Lecture 5

Density-dependent population growth

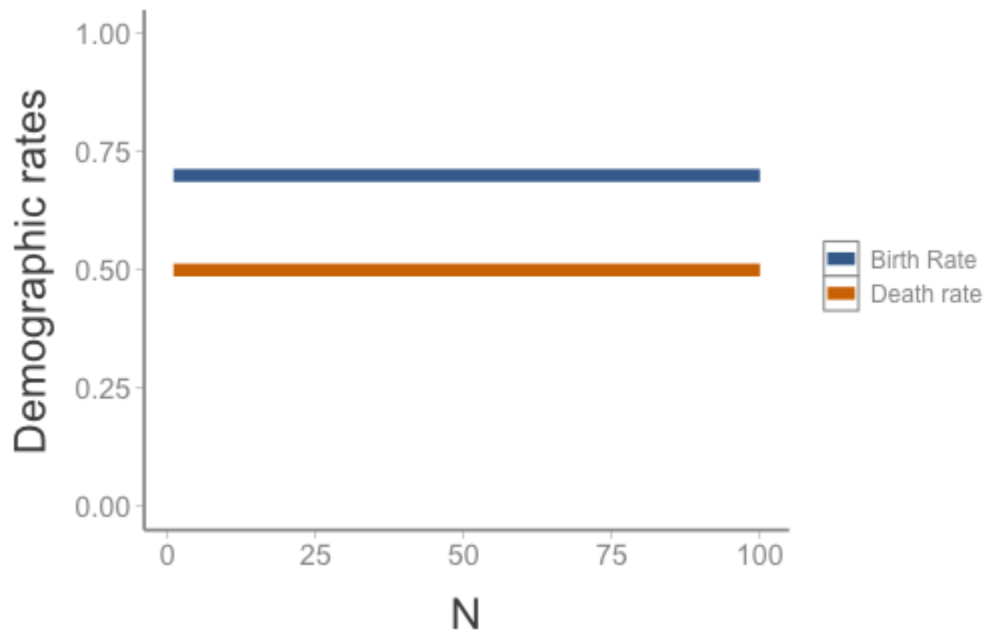
WILD3810 (Spring 2020)

Readings

> Mills 126-141

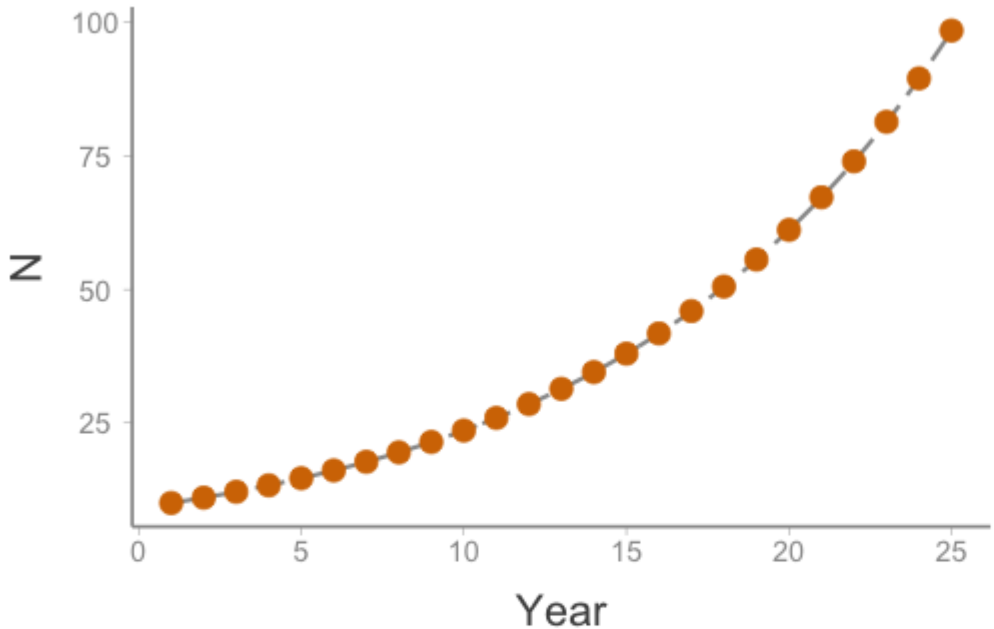
Density-independence vs density-dependence

In lecture 3, we learned about population growth models that assume demographic rates are unrelated to population size



Density-independence vs density-dependence

We also learned that this assumption leads to exponential population growth



Limitless population growth?

No population can grow exponentially forever (or even for relatively short periods of time)

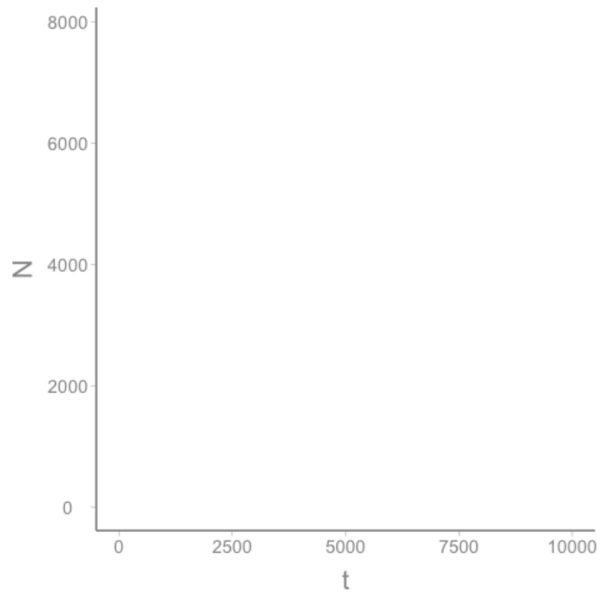
Thomas Malthus was the first to propose that no population could grow without bound forever (1798)

- At some point, resources will be become limited and populations must either stop growing or decline

Malthus' work inspired Darwin (1859) to suggest that limitation of resources is what drives evolution by natural selection

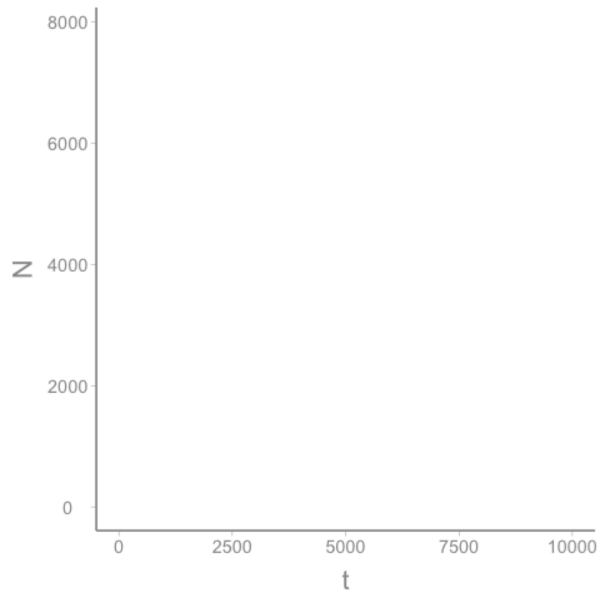
Stochasticity and extinction risk over time

We also learned that, given enough time, populations that experience stochasticity will eventually go extinct



Stochasticity and extinction risk over time

We also learned that, given enough time, populations that experience stochasticity will eventually go extinct



Why isn't extinction more common?

Density-dependence

> The tendency of population vital rates, and therefore population growth rate, to change (increase or decrease) as a function of population size

At small population sizes, individual organisms may be able to acquire all of the resources they need to survive and reproduce

As the population grows, competition, disease, and predation increase

Competition

At small population sizes, individual organisms may be able to acquire all of the resources they need to survive and reproduce

As N increases, the availability of resources per organism will decrease, leading to increased competition
Intra-specific competition:

> interaction between individuals of a single species brought about by the need for a shared resource

Intra-specific competition can arise in multiple ways:

Animals

- food
- shelter
- breeding sites
- mates

Plants

- space
- light
- water
- nutrients

Competition

Ecologists generally distinguish between two types of competition:

1) **Exploitation competition**

- consumption of limited resource by individuals depletes the amount available for others
- also known as: depletion, consumption, or scramble competition
- *indirect*

Competition

Ecologists generally distinguish between two types of competition:

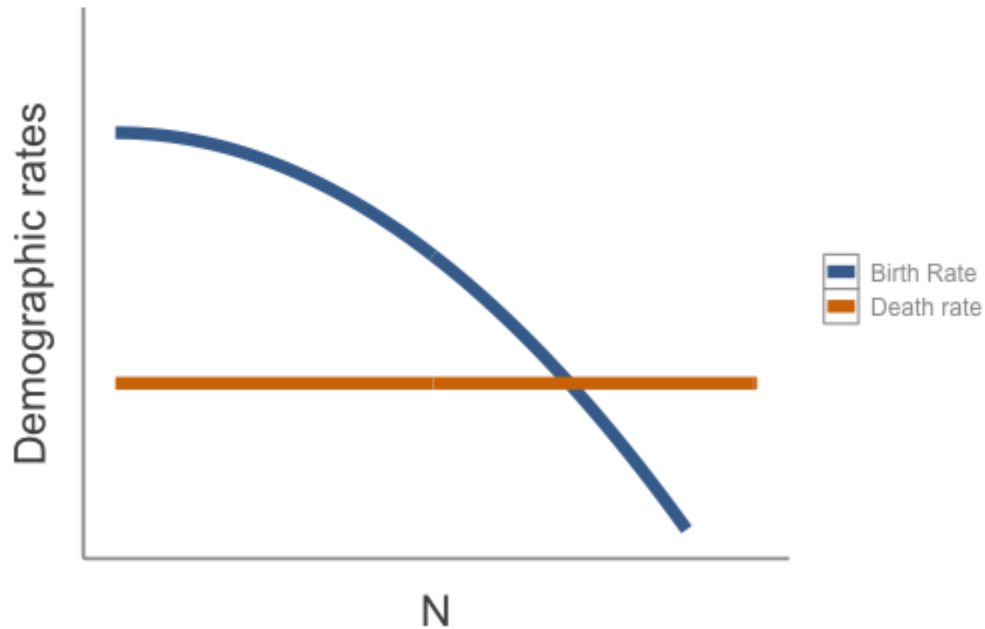
1) **Exploitation competition**

2) **Interference competition**

- individuals actively prevent others from attaining a resource in a given area or territory
- also known as: encounter or contest competition
- *direct*

Competition

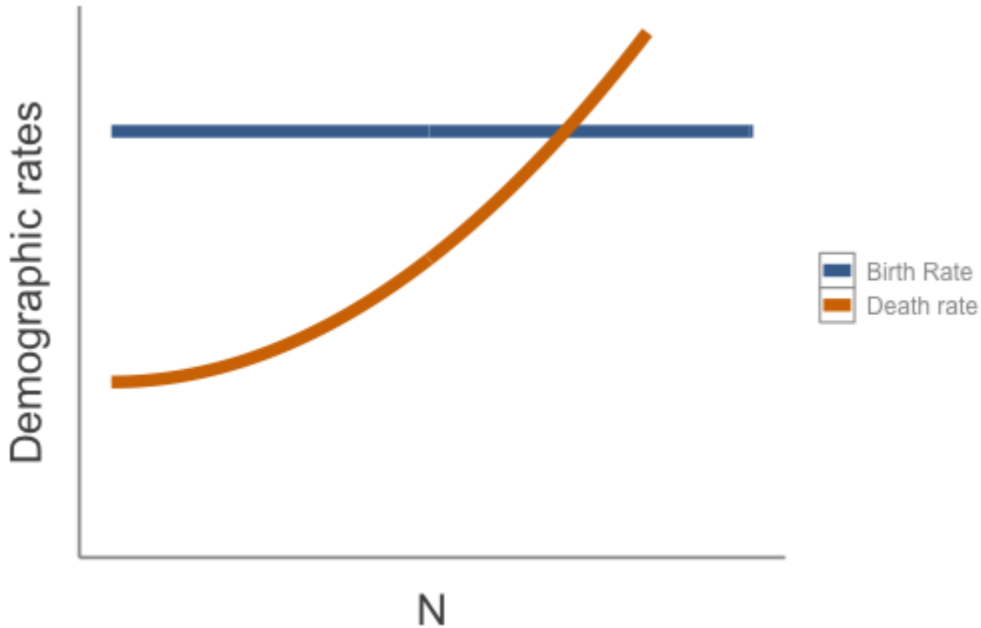
As population size increases, the resources available to each individual will eventually shrink to the point where demographic parameters are negatively effected



Competition

As population size increases, the resources available to each individual will eventually shrink to the point where demographic parameters are negatively effected

- Increased density can also increase rates of disease transmission or predation



Carrying-capacity

Remember that the population growth rate $r = b - d$

If $b = d$:

- $r = 0$
- population remains stable

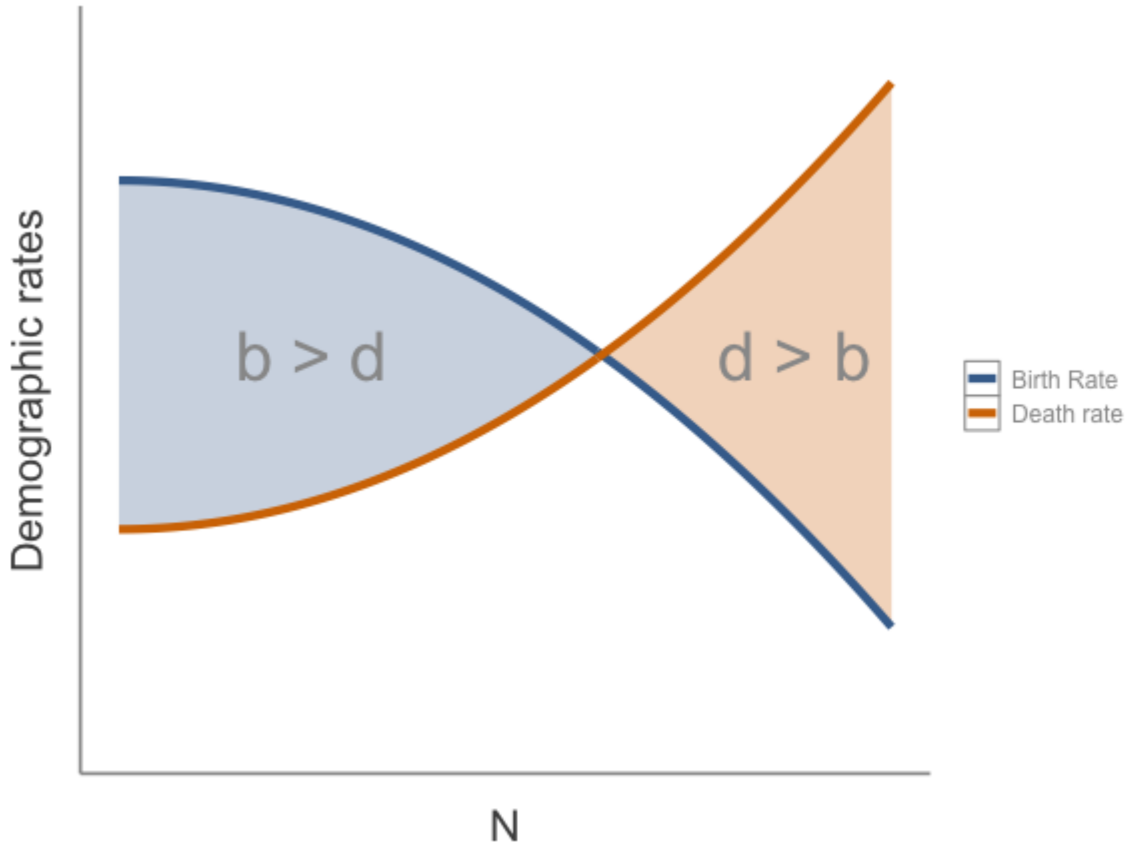
If $b > d$:

- $r > 0$
- population will grow

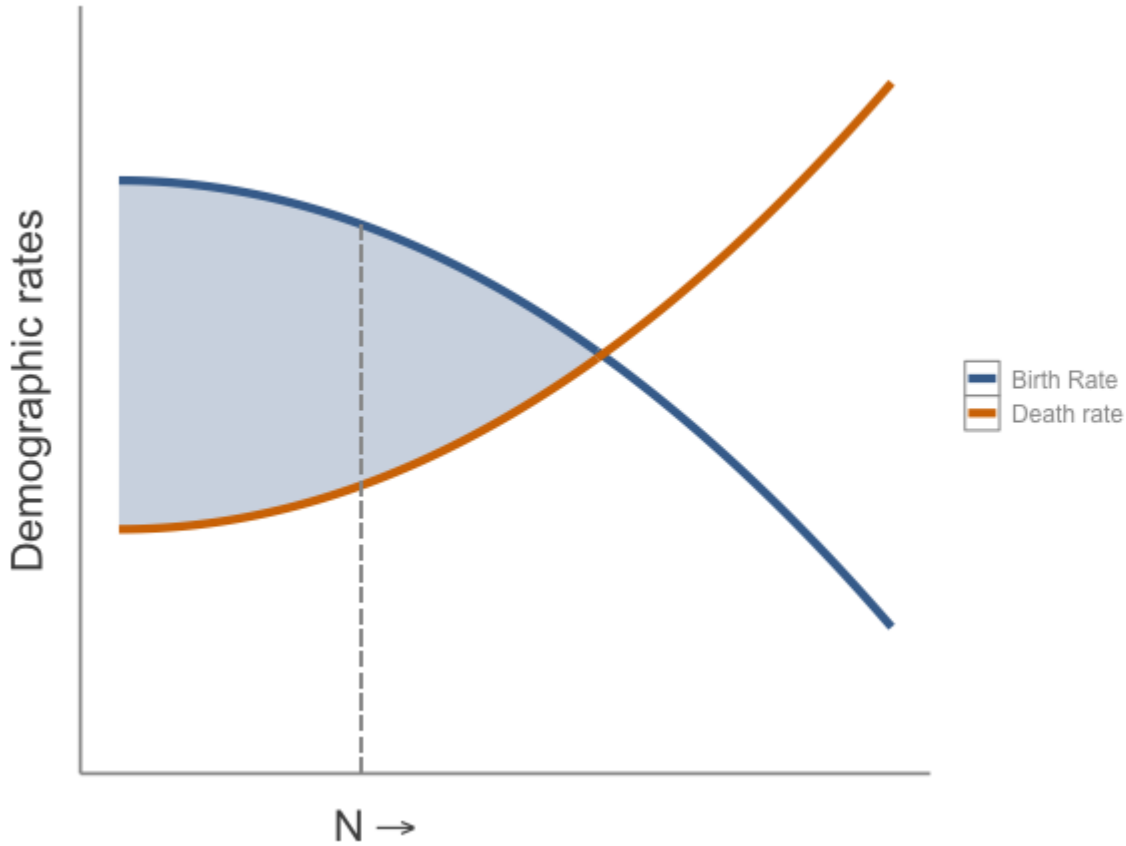
If $d > b$:

- $r < 0$
- population will decrease

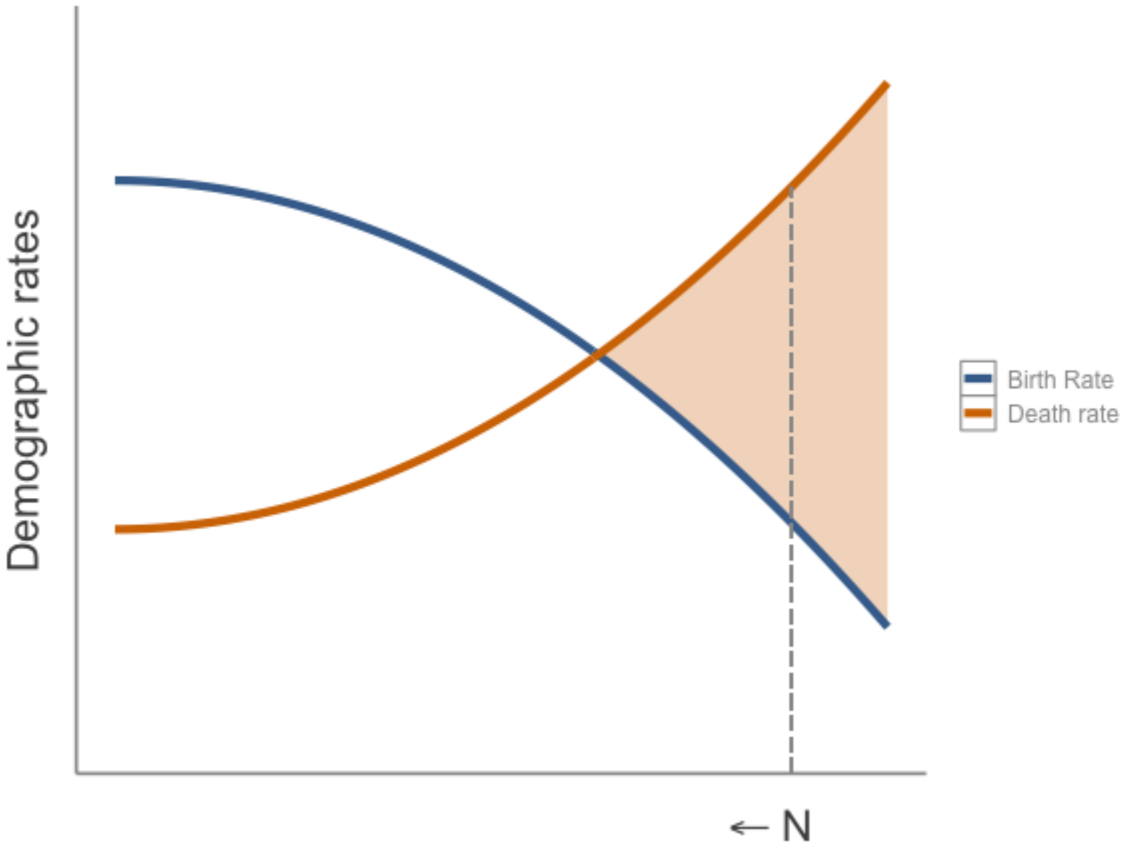
Carrying-capacity



Carrying-capacity



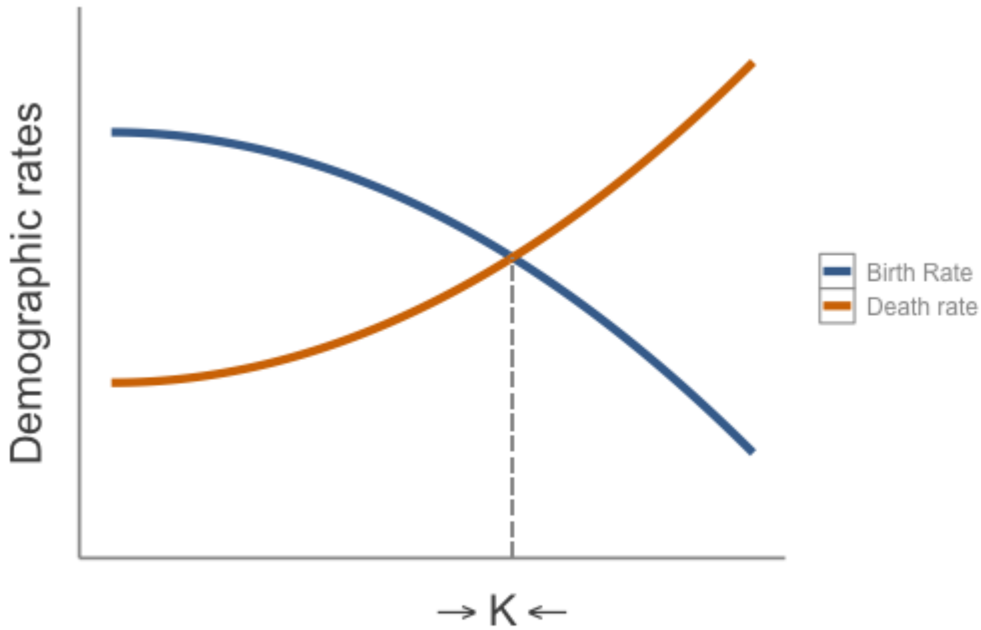
Carrying-capacity



Carrying capacity

Carrying capacity K:

> the population size that the environment can maintain [1]



Population regulation vs limitation

The density-dependent processes we just learned about are called **regulating** factors

- Regulating factors keep population size from going too far above or below K [2]

Limiting factors determine the actual value of K

- Limiting factors can be density-dependent (competition) or density independent (disturbance or extreme weather)

Models of density-dependent population growth

Models of D-D population growth

Remember the (continuous time) density-independent model of population growth:

$$\frac{dN}{dt} = N \times r$$

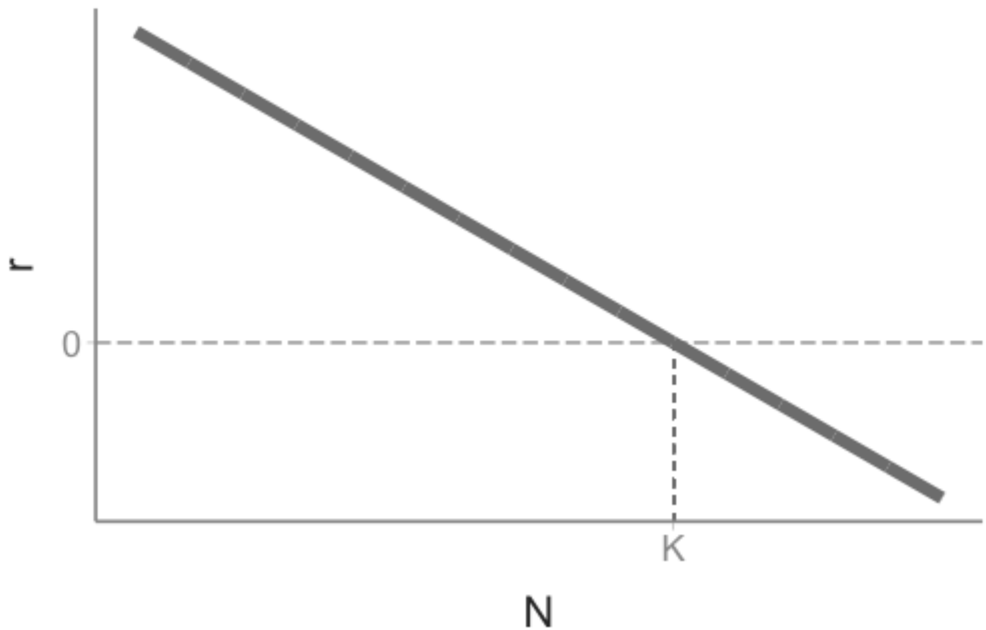
How can we modify this equation to include density-dependence?

To start, remember what density-dependence means:

> the rate of population growth changes as population size increases

Models of D-D population growth

A good starting point for this is a linear response that looks something like this:



Models of D-D population growth

How do we add this relationship to our model?

Remember the equation for a line: [3]

$$y = ax + b$$

In our model, we can write this as: [4]

$$r = aN + c$$

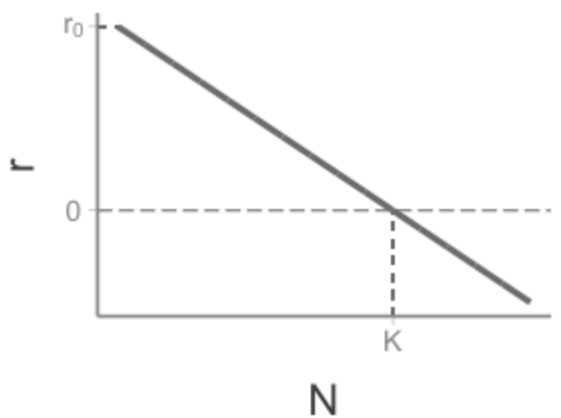
.

Models of D-D population growth

In our population model, c represents the rate of increase when the population is 0

We can see in the figure that this is the largest value of r the population can experience

- Call that r_0
- Because r_0 the maximum rate of increase (nothing limiting population growth), it is equivalent to r in the D-I model



Models of D-D population growth

What is a, the slope of the relationship between r and N?

- It has to be negative (r has to decrease as N increases)

Remember that $r = 0$ when $N = K$, so:

$$0 = aK + r_0$$

therefore,

$$a = -\frac{r_0}{K}$$

Models of D-D population growth

We now have a full equation for the relationship between r and N:

$$r = -\frac{r_0}{K}N + r_0$$

which simplifies to: [5]

$$r = r_0(1 - \frac{N}{K})$$

Models of D-D population growth

How does this work?

Assume $r_0 = 1$ and $K = 1000$

What is the population growth rate when $N = 100$?

- $r = 1 - \frac{100}{1000} = 0.9$

What about when $N = 500$?

- $r = 1 - \frac{500}{1000} = 0.5$

When $N = 1000$?

- $r = 1 - \frac{1000}{1000} = 0$

Models of D-D population growth

Now let's insert our new equation for r into the population growth model:

$$\frac{dN}{dt} = N \times r_0(1 - \frac{N}{K})$$

This is called the **logistic growth model**

Models of D-D population growth

How does this work? Again, $r_0 = 1$ and $K = 1000$

What is $\frac{dN}{dt}$ when $N = 100$?

- $\frac{dN}{dt} = 100 \times 1(1 - \frac{100}{1000}) = 90$

What about when $N = 500$?

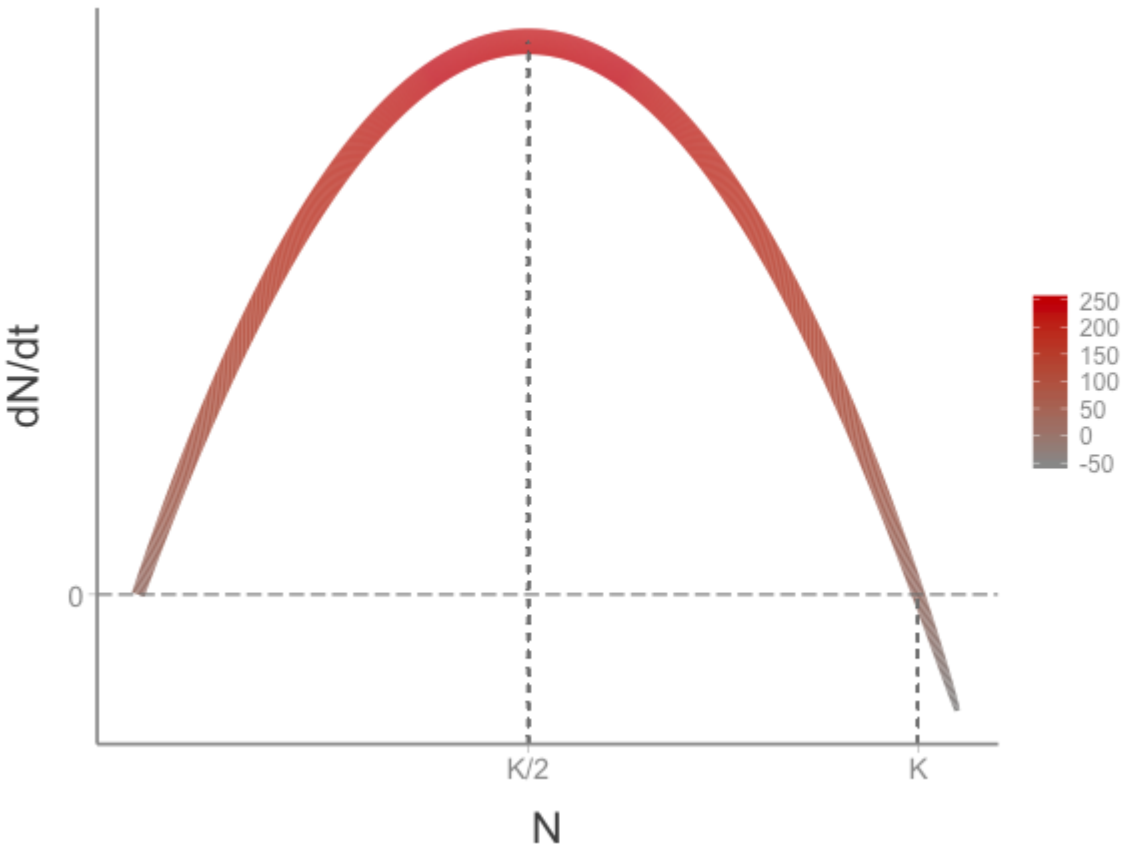
- $\frac{dN}{dt} = 500 \times 1(1 - \frac{500}{1000}) = 250$

When $N = 1000$?

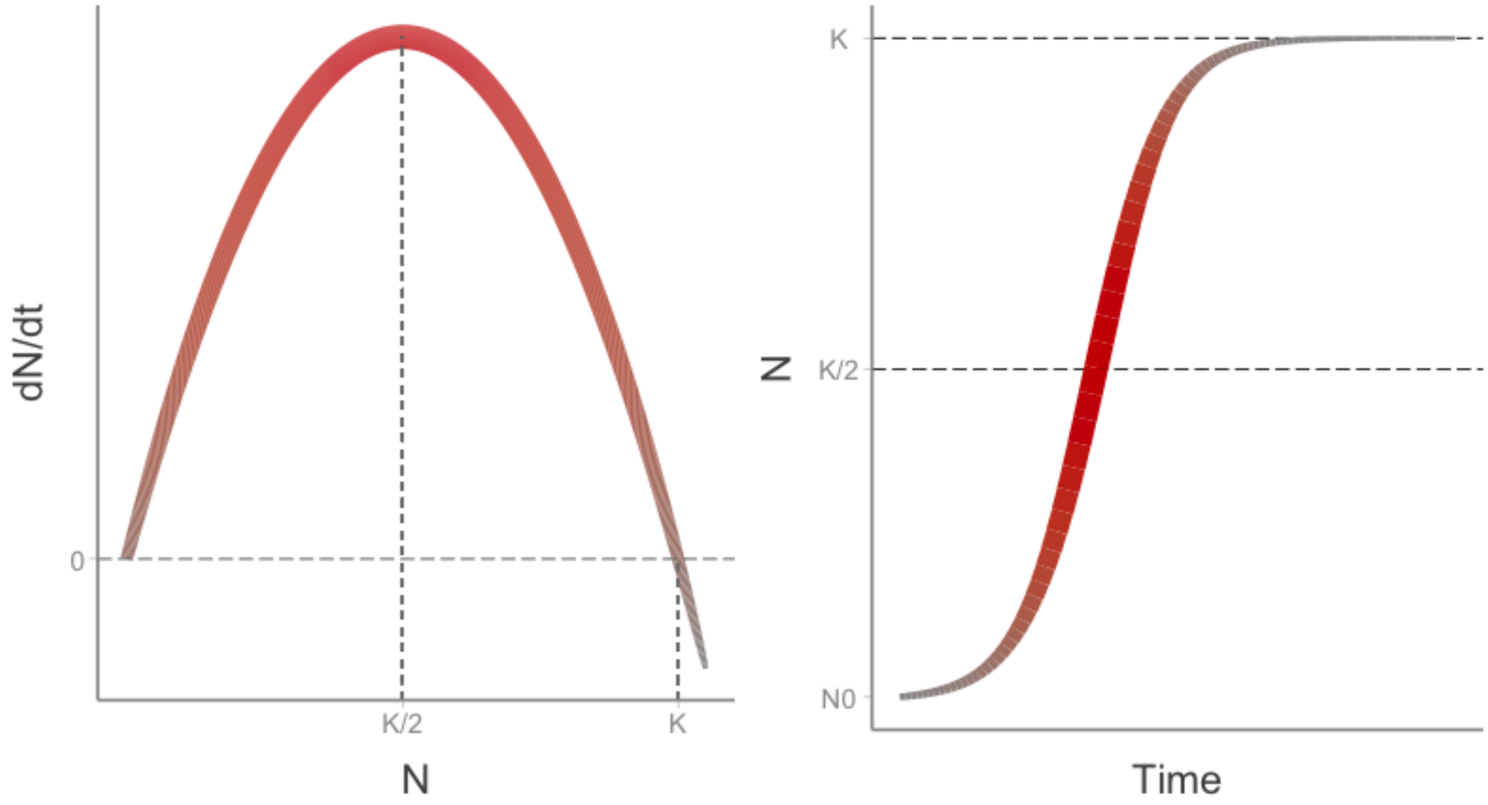
- $\frac{dN}{dt} = 1000 \times 1(1 - \frac{1000}{1000}) = 0$

Models of D-D population growth

How does this work? [6]



Models of D-D population growth



Non-linear effects

Non-linear effects

The logistic model assumes that r decreases linearly with increasing N

In reality, this relationship is not likely to be linear, for example:

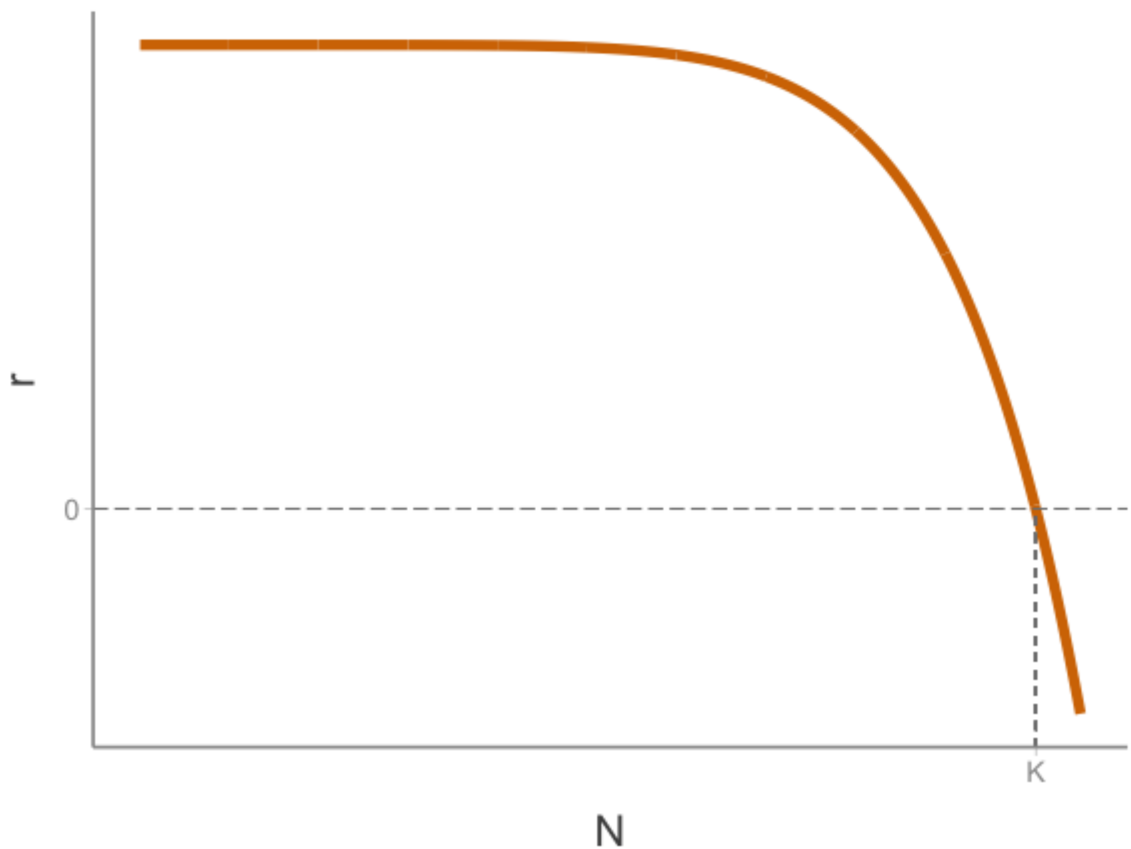
- r might not change much (or at all) until population size is high enough that resources start to become limited
- r decrease very quickly if resources are used rapidly by additional individuals

We can make the logistic model more flexible by adding a new term, θ: [7]

$$\frac{dN}{dt} = r_0 N(1 - [\frac{N}{K}]^{\theta})$$

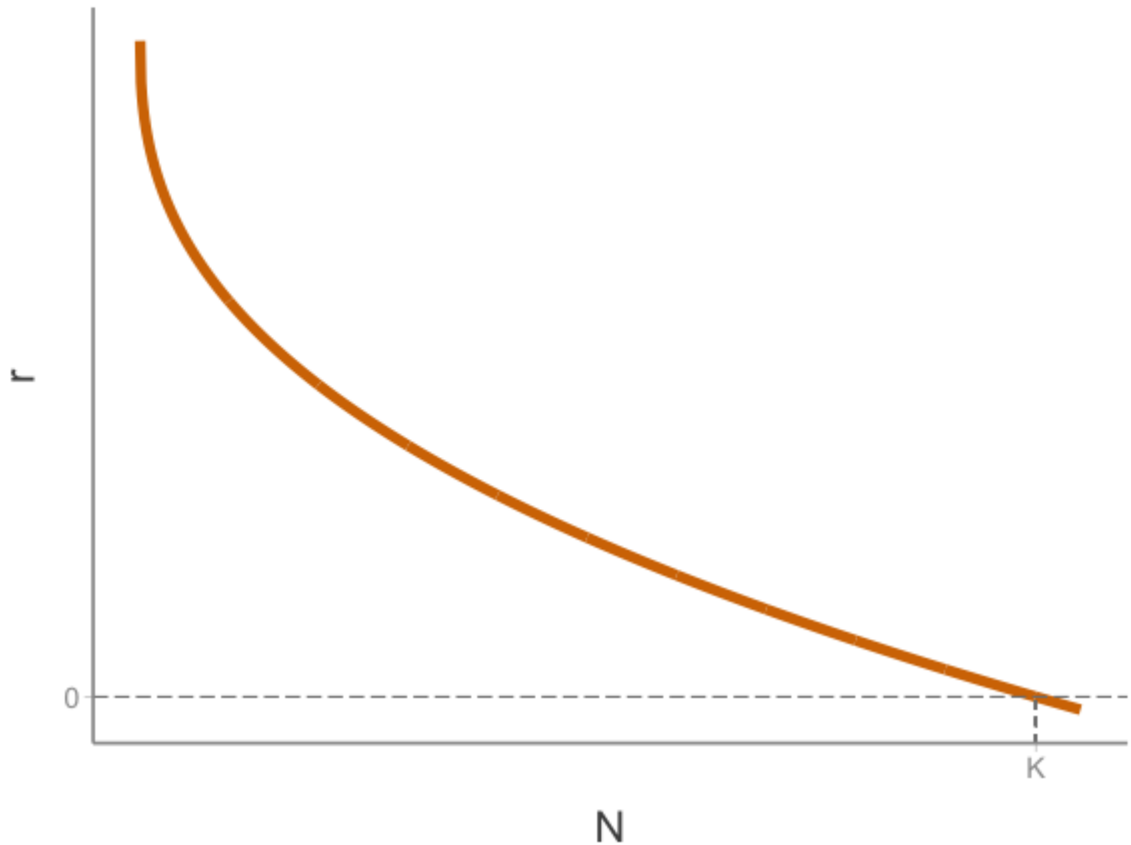
Non-linear effects

When $\theta > 1$, r does not respond to N until N is big enough that resources become limiting



Non-linear effects

If $\theta < 1$, resources quickly become scarce, and r is suppressed even at low N

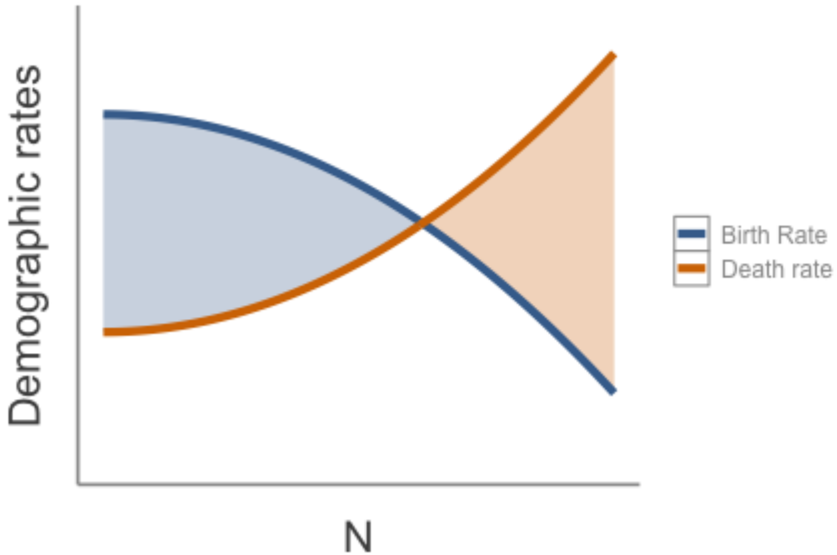


Allee effects

Allee effects

So far, we have assumed that b and d (and therefore r) decrease as population size increases

- This is called *negative* density dependence



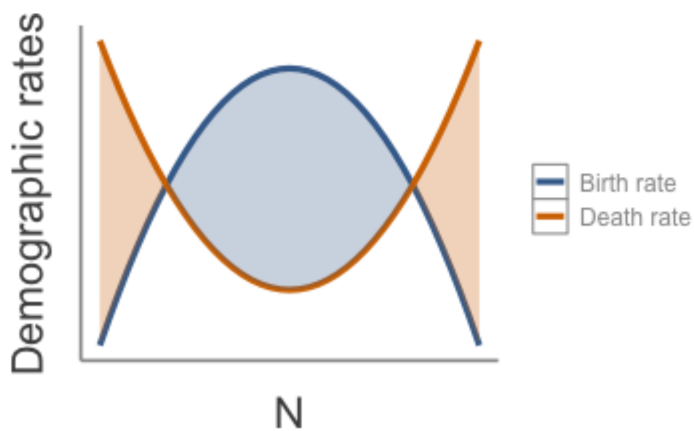
Allee effects

So far, we have assumed that b and d (and therefore r) decrease as population size increases

- This is called *negative* density dependence

In some cases, the slope could also be positive

- Positive relationships between N and d or b generally occur at small population sizes



Allee effects

Why might the death rate be high at small N?

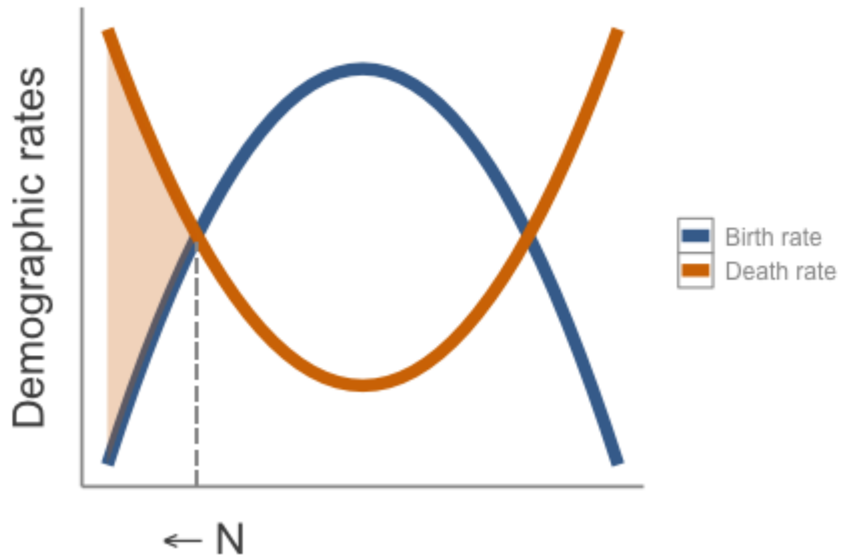
- Group signaling breaks down, predation increases
- Cooperative foraging becomes less efficient
- Inbreeding depression

Why might the birth rate be low at small N?

- Pollination failure
- Unable to find mates because of rarity
- Unable to find mates because of skewed sex ratio
- Inbreeding depression

Allee effects

When abundance drops below the minimum viable population (MVP), the population will likely approach extinction without help!



Discrete dynamics

Discrete dynamics

Remember the discrete-time model of density-independent growth

$$N_{t+1} = N_t \lambda$$

As before, we need to account for possible changes in λ caused by changes in population density

Remember that:

$$\lambda = e^r$$

and:

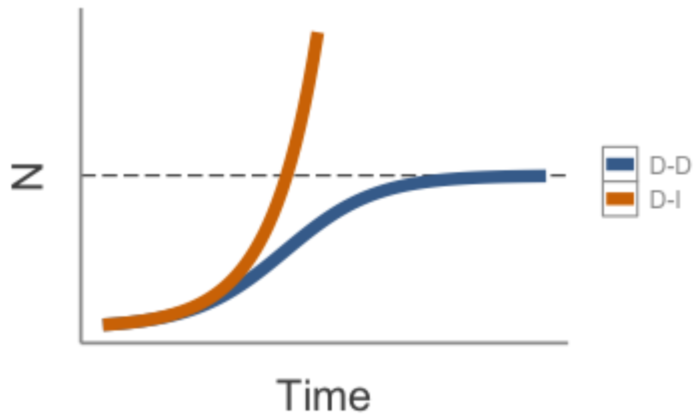
$$r = r_0(1 - \frac{N}{K})$$

Discrete dynamics

Therefore, one discrete-time density-dependent growth model is:

$$N_{t+1} = N_t e^{[r_0(1-\frac{N}{K})]}$$

This known as the **Ricker model**



Discrete dynamics

Any adjustment that can be made to the continuous time logistic model can also be made to the Ricker model

$$N_{t+1} = N_t e^{\left[r_0\left(1-\left[\frac{N}{K}\right]^{\theta}\right)\right]}$$