Age-structured populations

NRES 470/670

Spring 2024

When we began modeling wildlife populations, we treated b and d (per-capita birth rate and fractional death rate) as constants. This resulted in exponential growth.

Then we allowed b and d to change (becoming less favorable to growth) as population density increased- this resulted in logistic (S-shaped) population dynamics.

Here we ask: what if population vital rates (b and d) change as individuals get older (i.e., what if b and d are 'age-structured')?
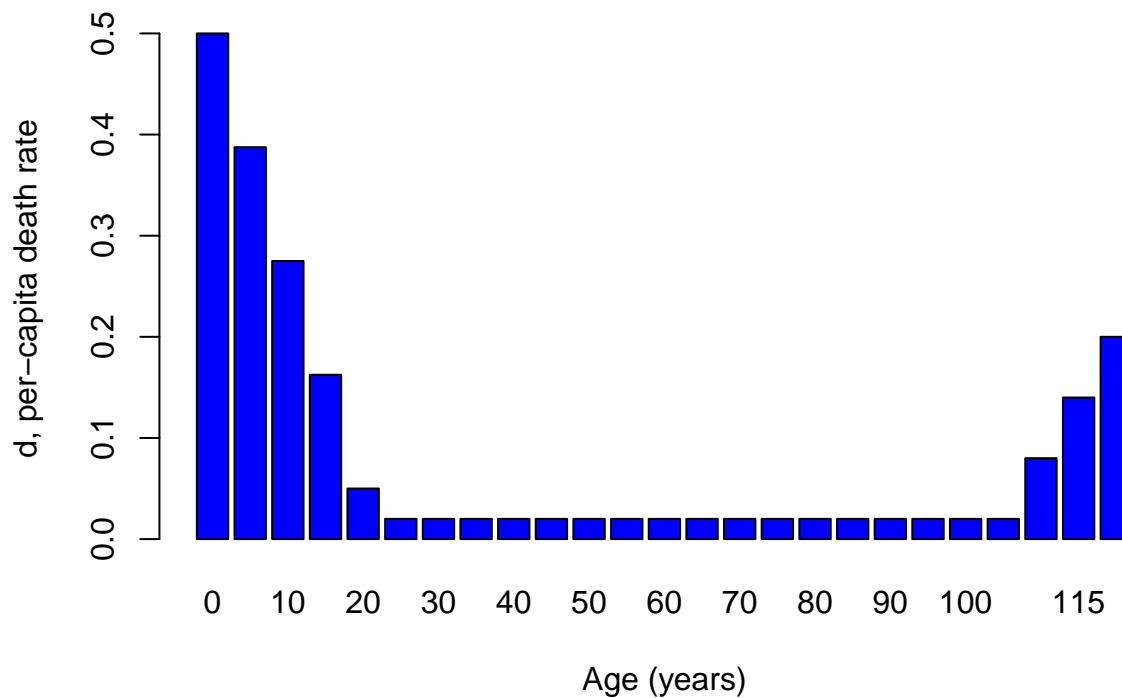
How can we model *age-structured* population vital rates? How might this affect population dynamics?

Take this Indian elephant for example. How does the per-capita birth rate (b) depend on age for this species?

We might imagine it looks something like this!
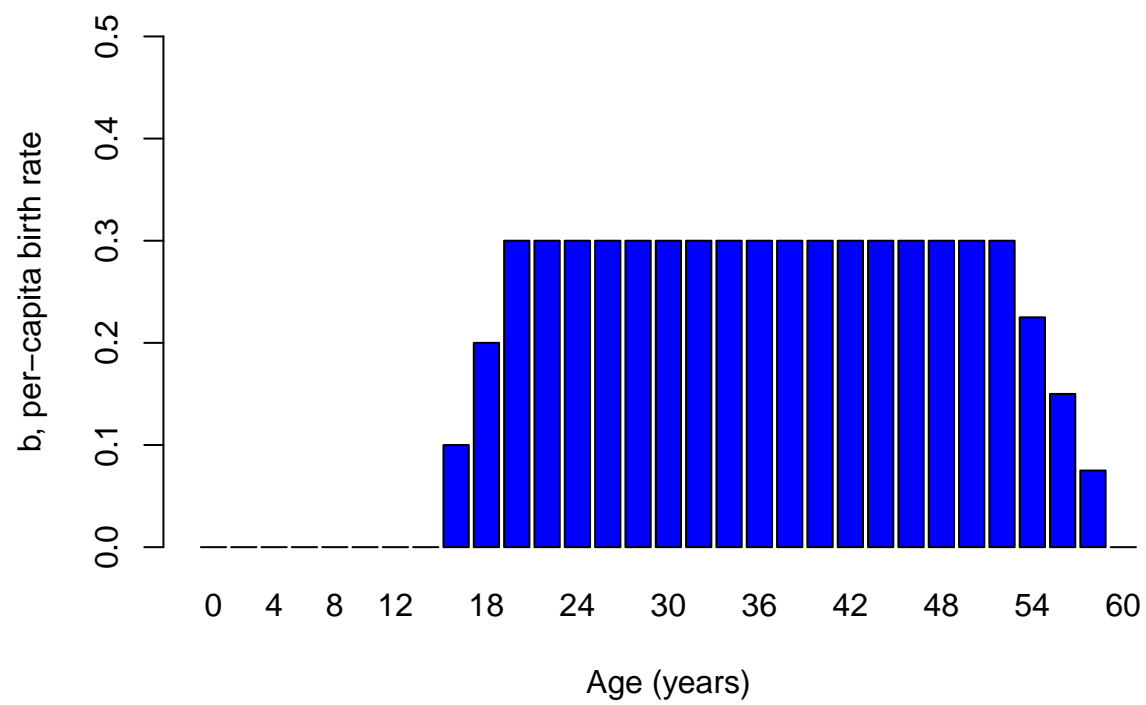
What about per-capita death rates for a tortoise? We might imagine something that looks like this...

So, for many species per-capita birth rates and death rates are fundamentally dependent on age!

Q: Imagine you were trying to re-establish a population of spadefoot toads, which tend to reproduce for the first time in their third year of life. You take 1000 tadpoles from a captive population and place them in a temporary wetland right after a rainstorm (to maximize survival rate). What would population growth look like over the next 4 years, assuming the reintroduction strategy was successful? [Top Hat]

Aside: sex-structured vital rates

Q: Can you think of some real-world examples where vital rates might differ between males and females?

Q: When is sex structure important to consider when modeling populations?

Q: Imagine a population of 100 golden-headed lion tamarins (*Leontopithecus chrysomelas*) that consists of all adult males and post-reproductive females. What is the conservation status of this population?

Life table!

Age-structured populations are often represented by a table called a **life table**. A life table typically represents a single **cohort** (group of organisms of the same species that are born during the same year) and whose survival and birth rates are tracked across time.

Here's an example:

x	S(x)	b(x)	l(x)	g(x)
0	500	0	1.0	0.80
1	400	2	0.8	0.50
2	200	3	0.4	0.25
3	50	1	0.1	0.00
4	0	0	0.0	NA

Reproductive schedule

The reproduction component of the life table is called the reproductive schedule (or sometimes, the "fecundity schedule")! The term $b(x)$ represents the per-capita birth rate for females of age x. The reproductive schedule describes how birth rate changes with age.

Survivorship schedule

Fecundity is only half the story! The survival component of the life table is called the "survivorship schedule"!

The term **cohort** represents a bunch of individuals in a population that were all born at the same time.

In a life table, the term S(x) refers to the number of individuals from a particular cohort that are *still alive x years after the cohort was born.*

From this raw data, we compute two terms, called **survivorship** and **survival rate**

The term $l(x)$ represents the *proportion of the cohort surviving from age 0 to age x.* This is known as **survivorship**.

The term $g(x)$ represents the *proportion surviving from age x to age x+1.* This is called the **survival rate** (contrast this with survivorship!).

The survivorship schedule describes how survivorship drops off with age. The survivorship schedule is typically visualized as a **survivorship curve**.

Types of survivorship curves. . .

Survivorship curves describe how the logarithm of survivorship $(log(l(x)))$ drops off with age.

There are three main types of survivorship curve, and these curves are classified as **Type I**, **Type II**, and **Type III**.

These three types of **life history** pattern can be illustrated with three real-world examples: humans, songbirds, and frogs.
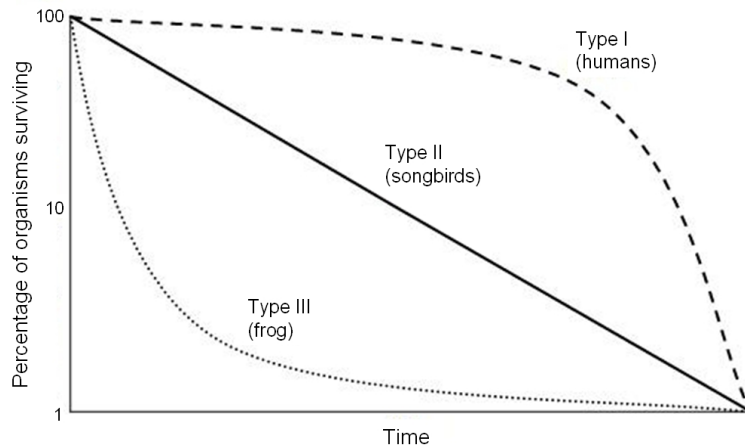

Type I

Type II

Type III

(Note the logarithmic scale on the Y axis. This is important!)

Q: Which survivorship curve is the most common in nature?? [Top Hat] (remember, you're not graded on correctness- just take a guess if you're not sure!)

In-class exercise: age-structured population growth

In this exercise we will explore some facets of **age-structured populations**.

1. Load up the life table from earlier in this lecture, by clicking here. Use this table to compute the **net reproductive rate,** R_0. This represents the expected number of female offspring produced per female over her lifetime. This is also known as *lifetime reproductive potential*! This can be computed as:

$R_0 = \sum_{x=0}^{k} l(x) \cdot b(x)$

Where k is the maximum age.

Try to implement this formula in Excel. What's the answer?

2. If the net reproductive rate, R_0 is above one, then the population is above the **replacement rate** of 1, and therefore the population will grow. If R_0 is less than 1, then the population will decline. This sounds familiar, right? Just like the finite rate of growth, λ (the multiplier needed to increment abundance from one time step to the next).

BUT, what is the time frame of R_0? What is the time frame of λ? They are different right? The difference is that R_0 describes growth per **generation**!.

What is a **generation**? The most common definition (for generation time) is the *Average age at which individuals in a cohort produce offspring* (consider all the offspring produced by the cohort- what is the average age of their parents?). This can be computed from the life table as:

$G = \frac{\sum_{x=0}^{k} l(x) \cdot b(x) \cdot x}{\sum_{x=0}^{k} l(x) \cdot b(x)}$

Try to implement this in Excel (or another spreadsheet software).

Q: What is the *generation time* of the population in the table?

3. Now, can you compute the *intrinsic rate of growth* (r) for this age-structured population?

To a first-order approximation, you can use this equation:

$r = \frac{ln(R_0)}{G}$ [Top Hat]

Just looking at this equation, you see that organisms with longer generation times (G) have slower intrinsic rates of growth, all else being equal.

And you can estimate the finite rate of growth (λ) for this population like this:

$\lambda = e^r$

4. Load up a stage-structured model in InsightMaker. You can clone this one, here.

4a. Initialize the population like the spadefoot toad example from above- with only juveniles in the population at time 0. What population dynamics occur at the beginning of the simulation? What about the end of the simulation?

4b. Can you modify the initial abundance of juveniles, subadults and adults so that the population exhibits smooth exponential growth for all three stage classes (and the population as a whole)? This is called **Stable Stage Distribution (SSD)**

4d. Now change the adult survival rate to 0.35. What happens? Is this a growing population? How many yearlings would need to be added to the population each year (population supplementation) to maintain a stable or growing population of >20 adults? [Top Hat]

What do you think? Is supplementation the best strategy for conserving this population?

–go to next lecture–