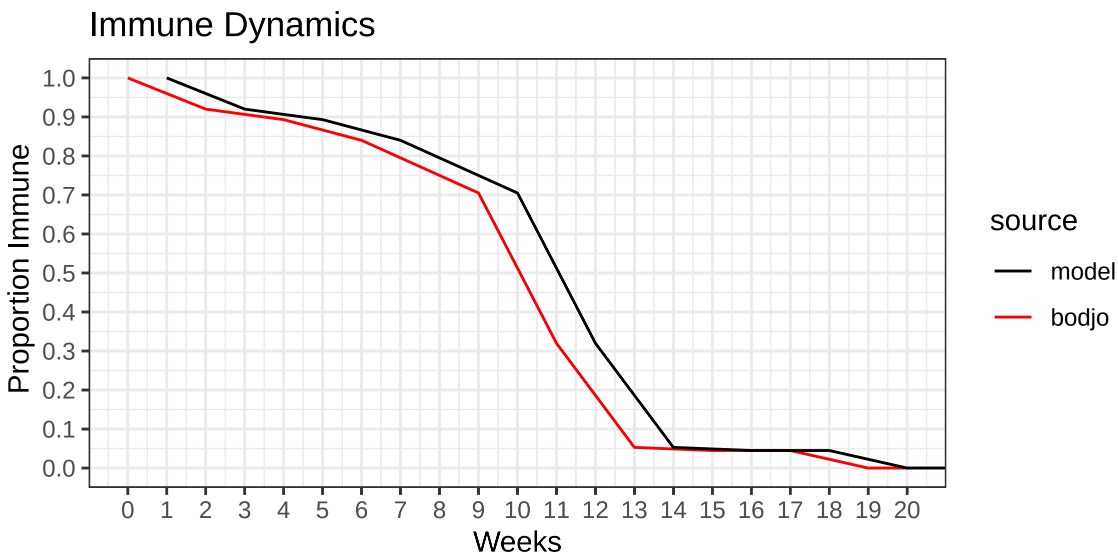
Maternal Immunity

- Check implementation of maternal immunity decay by comparing model output to empirical data (from Bodjo *et al*)
- Run model with conditions to replicate Bodjo *et al*
- Bodjo *et al* tested the duration of maternal immunity in 112 lambs up to 150 days after birth, born to ewes vaccinated with the homologous PPR vaccine "Nigeria 75/1" at day 90 and day 120 of pregnancy.
- Parameters:
  - set 112 lambs to immune offspring compartment
  - set rest of population to 0
  - set mortality, offtake, and all demographic rates (except maternal immune decay) to 0
  - set M:F ratio to 1:1
  - plot proportion immune for first 6 months of simulation
  - plot should mirror the immune decay from Bodjo raw data.



Maternal Immunity Interpretation

- The population remains constants at 112 animals for the duration of the simulation
- All animals begin in the `pKid` compartment, and move into the `pYou` compartment at week 18



Maternal Immunity Interpretation

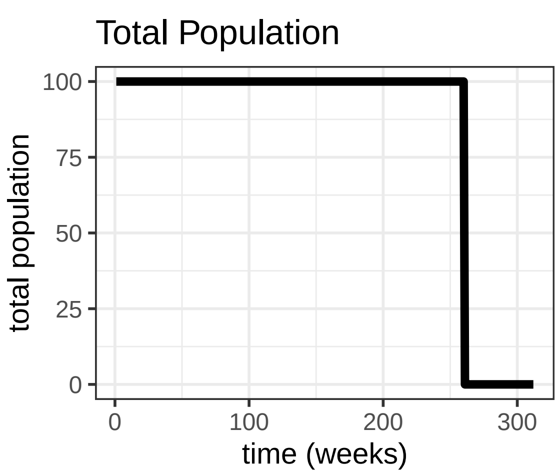
- The model exactly replicates immune decay from Bodjo data
- The apparent 1 week lapse is because the model starts at week 1 with 100% offspring in the immune compartment

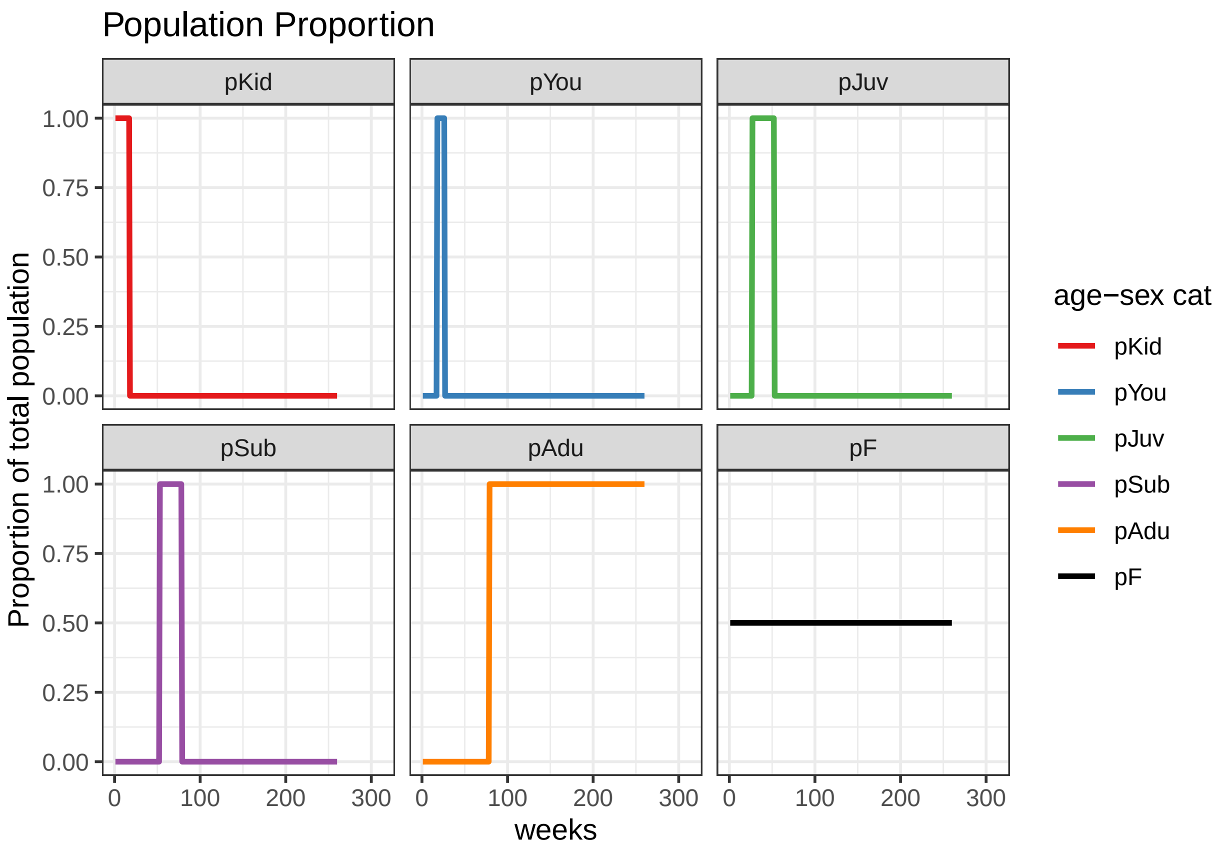
Demographic Processes: Basic Model

1) Do animals move through age compartments as expected?

- Parameters:
  - Set the population to 100 animals
  - Assign all animals to S1 age group (first age-group, susceptible offspring)
  - Set all demographic parameters (births, deaths, intake, offtake, maternal immunity) to 0
  - Set the max life-span of males and females to 5years
  - Set M:F ratio as 1:1
  - Animals should move through age compartments uniformly, at 5 years population will die out.

NB: NaN values due to dividing by 0 when population dies out (fix this in `demos_summary.R`)





Basic Model Interpretation

- The population remains constant up to 5 years (week 260)
- Animals move through discrete age groups uniformly as expected

Mortality

2) Check that model with mortality functions as expected i.e. should be able to analytically solve population decline?

- Parameters:
  - Set the population to 100 animals
  - Assign all animals to S1 age group (first age-group, susceptible offspring)
  - Set **mortality rate** to 0.01 per week
  - Set all other demographic parameters (births, intake, offtake, maternal immunity) to 0
  - Set the max life-span of males and females to 5years
  - Set M:F ratio as 1:1
  - Animals should move through age groups, with constant mortality rate, until 5 years

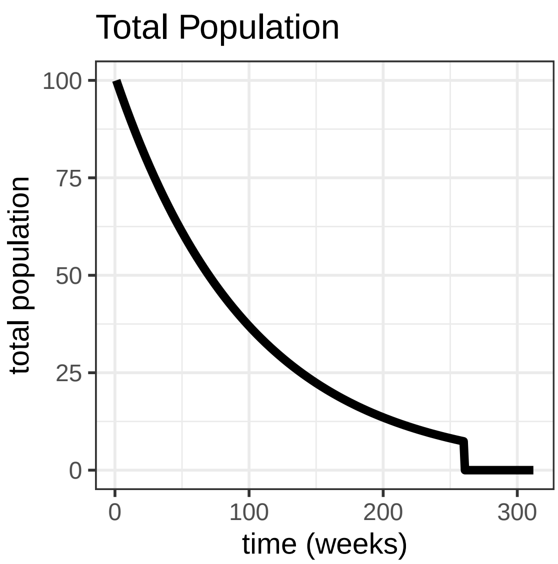
Test validation: what is the gradient of the curve?

- *Limited time to run tests so this is basic validation...*
- Briefly:
  - The mortality rate is 0.01/week in all age groups
  - Therefore survival is 0.99/week
  - Given survival we can calculate the expected population size after e.g. 1year, 5 years, and compare this to model output.
  - Expected 1 year survival $= 0.99^{52} = 0.59$
  - Expected 5 year survival $= 0.99^{(52*5)} = 0.07$

  - Compare these figures to model output (`output_df`) below…
  - *Calculate gradient of the curve..?*

- Model population output:

weeks	Population
53	59.3
260	7.4



Mortality Interpretation

- Model output for population size at years 1 (N = 59.3) and year 5 (N = 7.4) equal to expected population size based on mortality of 0.01 (survival of 0.99)

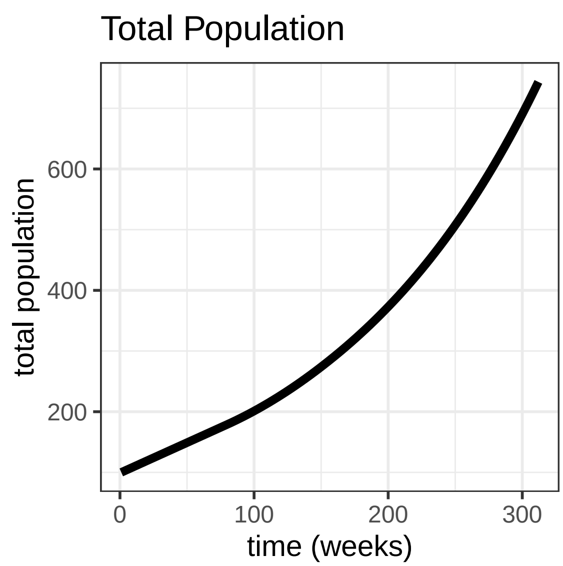
Further Tests - to be completed

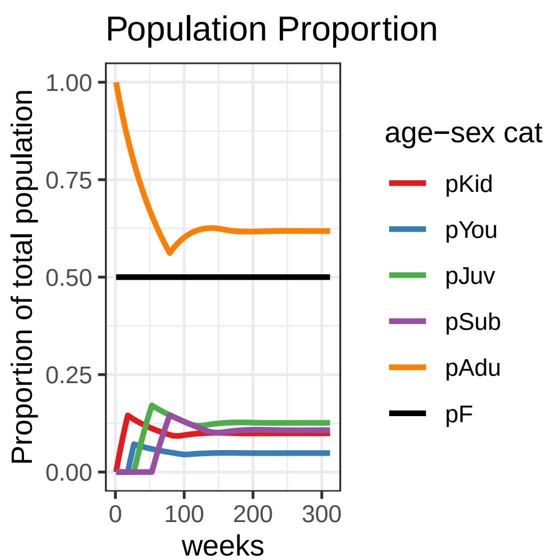
Births

3) Check model function with birth rate - slightly tricky as rate is per adult F

- Parameters:
  - Set the population to 100 animals
  - Assign all animals to S59 - first adult age category, 50:50 M:F
  - Set **birth rate** to 0.02 per week (2*0.01, pop birth rate of 0.01, f birth rate of 0.02)
  - Set all other demographic parameters (deaths, intake, offtake, maternal immunity) to 0
  - Set the max life-span of males and females to 10 years
  - Set M:F ratio as 1:1
  - Expect exponential growth, initially with rate of 0.01 (for population), this will change as young reach maturity

Test validation: what is the gradient of the curve?





Birth Interpretation

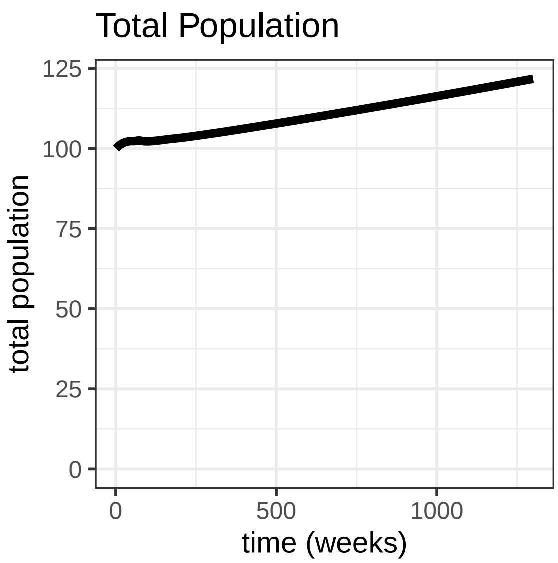
- How do I calculate overall birth rate, especially given that my input parameter is the adult female birth rate
- For timesteps 1-78 there should be a constant population growth:
  - the adult female population remains constant at 50 individuals (as all start in 1st adult age cat + no mortality)
  - the birth rate remains constant at 0.02
  - At each timestep rN_f new offspring are born (r is birth rate per adult female - 0.02 - and N_f is the female population - 50 -)
  - For timesteps 1-71 (i.e. 70 timesteps): $B = t(rN_f) = 70 * (0.02 * 50)$, hence $B = 70$
  - Expect 70 new births, with initial population of 100, population at timestep 71 should be 170, as below
- beyond timestep 78 this becomes more confusing since new animals start to join the Adu_F age cat + reproduce

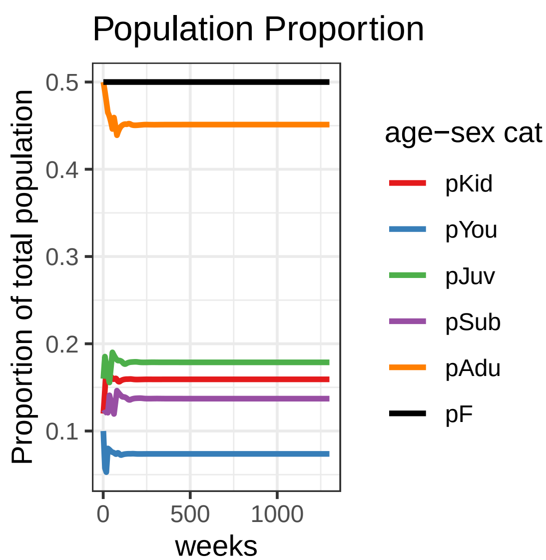
w	sum_pop
1	100
71	170

Births-Deaths Test: Stable Population

4) Attempt to find conditions under which population is stable (this is the closest I managed)

- Parameters:
  - Set the population to 100 animals
  - Proportion of animals in each age cat - defined based on stable state output of this simulation:
    - Kid: 0.1592371, You:0.07376386, Juv: 0.1787116, Sub: 0.1370716, Adu: 0.4512159
  - **Mortality Rate** set at 0.01 for all animals (Young + Adult)
  - Attempted to match this defining **Birth Rate** for adult females at 0.02 initially
    - through trial and error **Birth Rate** of 0.045 gave the below result…
  - All other demographic parameters (intake, offtake, maternal immunity) set to 0
  - Set the max life-span of males and females to 50 years
    - Obviously unrealistic but meant I avoided contending with slaughter of all animals at max_age and could observe population trend over longer simulation time.
  - Set M:F ratio as 1:1
  - See test_parameters.csv : births_deaths for details
  - *Attempt to find a solution where the population is stable*





Births - Deaths Interpretation

Crude validation:

- Given death rate of 0.01 for all age groups
- Mature female birth rate of 0.045
- To get a fixed population size of which the above is an approximation we need an overall birth rate of 0.01
- Here we have a pop of 100…
- The proportion in each age group is stable at:
  - Kid: 0.1592371 You:0.07376386 Juv: 0.1787116 Sub: 0.1370716 Adu: 0.4512159
- Hence the adult female proportion is: adu_f ~ 0.225
- To calculate overall birth rate from female birth rate:
  - $B_{total} = (B_f * p_{aduF} N) /N = B_f \; p_{aduF}$
- So:
  - $B_{total} = 0.045 * 0.225 = 0.010125$ approx equal to the birth rate of 0.01
- *Reversing this: given population birth rate and stable age-sex structure (p_{aduF}):*
  - $B_{total} / p_{aduF} = B_f$.
- **Whilst this is not a tidy proof it satisfies me that a constant population size can be**

approximated if the birth and death rates are equal

Population Size

Population Structure

BAOBAB data

- Test model using demographic rates from (simple) BAOBAB dataset
- Parameters calculated from data supplied by Andrea from Louga & Kolda (Senegal) Sheep & Goats
- Here use Kolga Goats data
  - Data provided as monthly rates
  - For testing calculate median monthly rates
  - Convert to weekly rate by dividing median monthly rate by 4.345 (av. wk/mnth)
  - See `'~/OneDrive - Royal Veterinary College/PPR Collaborations/Data Bank/Baobab_data (Apr2021)/look-at-data.R'` for details
- Parameters:
  - mortality: 0.00537 (constant for all youth, adult, m, f)
  - births: 0.023 (adult F only)
  - intake: 0.0121
  - offtake: 0.0121
  - NET offtake: 0
  - Population: 100
  - M:F ratio (0.25:0.75)
  - Population proportions:
    * `Kid` (0.05),
    * `You` (0.05),
    * `Juv` (0.2),
    * `Sub_M` (0.05), `Sub_F` (0.15),
    * `Adu_M` (0.05), `Adu_F` (0.45)
- *NB: data for population size, M:F ratio and population proportions are estimates, not provided in Baobab dataset*