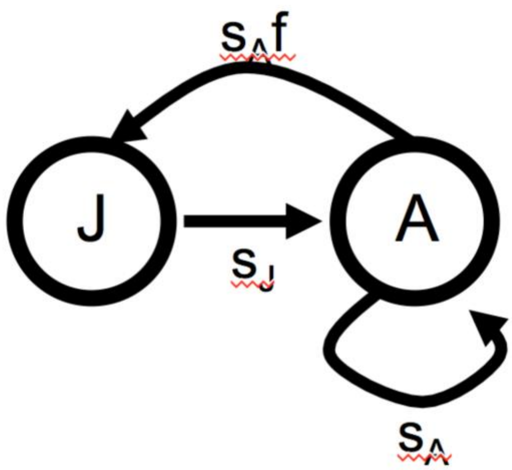
**EEB 319 Lab – Stage Structured Population Dynamics**
**Due: Beginning of Lab on Thurs Nov 16, 2017**

Materials to hand in: One paper copy of your lab report with plots and text answers to the questions in the assignment.

Marking: Each question is worth 10 marks, for a total of 100 marks.

Part 1. Consider a species of marine invertebrate that has a life-history that consists of non-breeding juveniles in the first year of life and then breeding adults that can reproduce annually and live for many years. A stage-structured population model for the species can be represented by the life-history graph




where the variable J is the abundance of juveniles, A is the abundance of adults, and the arrows represent annual transitions in the abundance of life-history stages due to survival and reproduction. The parameters $s_J$ and $s_A$ represent the annual survival of juveniles and adults respectively. The parameter f represents the number of juveniles produced per adult per year.

1. Write down the two equations for $J_{t+1}$ and $A_{t+1}$ that come from the life-history graph.

2. Write down the population projection matrix.

3. List three assumptions of the stage-structured model.

4. Assume that there is an initial small colonizing population of 10 juveniles and zero adults at time t=0 and that the species has life-history parameters $s_J$ = 0.1, $s_A$ = 0.8, and f = 3.5. In Excel, simulate the model to get a prediction for the growth of the population from the initial population size until time t=40. Create a single plot of two lines that represent juvenile and adult abundance versus time. Remember to label your axes and use a legend to identify which line is adults and which line is juveniles. Hint: create three columns in Excel where one is for time, one is for juveniles, and one is for adults.

5. From your simulation in (4) you should notice that the lines smooth out after several time steps into a familiar form of geometric population growth. Calculate the geometric population growth rate, λ, for adults and juveniles at time t = 20, t=30, and t=40 according to the formula $\lambda = N_t / N_{t-1}$. What is the value of λ for adults and juveniles at these time points? Do they differ?

6. From your simulation in (4) calculate the proportion of the population that are juveniles and adults at times t = 20, t=30, and t=40. Do they differ through time?

7. Your answers to (5) and (6) give two key properties of the stage-structured population that the population growth in each stage converges to a constant value and so too does the proportion of the population in each stage. These two characteristics are referred to as the dominant eigenvalue and associated right eigenvector of the population projection matrix. To understand these further, create a plot of your simulation in the phase plane with $A_t$ on the y axis and $J_t$ on the x axis. Use round symbols connected by lines, and label on the graph the points t=0 and t=40. What pattern do you see and how does it relate to the eigenvalue and eigenvector?

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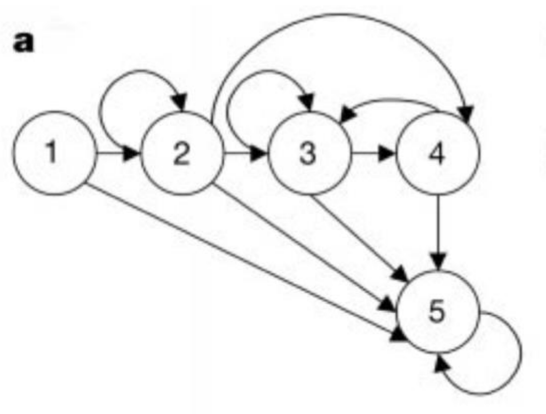
Part 2. The population dynamics of the critical endangered northern right whale was studied by Fujiwara and Caswell (*Nature*, 2001). The life-history graph is




where the numbers represent different stages: 1, calf; 2, immature female; 3, mature female; 4, mature females with newborn calves (mothers); 5, dead.

The fecundity terms are not yet shown, but the population projection matrix that represents the life-history graph is

$$\begin{pmatrix} 0 & F_2 & F_3 & 0 \\ p_{21} & p_{22} & 0 & 0 \\ 0 & p_{32} & p_{33} & p_{34} \\ 0 & p_{42} & p_{43} & 0 \end{pmatrix}$$

(we don't need to explicitly model dead whales as a fifth stage). The parameter values are:

$p_{21}$=0.92, $p_{22}$=0.86,
$p_{32}$=0.08, $p_{33}$=0.8, $p_{34}$=0.75,
$p_{42}$=0.02, $p_{43}$=0.19.

The equations for the fecundity terms that Fujiwara and Caswell use involve assumptions on the sex ratio and dependence of the calf on survival of her mother:

$$F_2 = 0.5 \times p_{42} \times p_{34}^{0.5}$$

and

$$F_3 = 0.5 \times p_{43} \times p_{34}^{0.5}$$

which reflects the assumptions of a 50% sex ratio, there is only one calf per mother, and the calf survives to independence due to the mother surviving gestation ($p_{42}$ and

$p_{43}$, respectively) and that the calf is dependent on the mother's survival for half of its first year of life ( the $p_{34}^{0.5}$ term; this is the square root of $p_{34}$).

8. Using the symbols in the population project matrix and $n_1$, $n_2$, $n_3$, and $n_4$ for the four life-history stages, write down the four equations for the abundance for stages 1-4 in time step t+1 based on the abundances in time step t.

9. In Excel, create a series of cells at the top of a spreadsheet that contain the parameter values for the elements of the population projection matrix. Make sure that the fecundity terms are functions of the survival terms as per the fecundity equations for F2 and F3 so that if you change a survival term the fecundity term is automatically updated. Simulate the model for 100 years using the parameter values you set in the cells at the top of the sheet and using a starting abundance of 200 whales in each stage (Hint: create one column for time plus four columns for the lifehistory stages and use the equations from (8) to update the abundance in the next time step based on abundances in the current time step. Also make use of the $ notation in Excel to anchor the parameters in the simulation on the values of the parameters you set at the top of the sheet). Plot the abundance of the four life-history stages against time. What is the geometric population growth rate and the stable stage distribution?

10. Adjust the survival rate of mothers with calves ($p_{34}$) upwards and re-examine your simulations. What is the smallest value of $p_{34}$ that is needed to reverse the population decline of this critically endangered species? Further, assume that the population is at its stable stage distribution and that there are currently a total of 77 whales and that a key source of mortality of mothers with newborn calves is entanglement in fisheries gear. How many mothers with calves are there? How many mothers need to be saved each year from fisheries mortality to prevent extinction (i.e. to change $p_{34}$ so that $\lambda>1$)?