From this stage...

To this stage...

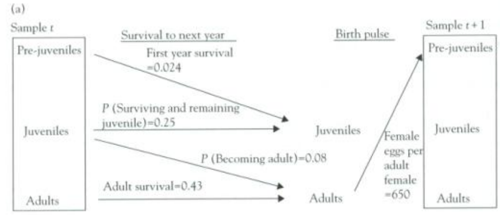
	Pre-juvenile	Juvenile	Adult
Pre-juvenile	0	52	279.5
Juvenile	0.024	0.25	0
Adult	0	0.08	0.43

From this stage...

To this stage...

	Pre-juvenile	Juvenile	Adult
Pre-juvenile	0	52	279.5
Juvenile	0.024	0.25	0
Adult	0	0.08	0.43

(a)



(b)

0	P (Juvenile becoming adult * eggs/adult)	P (Adult survival * eggs/adult)
P (First year survival)	P (Remaining juvenile)	0
0	P (Juvenile becoming adult)	P (adult survival)

Fig. 7.3 A real-life example of a female-based post-birth-pulse matrix model for the common frog (Fig. 7.1). Female eggs per adult female refers to fecundity (see Box 4.8). (a) A diagramatic representation of the model; (b) the matrix (try plugging in the values and make sure you get the matrix in Fig. 7.1). Note that the matrix shows reproduction for juveniles (row 1, column 2) as well as adults (row 1, column 3) because a portion of the juveniles transition during the time step to become adults, at which point they reproduce. In general, for post-birth-pulse models for iteroparous species with n reproductive stages there should be $(n+1)$ non-zero elements in row 1.

Box 7.2 An example of how to model environmental stochasticity, based on a population-projection matrix for red-legged frogs (*Rana aurora*)

Notice that this is a different frog species than the one discussed previously in this chapter. Data come from Biek et al. (2002).

Step 1: here is the matrix of vital rates.

0	(Probability of juvenile becoming adult * probability of laying * **clutch size**)	(**Adult survival** * probability of laying * **clutch size**)
(Embryo survival * larval survival * metamorph survival)	(Probability of remaining a juvenile)	0
0	(Probability of juvenile becoming adult)	[**Adult survival**]

Step 2: environmental stochasticity for the two emboldened vital rates (clutch size and adult survival) is as follows.

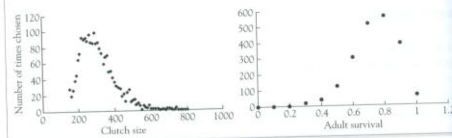
	Clutch size	**Adult survival**
Mean	303	0.69
SD	95	0.13
Distribution for random numbers	Lognormal	Beta

Adding stochasticity to population projection models

Step 3: for five time steps, the vital rates chosen randomly from the specified distributions might, for example, be as follows.

Time step	**Clutch size**	**Adult survival**
1	287.6	0.66
2	326.8	0.71
3	252.0	0.93
4	382.9	0.55
5	251.9	0.60

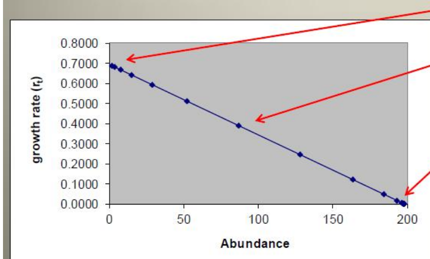
Step 4: the distribution of vital rates chosen many times would look like the graphs below.



How would you add density dependence to population projection models?

**Remember that for dd models, growth rate decreases with increasing density

$$\ln(n_{t+1}) / \ln(n_t) = + r_{max} + b(n_t) + F$$



r_{max} is the y-intercept of this line

b is the slope of this line

K (carrying capacity) is the x-intercept of this line

How would you add density dependence to population projection models?

	Pre-juvenile	Juvenile	Adult
Pre-juv	m1 * p0	m2 * p0	m3 *p0
Juvenile	p1	0	0
Adult	0	p2	p3

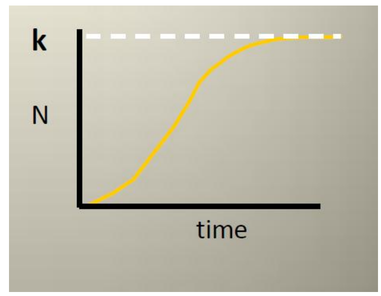
Where would we incorporate this idea into the projection matrix?

Adjust fecundity:

$m_0 = a + b(n_t) + E$

Adjust survival:

$p_0 = a + b(n_t) + E$



Stable stage distribution (SSD)

After enough time, if matrix is stable, the population will reach a stable state were the distribution among age classes is stable and so is the growth rate.

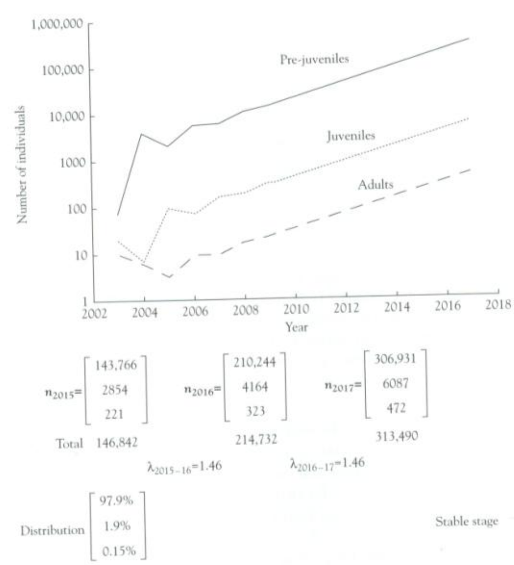


Fig. 7.5 Convergence to a SSD for the common frogs considered in previous figures. Population numbers over 14 years (from 2003 to 2017) are shown by stage class. The number of frogs is plotted on a logarithmic scale to accommodate the huge numbers of pre-juveniles, and because at SSD the trajectories become linear. Below the graph are the vectors (**n**), total population sizes, and geometric growth rates (λ) for the final 3 years. When the population reaches SSD, both the population growth rate (λ) and the proportion of individuals in each stage remain constant.

Sensitivity Analysis

As with stage classes, sometimes different vital rates influence population growth and structure more than others. Sensitivity analyses help identify such cases and can help inform management decisions.

Types:

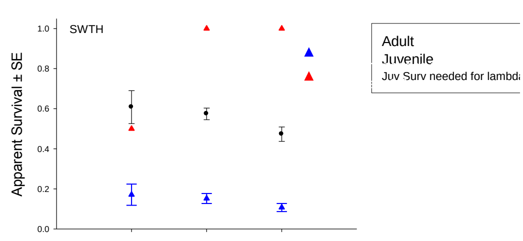
- Manual perturbations
- Analytical Sensitivity and Elasticity Analyses
- Life Stage Simulation Analysis (LSA)

Manual Perturbation

Manually change matrix element(s) of interest and observe how changes influence growth rate (λ)

(Oleyar & Marzluff, in prep)

Changing and developed landscapes are sinks for Swainson's Thrushes.



Life Stage Simulation Analysis (LSA)

A computer simulation approach to sensitivity analysis that evaluates how changes and stochasticity around vital rates influences growth rates and elasticities of matrix elements.

Many ways to interpret results, one of which is the proportion of replicates that have positive population growth (λ > 1)

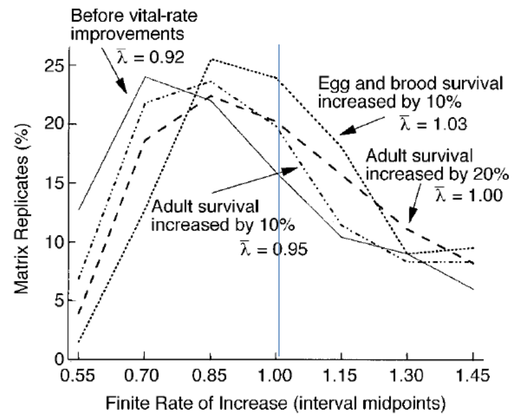


FIG. 4. Distribution and range of the finite rate of increase (λ) for Greater Prairie Chickens under four conditions: before vital-rate improvements (———); after increasing egg and brood survival (s_{1_a} and s_{1_b}) by 10%, with 20% reduction in variation (········); after increasing adult survival (s_2–s_4) by 10%, with 20% reduction in variation (–··–··–); after increasing adult survival by 20%, with 20% reduction in variation (– – – –). Results are based on analysis methods described for Application 2. Vital rates are defined in the Appendix.

Wisdom et al (2000)

Metapopulation Models

Each population has a projection matrix

Individuals move between populations (dispersal – researcher sets rate based on literature or other knowledge)

Matrices can be correlated, degree of correlation related to what metapopulation structure is being considered