4. Population Growth and Intraspecific Competition

Jasper Slingsby, BIO2014F

2024-04-23

The Hutchinsonian Niche

G Evelyn Hutchinson proposed that *the niche is an n-dimensional hypervolume within which a species is* ***able to maintain a viable population*** - **Hutchinson 1957**

Does the occurrence of a species at a locality mean it is able to maintain a viable population there...?

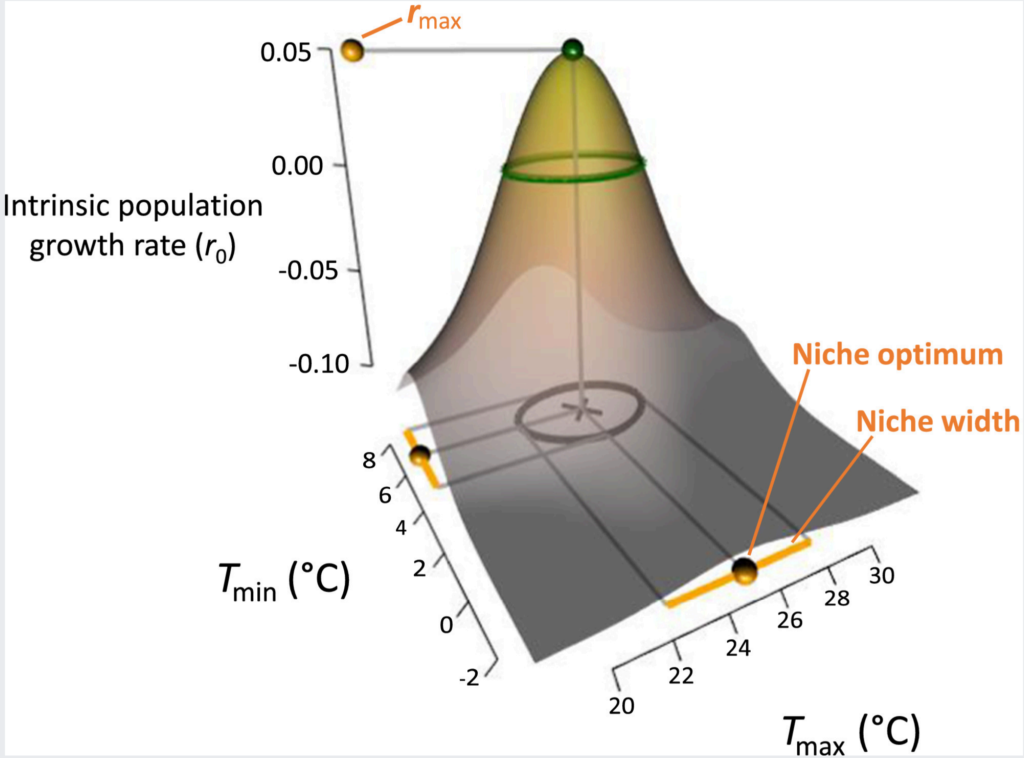


Figure from **Treurnicht et al. 2020**

What does maintaining a viable population even mean?

It means maintaining population growth...

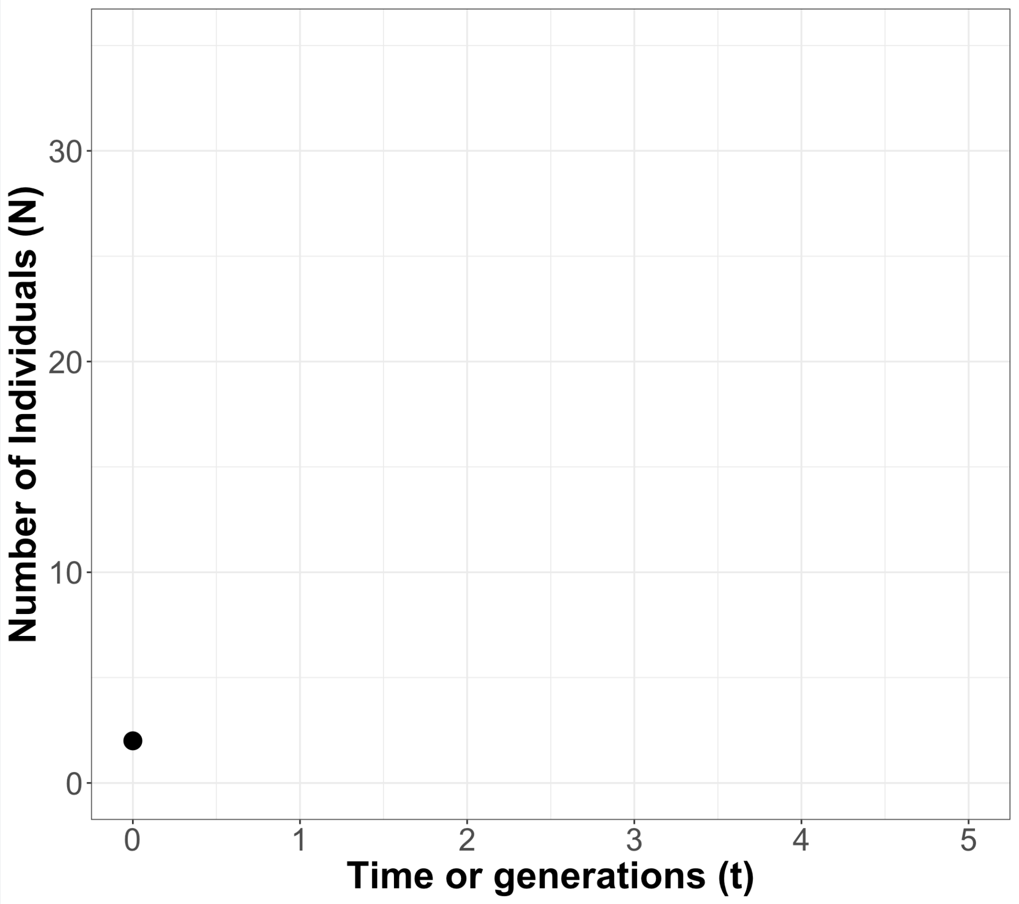
But that's not easy...

Especially where there is competition for resources...

Population growth curve

Consider growth of a population, starting with 2 individuals at t = 0.

- Assume a per-capita reproductive rate, r = 2



Population growth curve

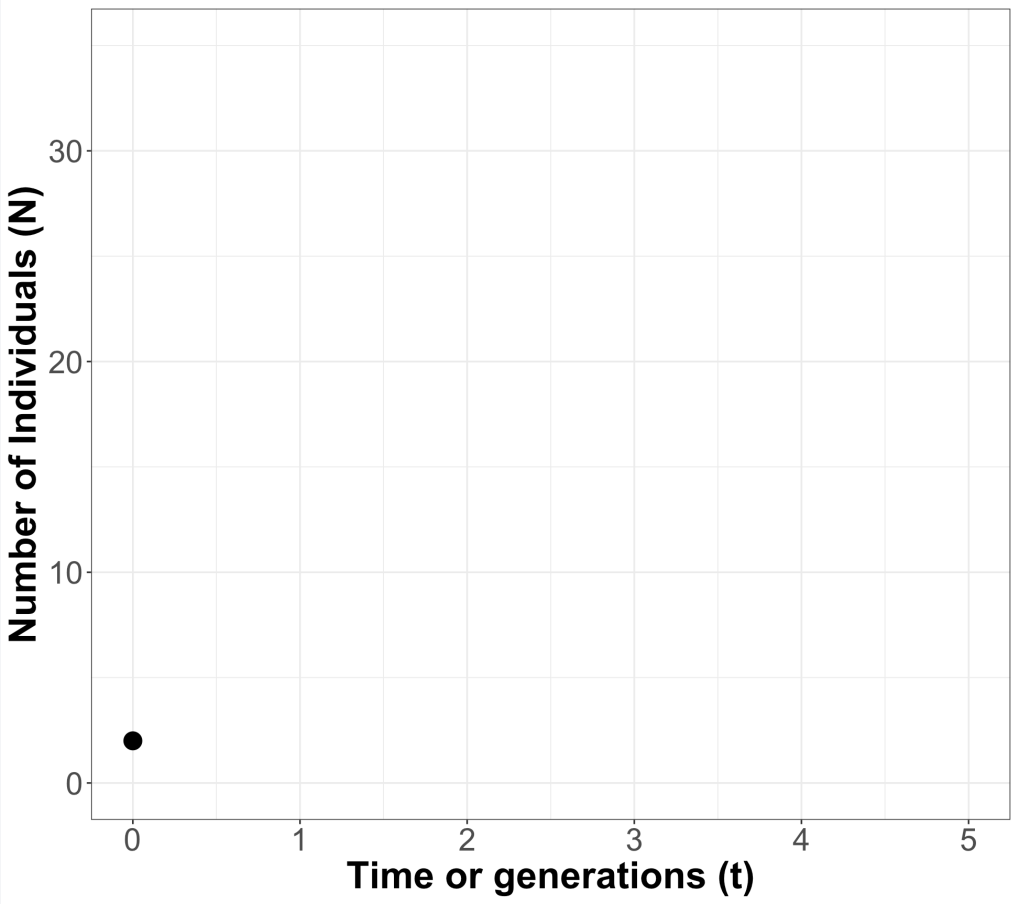
Consider growth of a population, starting with 2 individuals at t = 0.

- Assume a per-capita reproductive rate, r = 2

Note: *The per-capita reproductive rate (r) is the number of reproductively mature individuals contributed per individual from one generation to the next. Population growth is positive where $r > 0$.*

It is a fundamental biological parameter, determined by things like the number of eggs/seeds produced, the hatching/germination success of eggs/seeds, and the success with which hatchlings/germinants survive to reproductive maturity.

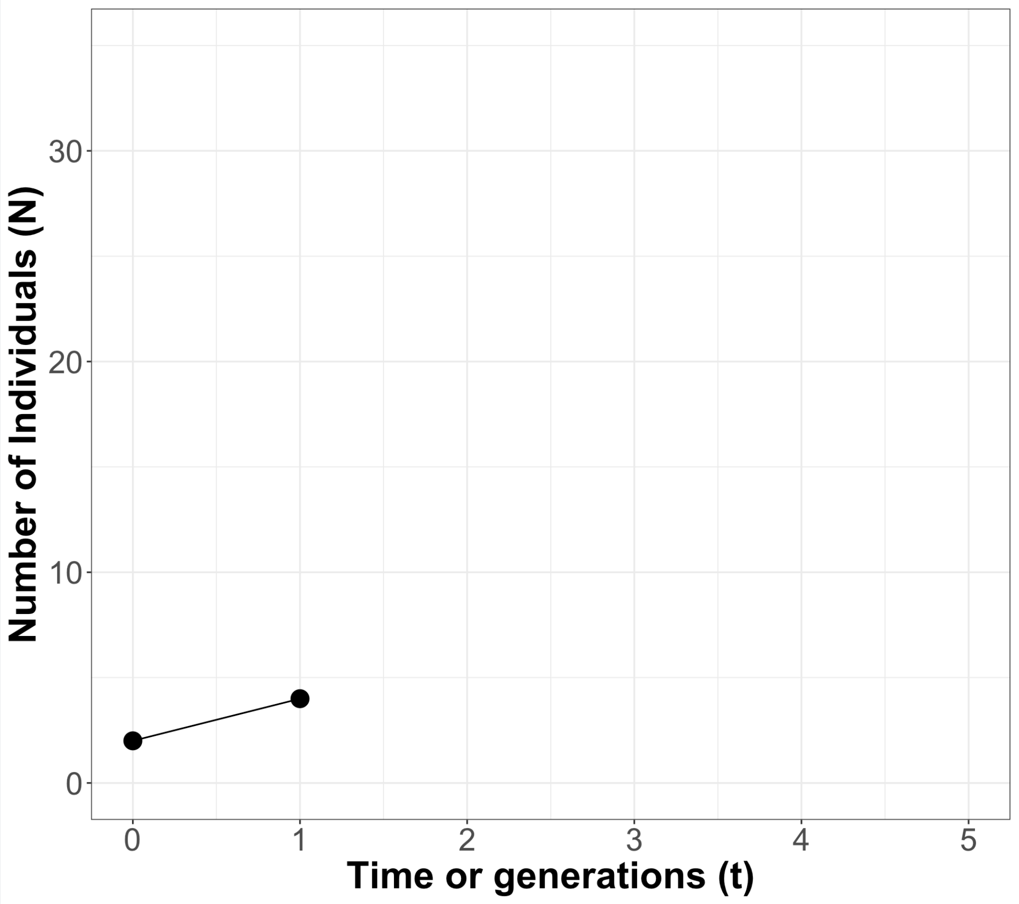
It is the birth rate minus the death rate.



Population growth curve

Consider growth of a population, starting with 2 individuals at t = 0.

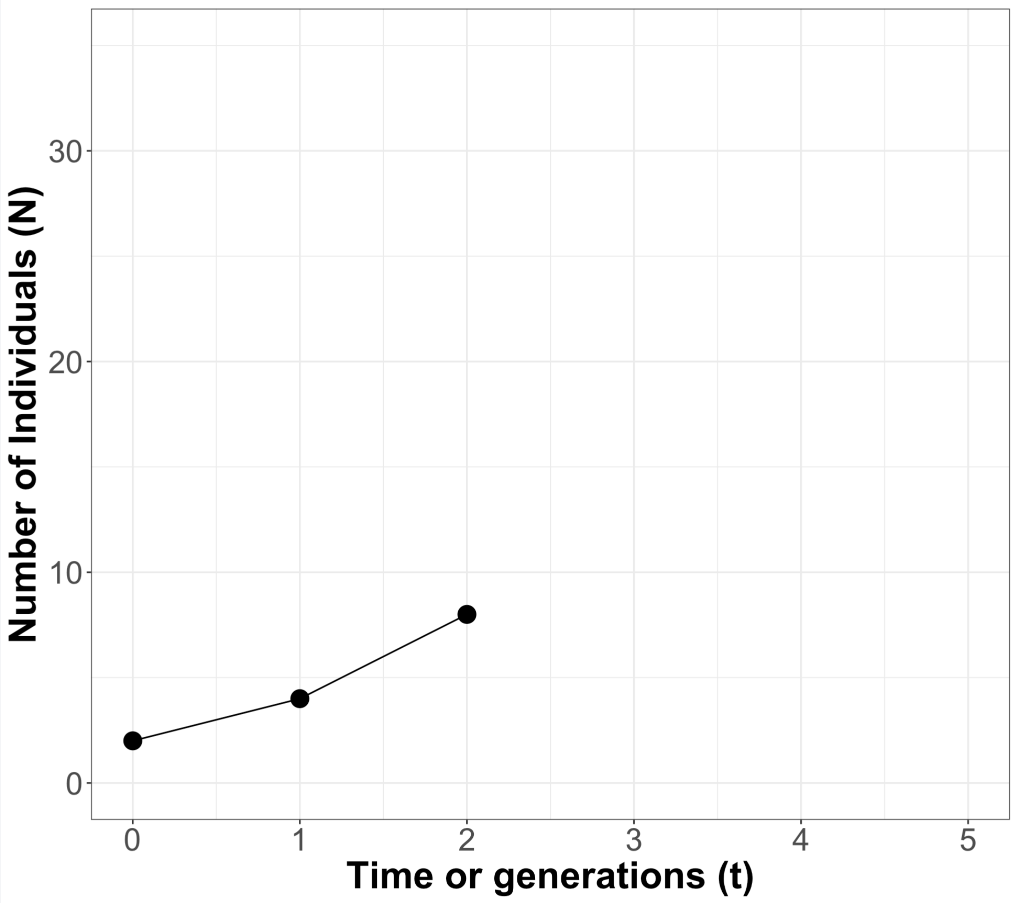
- Assume a per-capita reproductive rate, r = 2



Population growth curve

Consider growth of a population, starting with 2 individuals at t = 0.

- Assume a per-capita reproductive rate, r = 2

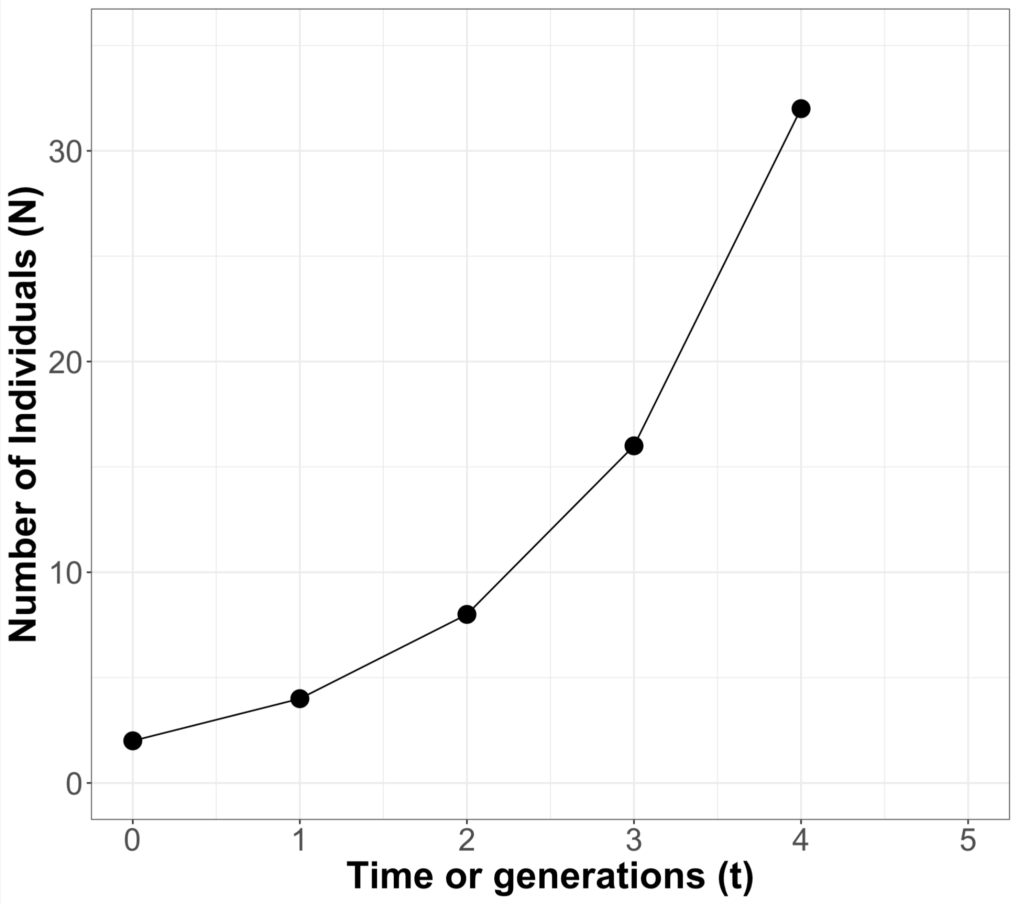


Population growth curve

Consider growth of a population, starting with 2 individuals at t = 0.

- Assume a per-capita reproductive rate, r = 2

Growth is exponential!



Population growth curve

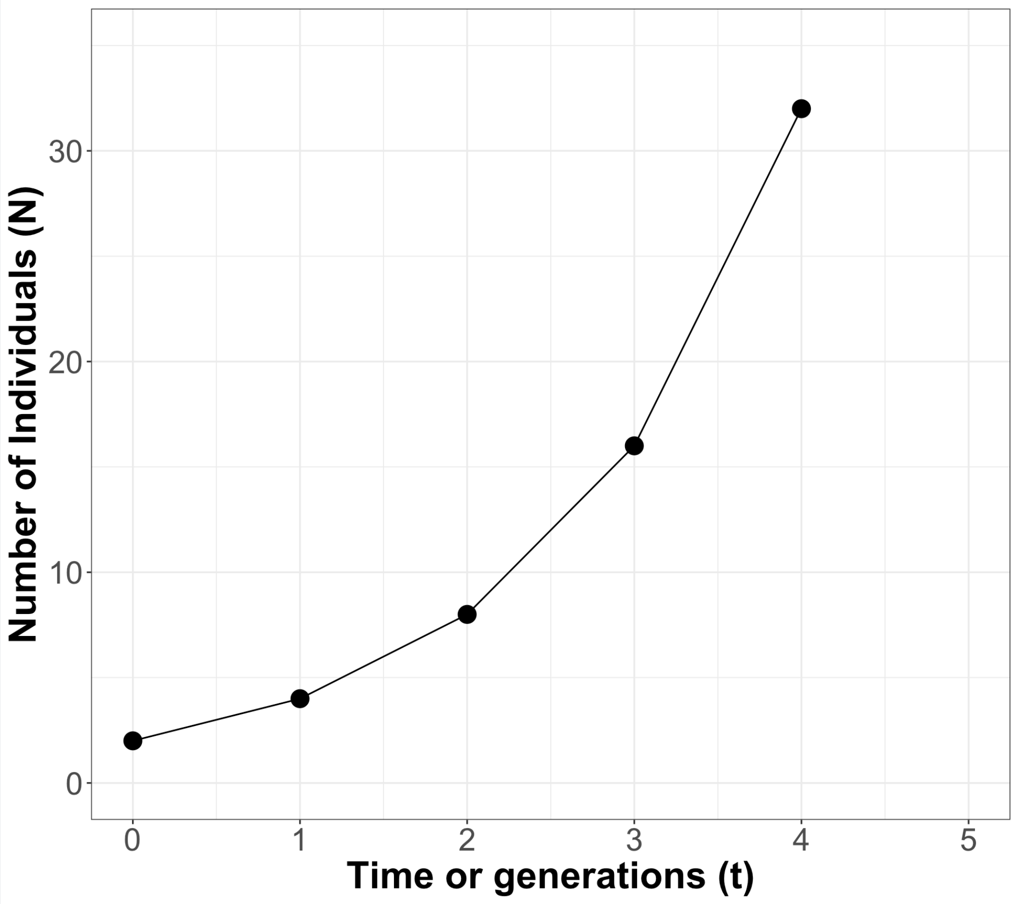
Consider growth of a population, starting with 2 individuals at t = 0.

- Assume a per-capita reproductive rate, r = 2

Growth is exponential!

Using calculus, we can express growth as an instantaneous rate as dN/dt, the rate of change in number of organisms at a particular instant in time.

Since our example is an exponential function, the slope of this curve is given by $dN/dt = rN$



Is growth always exponential?

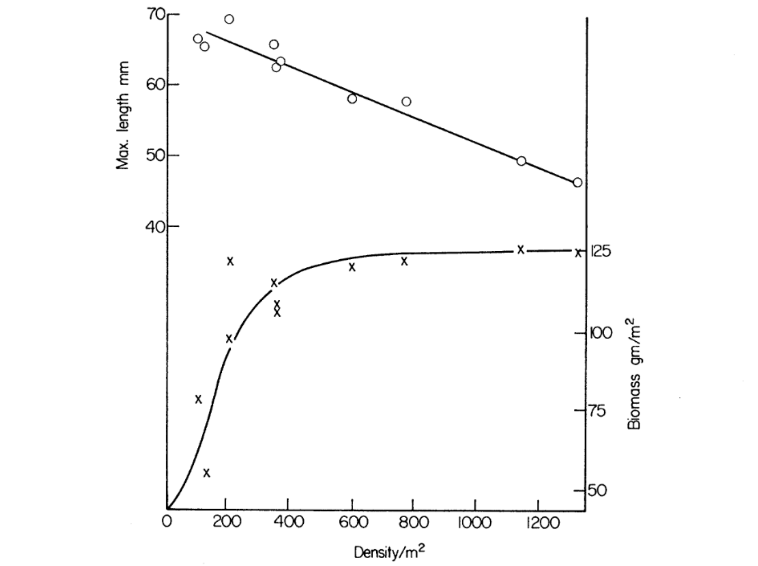


FIG. 3. Maximum length (○) and biomass (×) of *Patella cochlear* relative to density.

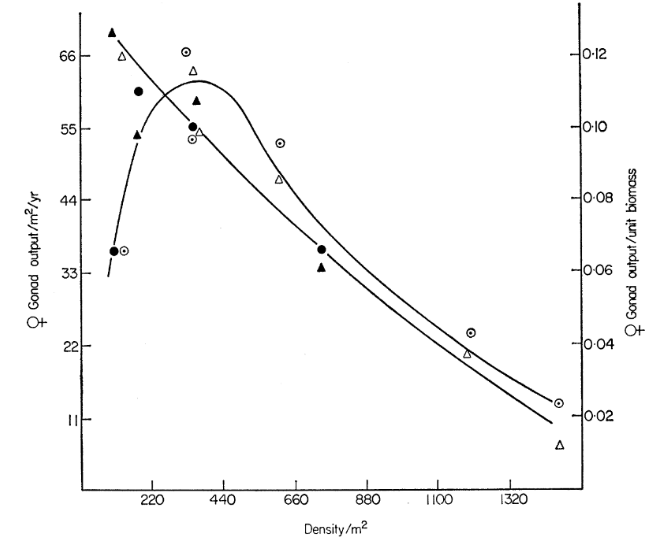


FIG. 6. Gonad output in *Patella cochlear*, relative to density. Gamete output per m²: ●, measured; ⊙, calculated. Gamete output per unit biomass; ▲, measured; △, calculated.

Resources available to individuals typically shrink as population size and density increase.

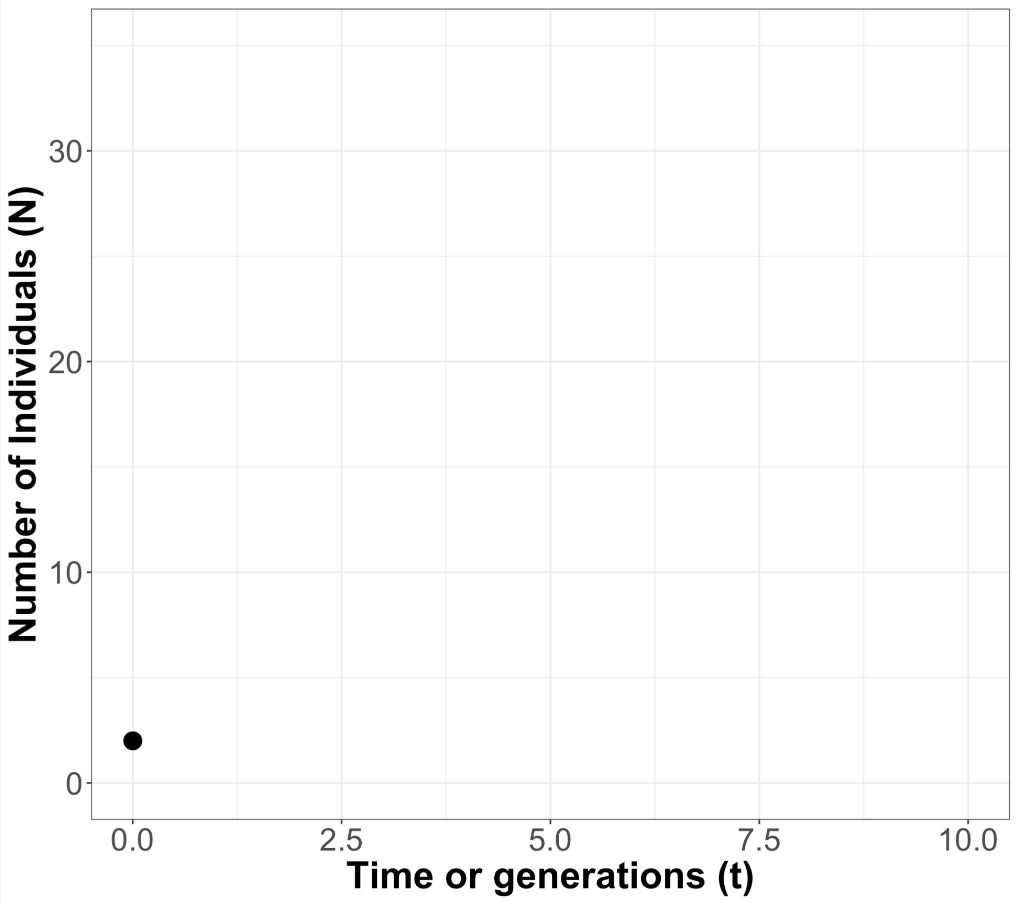
Competition between individuals limits growth and reproductive output.

A study of the Pear Limpet, *Scutellastra cochlear*, by **Branch 1975**

image: Allan Ellis, **iNaturalist**

Population growth curve

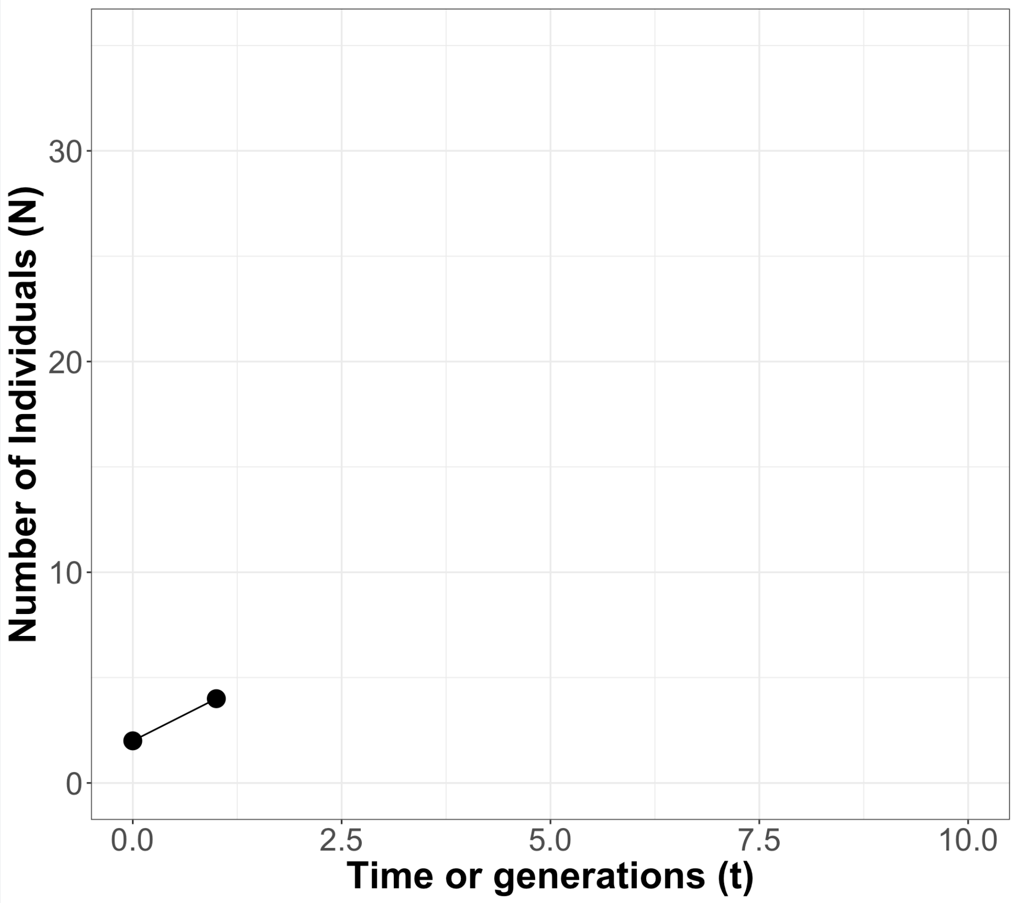
What does our curve look like once we include **density-dependent** effects like intr*a*specific competition (competition among individuals of the same species)?



Population growth curve

What does our curve look like once we include **density-dependent** effects like intr*a*specific competition (competition among individuals of the same species)?

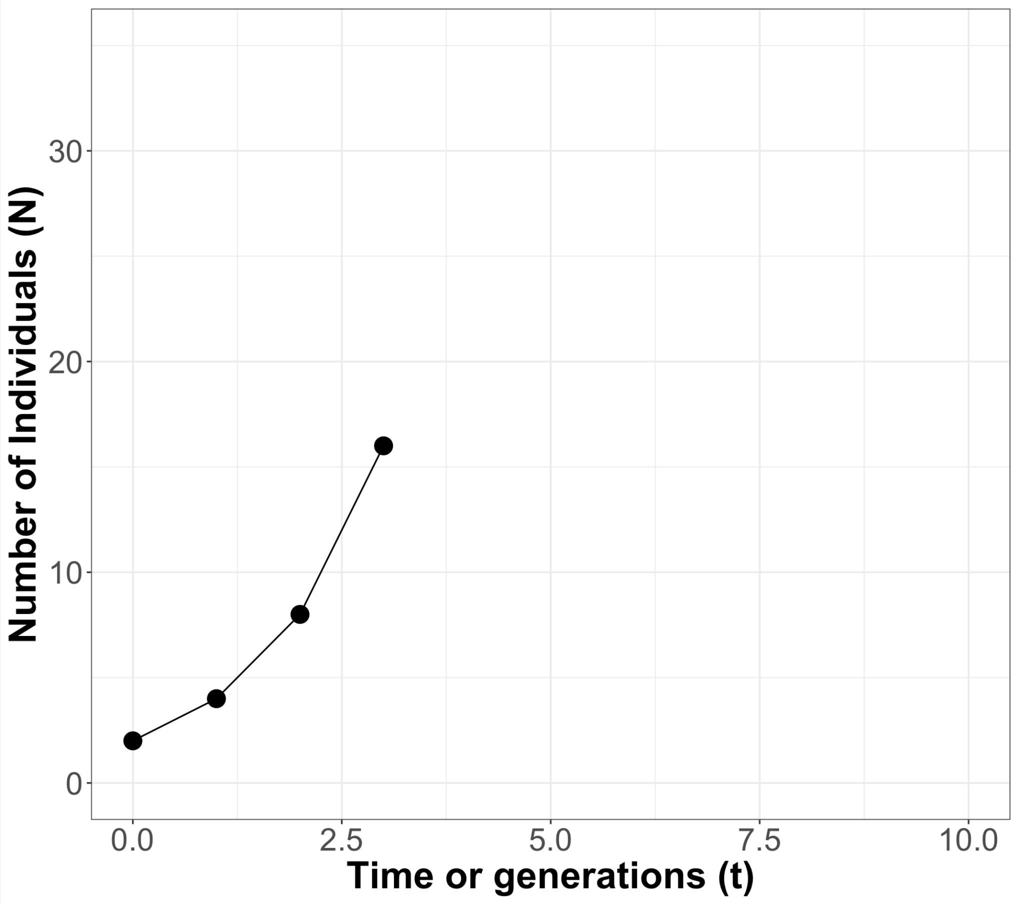
It starts out much the same while resources are abundant...



Population growth curve

What does our curve look like once we include **density-dependent** effects like int*ra*specific competition (competition among individuals of the same species)?

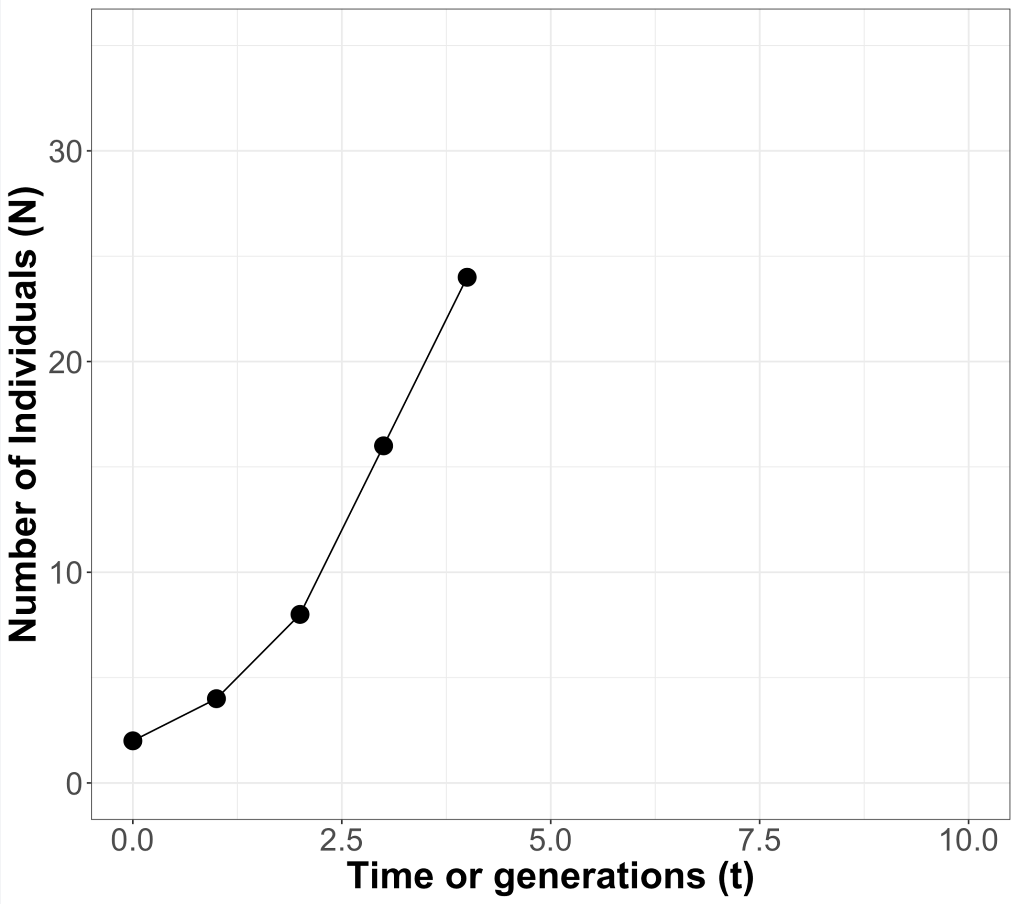
It starts out much the same while resources are abundant...



Population growth curve

What does our curve look like once we include **density-dependent** effects like intr*a*specific competition (competition among individuals of the same species)?

It starts out much the same while resources are abundant…

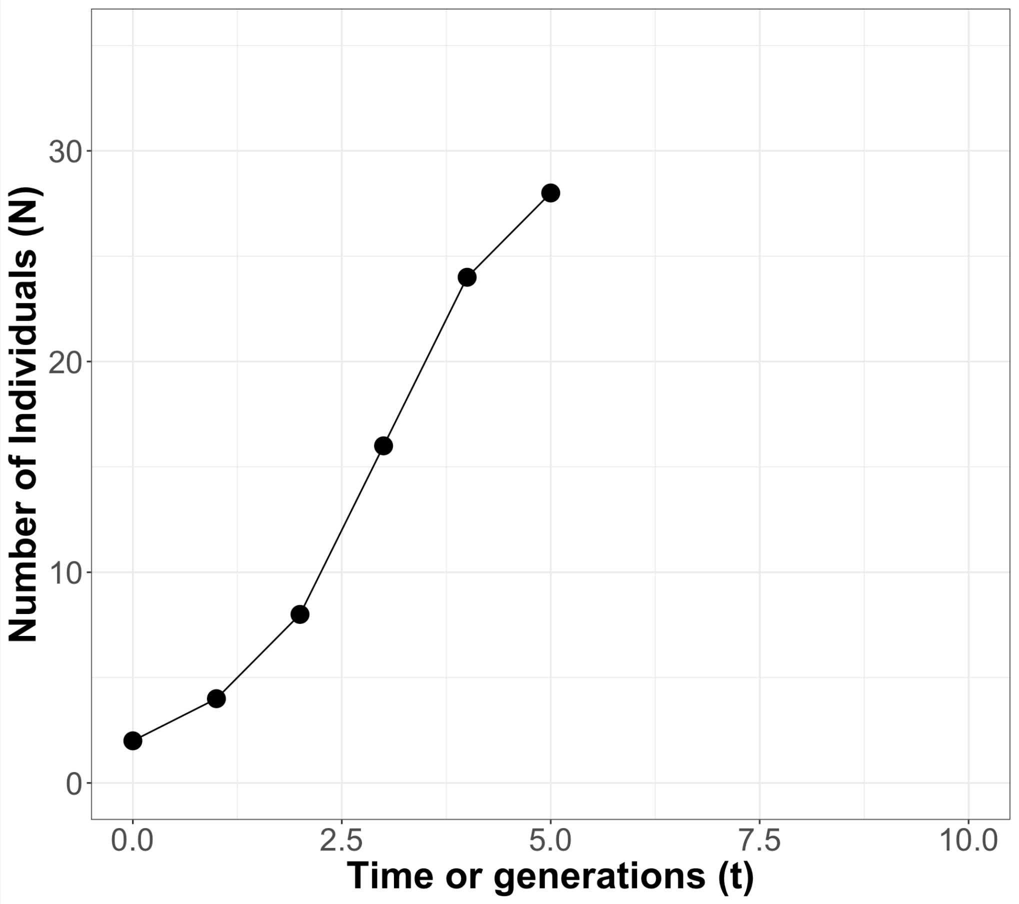


Population growth curve

What does our curve look like once we include **density-dependent** effects like intr*a*specific competition (competition among individuals of the same species)?

It starts out much the same while resources are abundant…

…but slows as resources become limiting…

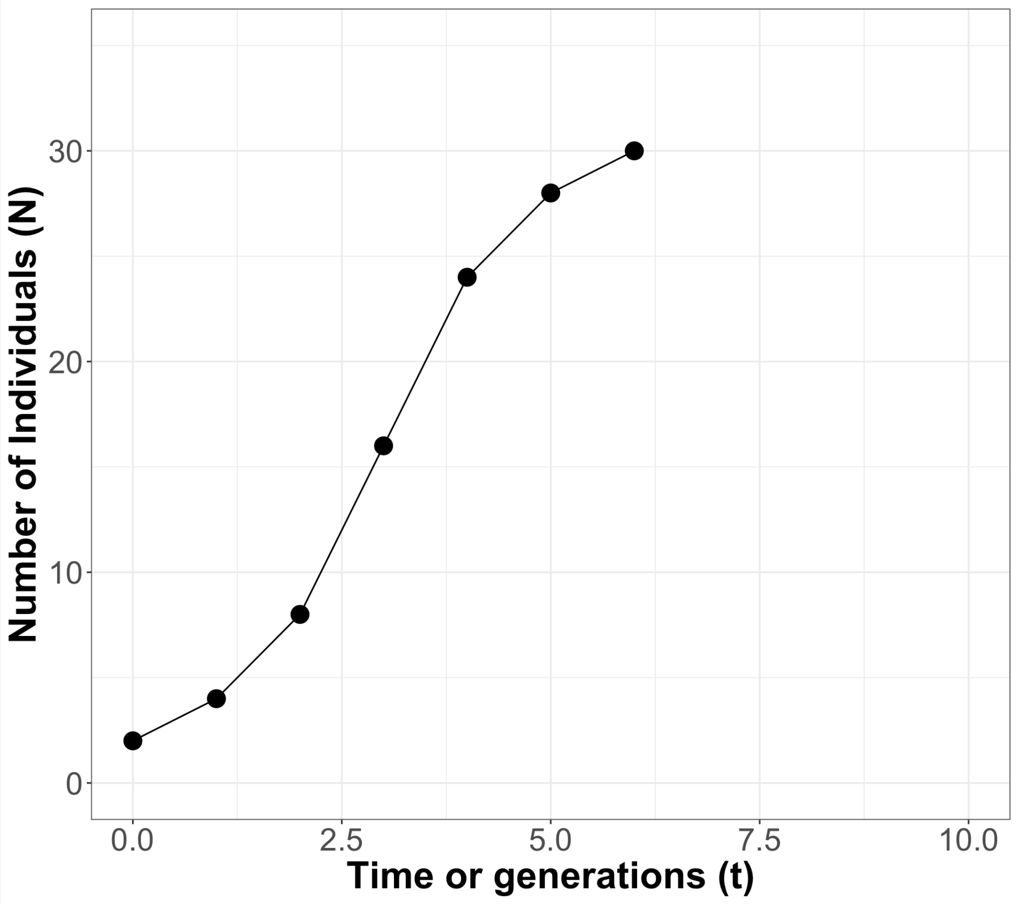


Population growth curve

What does our curve look like once we include **density-dependent** effects like intr*a*specific competition (competition among individuals of the same species)?

It starts out much the same while resources are abundant...

...but slows as resources become limiting...



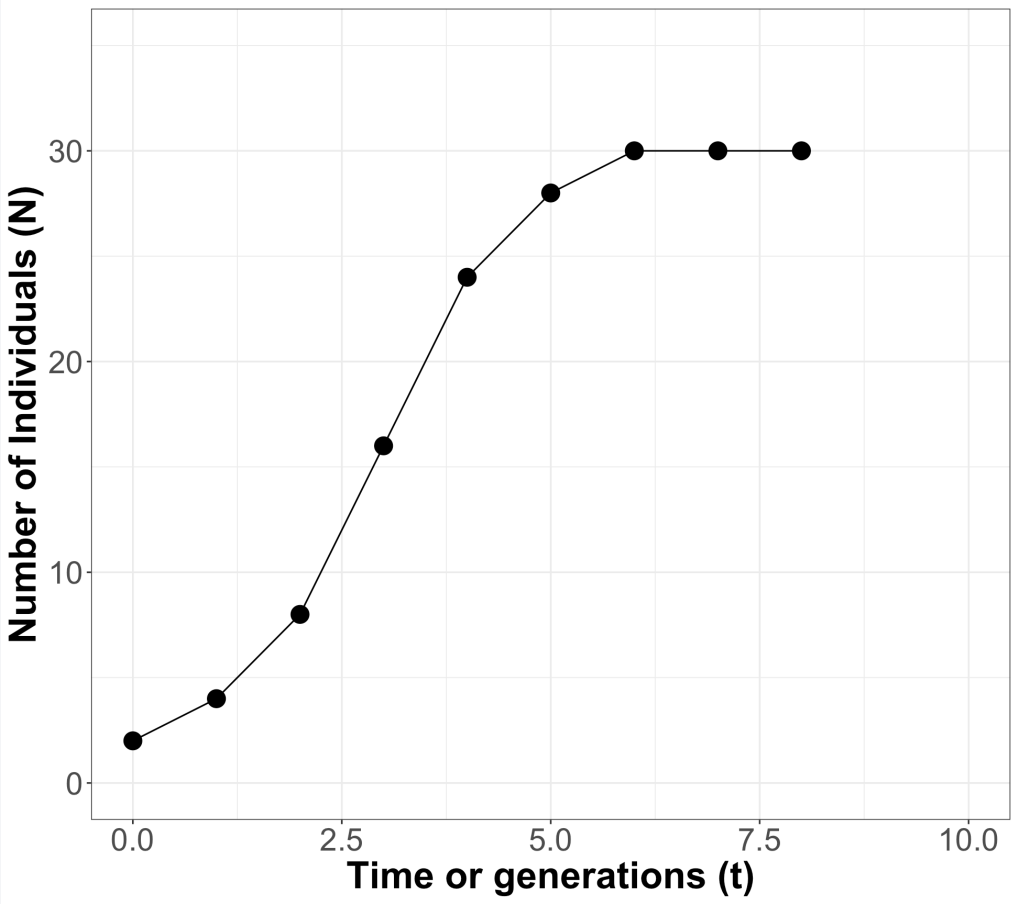
Population growth curve

What does our curve look like once we include **density-dependent** effects like int*ra*specific competition (competition among individuals of the same species)?

It starts out much the same while resources are abundant…

…but slows as resources become limiting…

…and eventually flattens out…



Population growth curve

What does our curve look like once we include **density-dependent** effects like intr*a*specific competition (competition among individuals of the same species)?

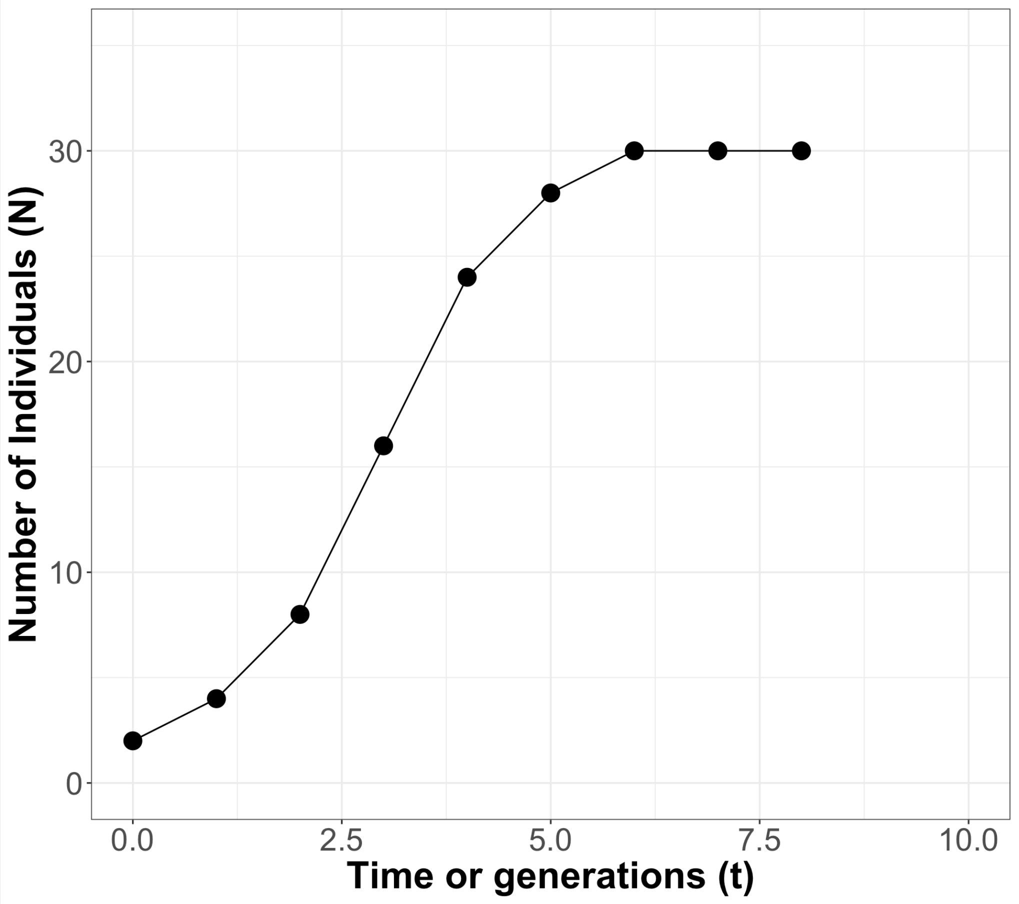
It starts out much the same while resources are abundant…

…but slows as resources become limiting…

…and eventually flattens out…

Any thoughts on the equation to fit this curve?

$dN/dt = ?$



Population growth curve

What does our curve look like once we include **density-dependent** effects like intr*a*specific competition (competition among individuals of the same species)?

It starts out much the same while resources are abundant...

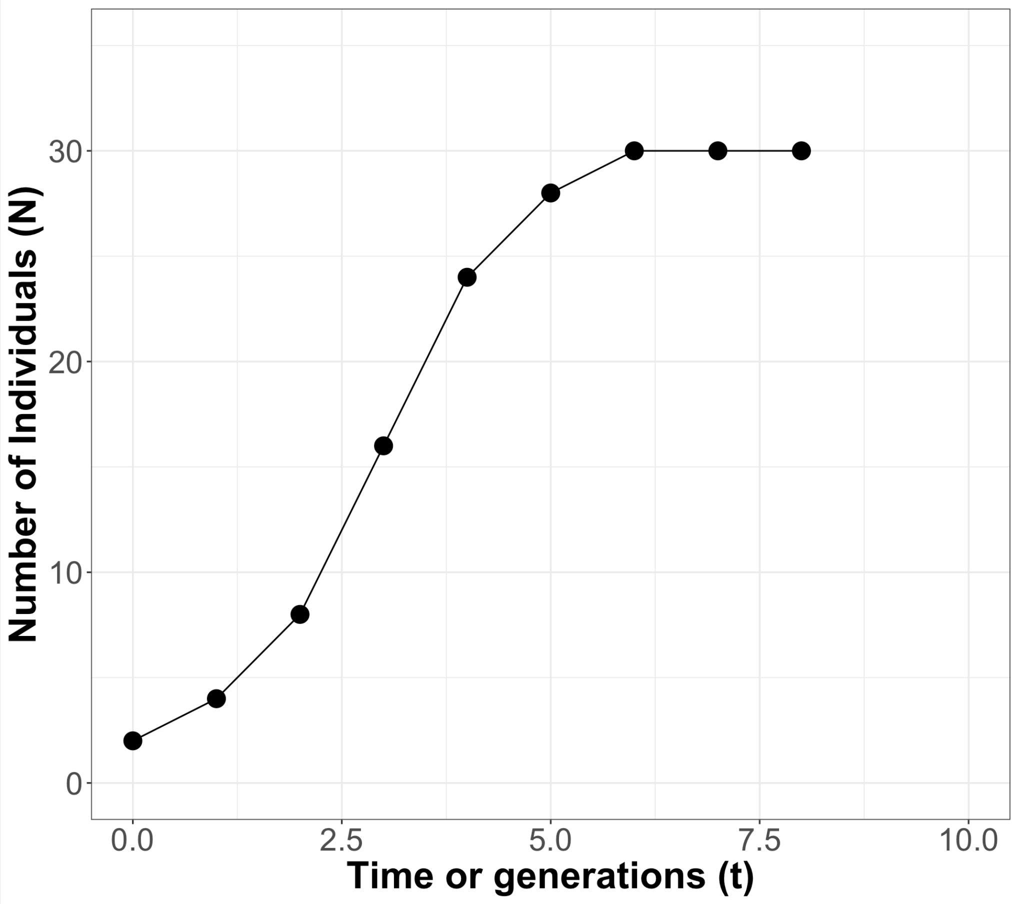
...but slows as resources become limiting...

...and eventually flattens out...

Any thoughts on the equation to fit this curve?

$$dN/dt = rN(K - N)/K$$

A logistic function, or what we call the logistic growth curve.

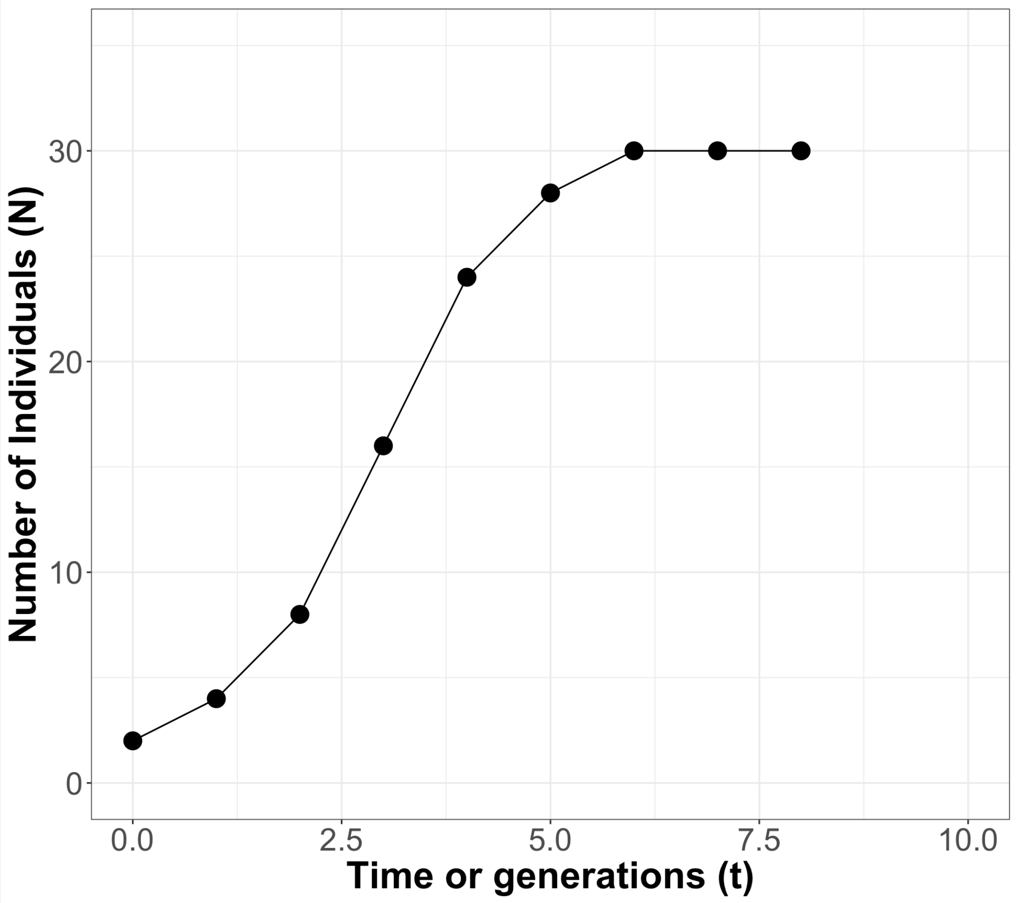


Population growth curve

The population growth curve including **density-dependent** effects like intr*a*specific competition (competition among individuals of the same species) is a logistic function, flattening out as resources become limiting.

$$dN/dt = rN(K - N)/K$$

We know N, t and r, but what is K?



Population growth curve

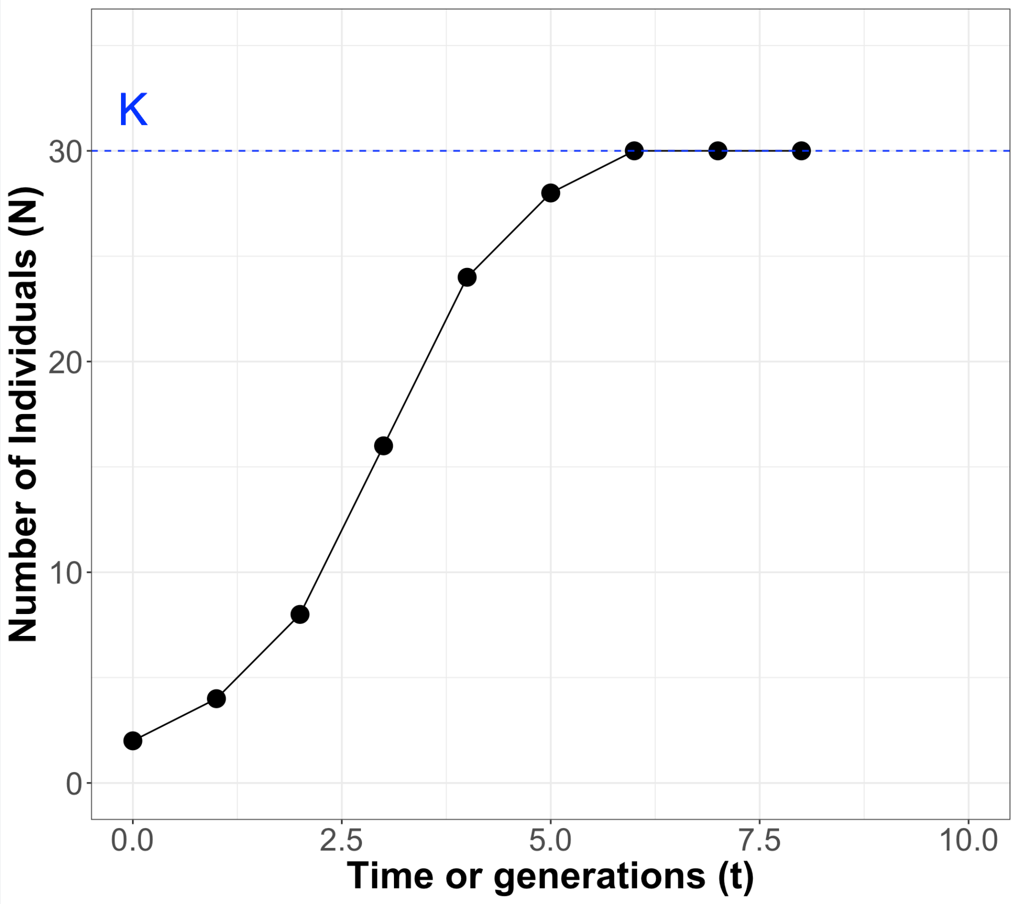
The population growth curve including **density-dependent** effects like intr*a*specific competition (competition among individuals of the same species) is a logistic function, flattening out as resources become limiting.

$$dN/dt = rN(K – N)/K$$

We know N, t and r, but what is K?

K = carrying capacity

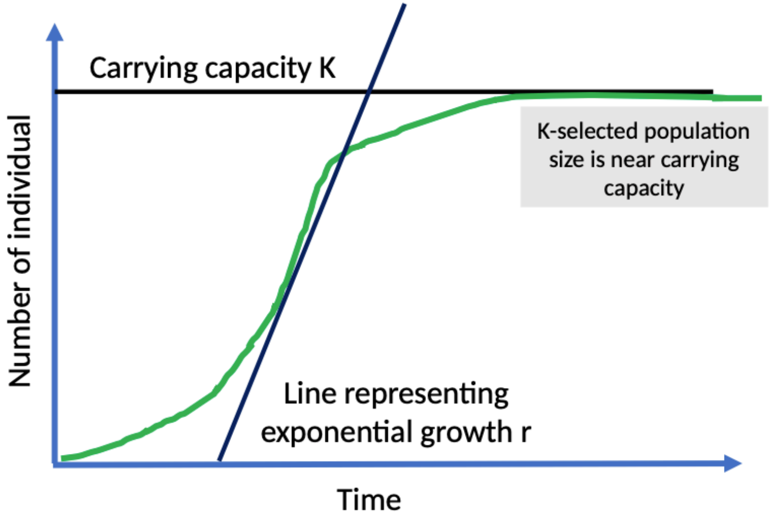
Familiar?



r and K selection

Mac Arthur & Wilson, 1967

- r-selected: (*r is for reproduction*). Favoured for the ability to reproduce rapidly (high r - values) in r-selecting habitats (more unstable).
- K-selected: Favoured for the ability to make a large proportional contribution to a population which remains at its *carrying capacity (K)* in K-selecting habitats (more stable).



2

Terry Hedderson's lecture on life history models

Population growth curve

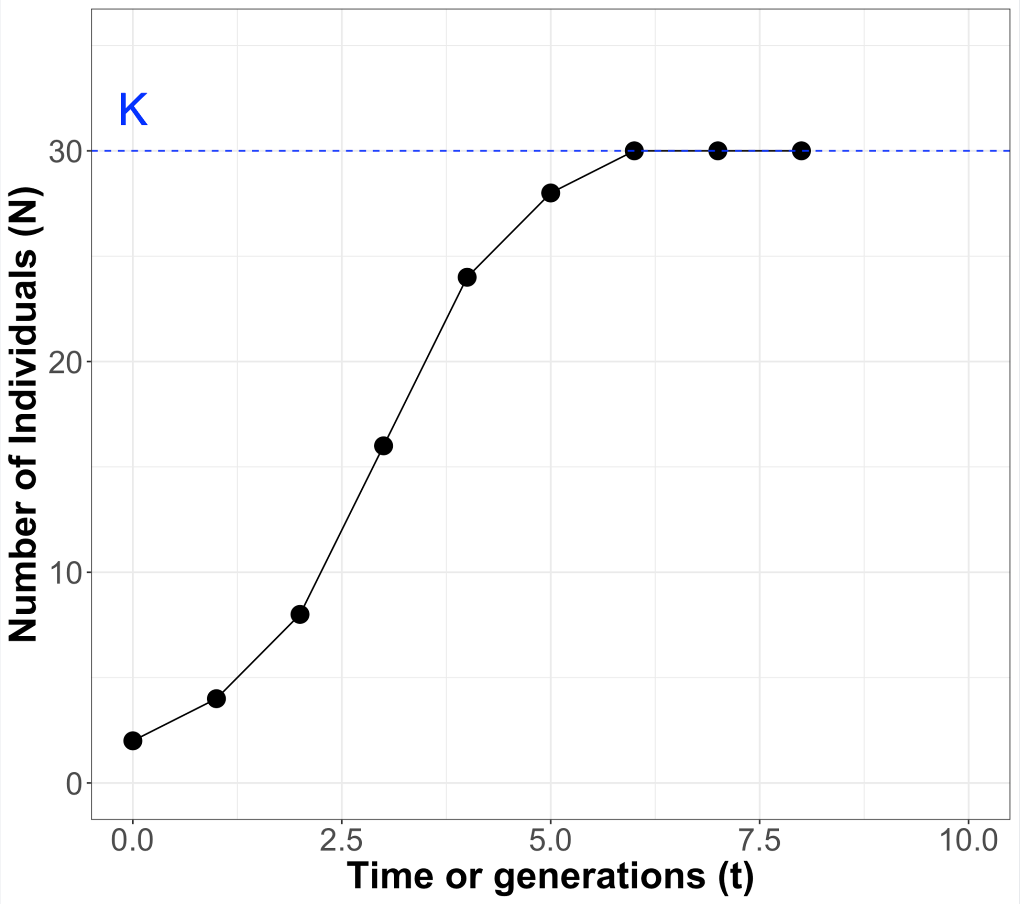
The population growth curve including **density-dependent** effects like intr*a*specific competition (competition among individuals of the same species) is a logistic function, flattening out as resources become limiting.

$$dN/dt = rN(K – N)/K$$

K = carrying capacity

Note: *Where N is small, the logistic growth curve approximates the exponential growth curve (rN), because $(K – N)/K$ is close to 1.*

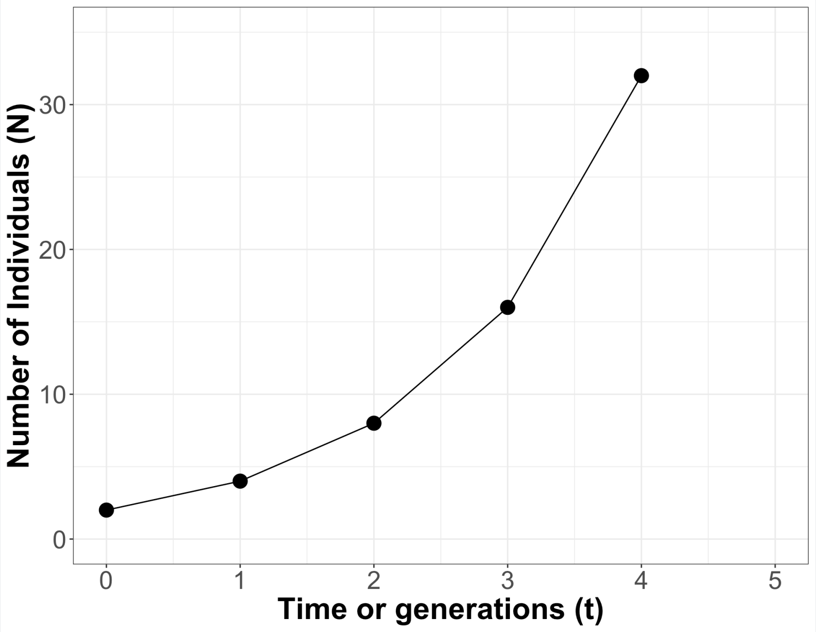
It begins to deviate as N increases.



Exponential growth

$dN/dt = rN$

Population growth rate, r, doesn't change with population size

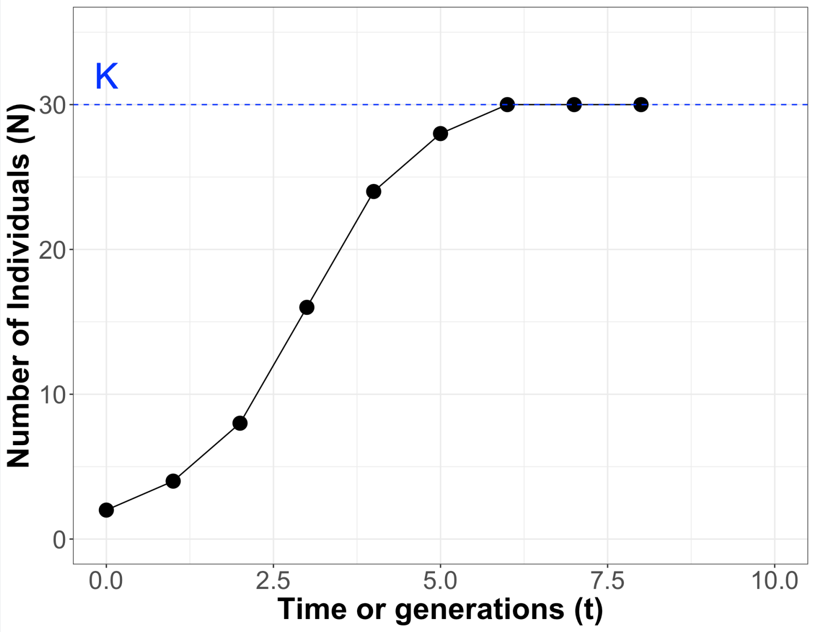


Density independent population growth

Logistic growth

$dN/dt = rN(K - N)/K$

Population growth rate, r, gets small as the population approaches carrying capacity, K



Density independent population growth

What are the implications of density-dependent growth?

What are the implications of density-dependent growth?

Serotinous Proteaceae are well known for extreme population density fluctuations after fire.

image: Roets et al 2006

ECOSCIENCE

Fire life histories and the seeds of chaos[1]

William J. BOND, Kristal MAZE & Phillip DESMET, Botany Department, University of Cape Town, Private Bag, Rondebosch, 7700, South Africa, e-mail: bond@botzoo.uct.ac.za

While some of this may be exogenous, driven by external forces like climate fluctuations or variability in the fire regime, **Bond et al 1995** demonstrated that it could be endogenous, driven by internal population dynamics due to density-dependent effects.

Bond et al 1995

Density-dependence in serotinous Cape Proteaceae

Empirical datasets showed evidence for a negative impact of density-dependence on:

- recruitment (Figure 1)
- fecundity (Figure 4)

Notice the exogenous effect of aridity on *Protea repens* seedling establishment at the arid inland site (Figure 1, bottom).

Bond et al 1995

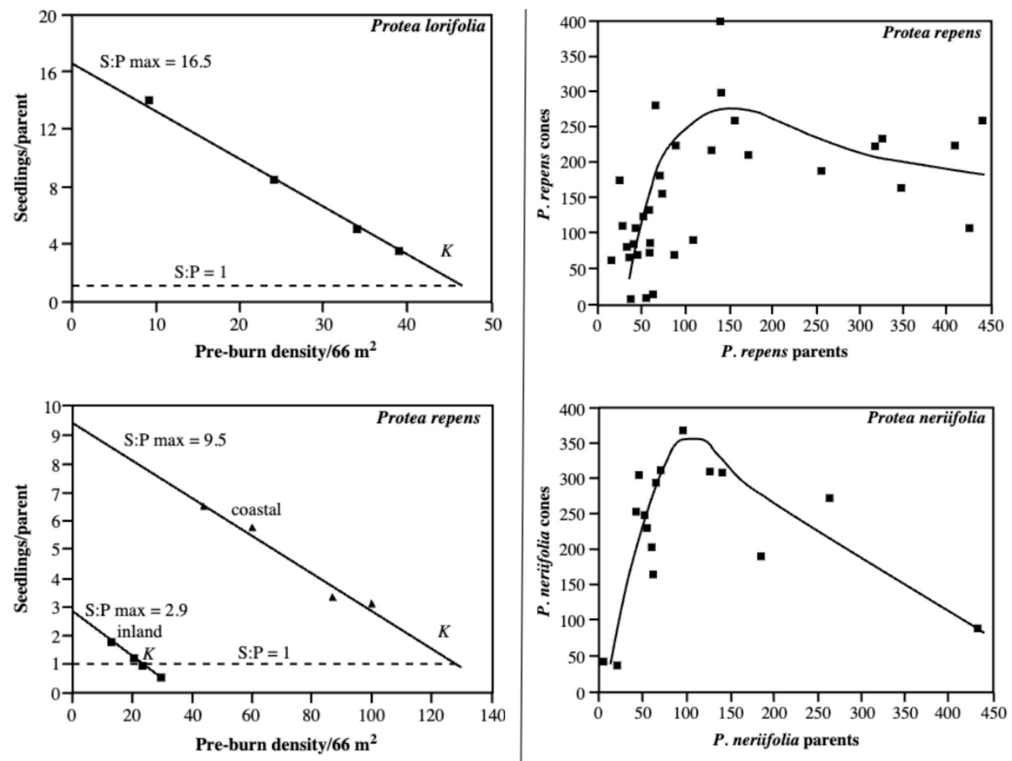


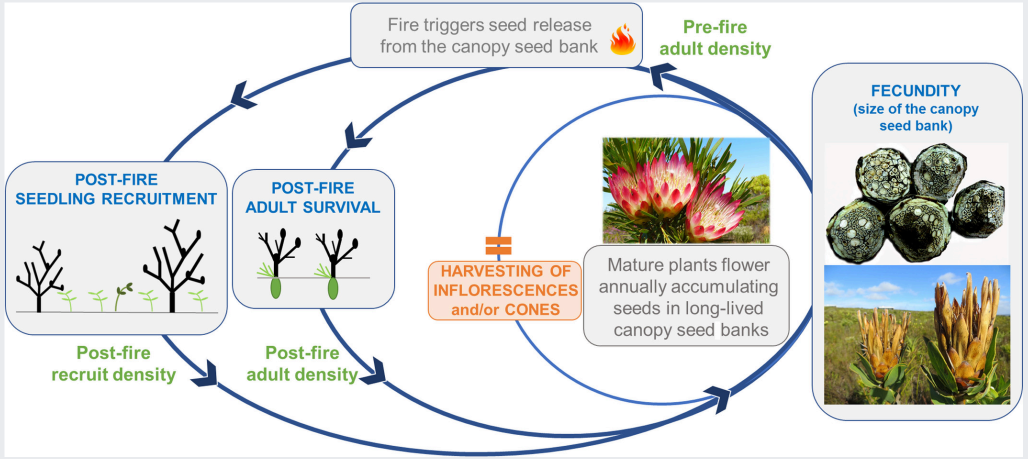
FIGURE 1. Density-dependent seedling recruitment in *Protea lorifolia* and *Protea repens* populations burnt in autumn fires. Values are derived from post-burn censuses of seedlings and skeletons of pre-burn individuals (Bond, Vlok & Viviers, 1984). The intercept of the regression equation gives λ_{max} (= S:P max) while K, the carrying capacity, is the pre-burn density at which seedlings reach replacement levels (λ = S:P = 1). Two populations of *P. repens* are shown, one from a mesic coastal site and one from a more arid inland mountain range.

FIGURE 4. The relationship between number of cones per 10 m × 10 m plot and plant density for two proteoid shrubs, *Protea repens* and *P. neriifolia* (Maze & Bond, 1995). The curves are fitted by hand.

Protea density-dependence

They fed their empirical data into demographic models and projected population growth over multiple generations.

Note that generations and fires are synonymous, because serotinous Proteaceae mostly only recruit after fire.



Bond et al 1995

Figure from **Treurnicht et al 2021**. Ignore the harvesting...

Protea density-dependence

They fed their empirical data into demographic models and projected population growth over multiple generations.

Note that generations and fires are synonymous, because serotinous Proteaceae mostly only recruit after fire.

Bond et al 1995

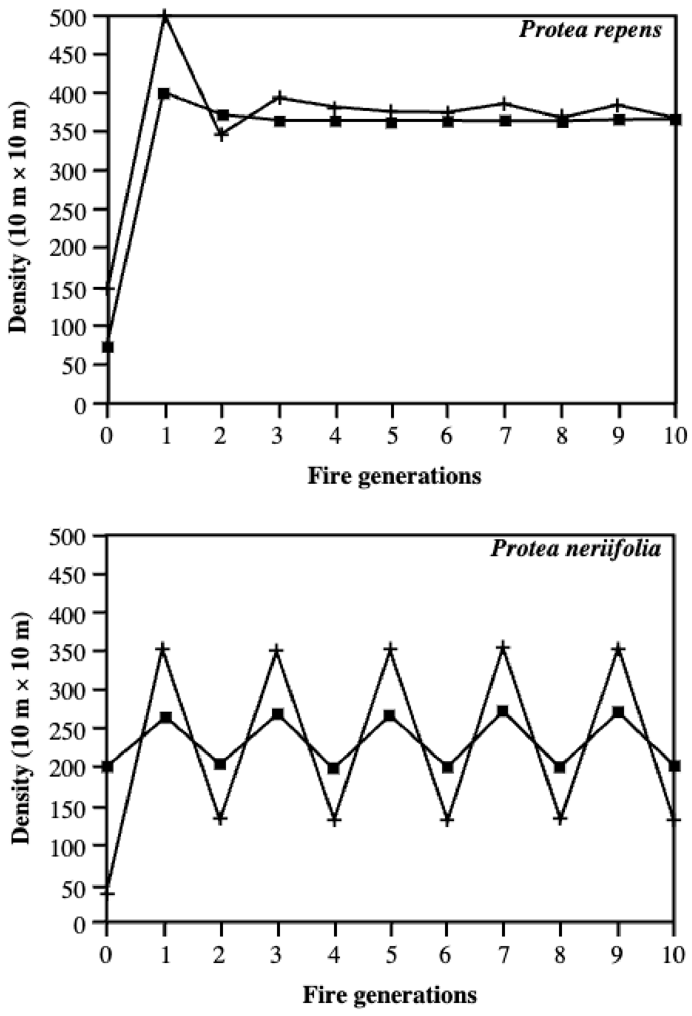


FIGURE 5. Graphic interpolation of population trajectories derived from the curves shown in Figure 4 (see Symonides, Silvertown & Andreasen, 1986 for the procedure used). The population trajectories were adjusted for seeds per cone, seed survival through fire and first dry season seedling mortality using data from Maze & Bond (1995) collected after an experimental burn. The different trajectories for each species indicate sensitivity to initial starting populations. N_o for *P. repens* = 75 (squares), 150 (crosses). N_o for *P. neriifolia* = 50 (crosses), 200 (squares).

Protea density-dependence

They fed their empirical data into demographic models and projected population growth over multiple generations.

Note that generations and fires are synonymous, because serotinous Proteaceae mostly only recruit after fire.

Decreasing the starting population size (N_0), which would reduce the initial effect of density on population growth, increased the amplitude of population fluctuations, creating risk of total population crashes.

This effect was stronger in *P. neriifolia*, because it had higher cone production (fecundity) and was more sensitive to population density.

Bond et al 1995

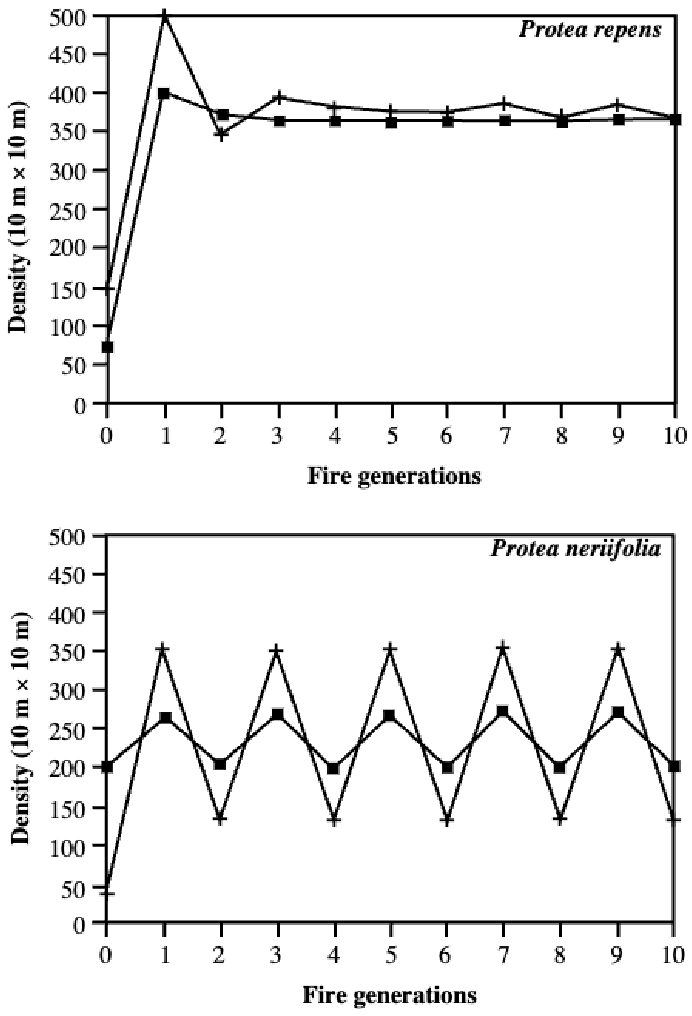


FIGURE 5. Graphic interpolation of population trajectories derived from the curves shown in Figure 4 (see Symonides, Silvertown & Andreasen, 1986 for the procedure used). The population trajectories were adjusted for seeds per cone, seed survival through fire and first dry season seedling mortality using data from Maze & Bond (1995) collected after an experimental burn. The different trajectories for each species indicate sensitivity to initial starting populations. N_o for *P. repens* = 75 (squares), 150 (crosses). N_o for *P. neriifolia* = 50 (crosses), 200 (squares).

How does this relate to the original question at the start of the lecture?

The Hutchinsonian Niche

G Evelyn Hutchinson proposed that *the niche is an n-dimensional hypervolume within which a species is* ***able to maintain a viable population*** - **Hutchinson 1957**

Does the occurrence of a species at a locality mean it is able to maintain a viable population there...?

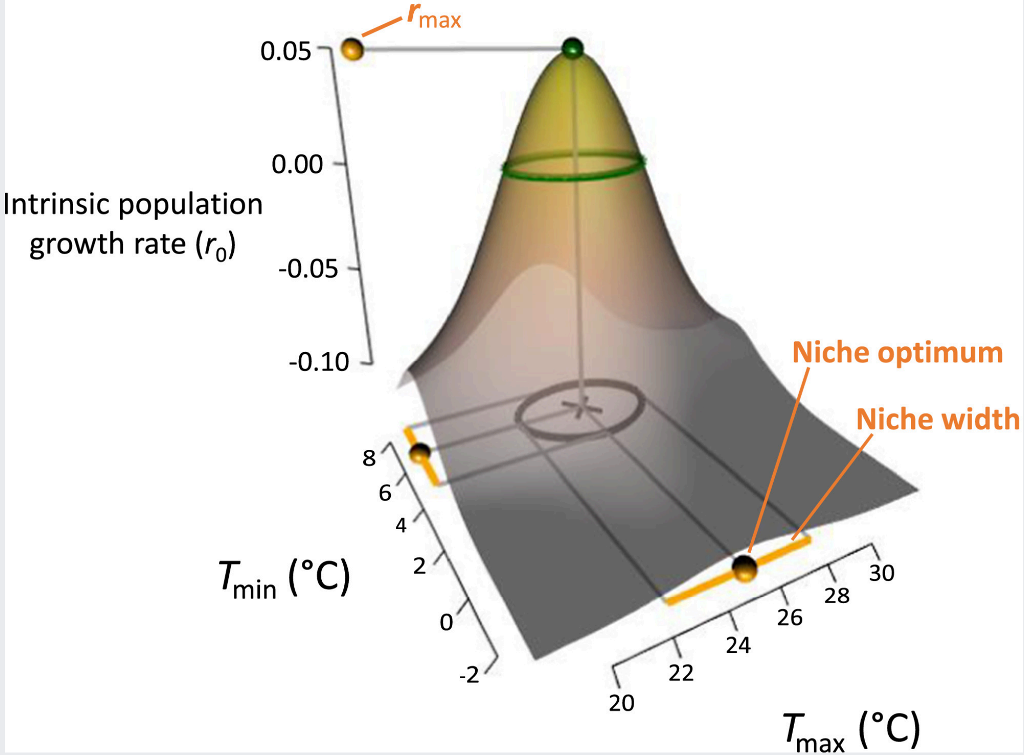


Figure from **Treurnicht et al. 2020**

How does this relate to the original question at the start of the lecture?

The Hutchinsonian Niche

G Evelyn Hutchinson proposed that *the niche is an n-dimensional hypervolume within which a species is* ***able to maintain a viable population*** - **Hutchinson 1957**

Does the occurrence of a species at a locality mean it is able to maintain a viable population there…?

> No! We need estimates of their population growth rate (r).

We can estimate population growth rate (r) from demographic parameters that we can measure in the field (e.g. birth, death and dispersal rates) using demographic models.

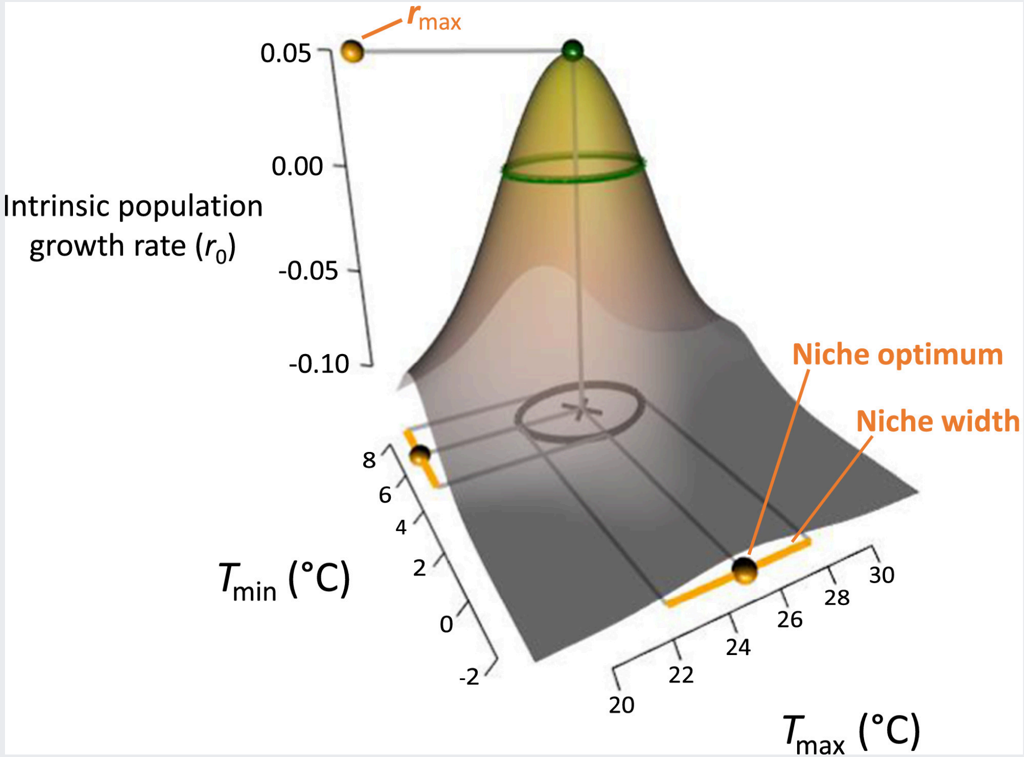


Figure from **Treurnicht et al. 2020**

How does this relate to SDMs?

We can build SDMs based on demographic models that estimate population growth across different environmental conditions.

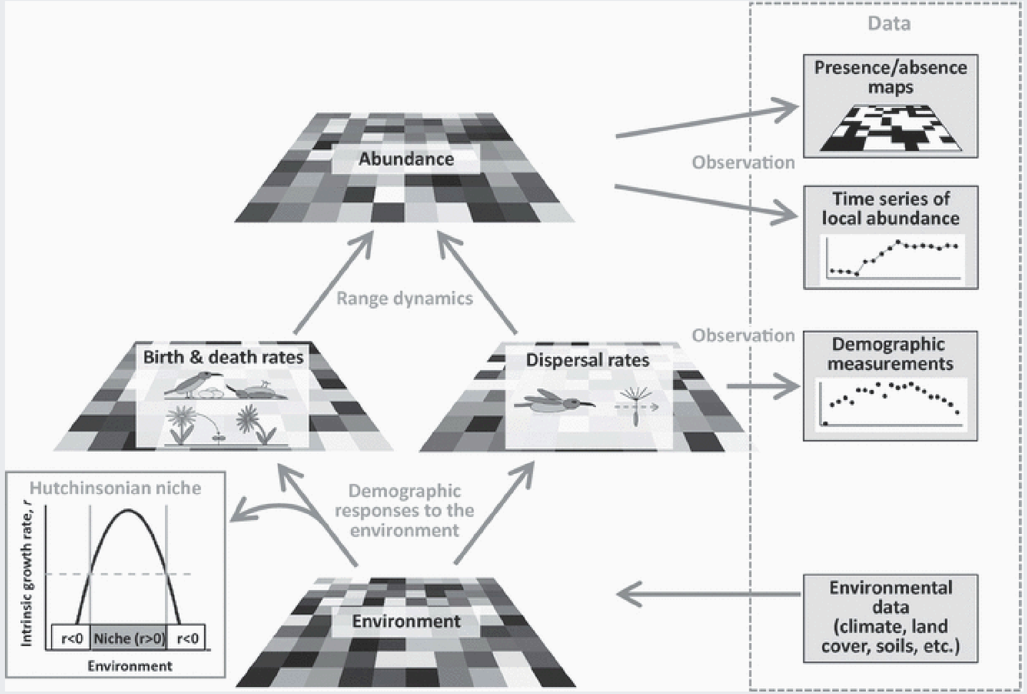

Journal of Biogeography (J. Biogeogr.) (2012) 39, 2146–2162

SPECIAL ISSUE

How to understand species' niches and range dynamics: a demographic research agenda for biogeography

Frank M. Schurr[1,2,3*], Jörn Pagel[1,4], Juliano Sarmento Cabral[5], Jürgen Groeneveld[6,7], Olga Bykova[8], Robert B. O'Hara[4], Florian Hartig[6], W. Daniel Kissling[9], H. Peter Linder[10], Guy F. Midgley[11,12], Boris Schröder[13,14], Alexander Singer[6] and Niklaus E. Zimmermann[15]

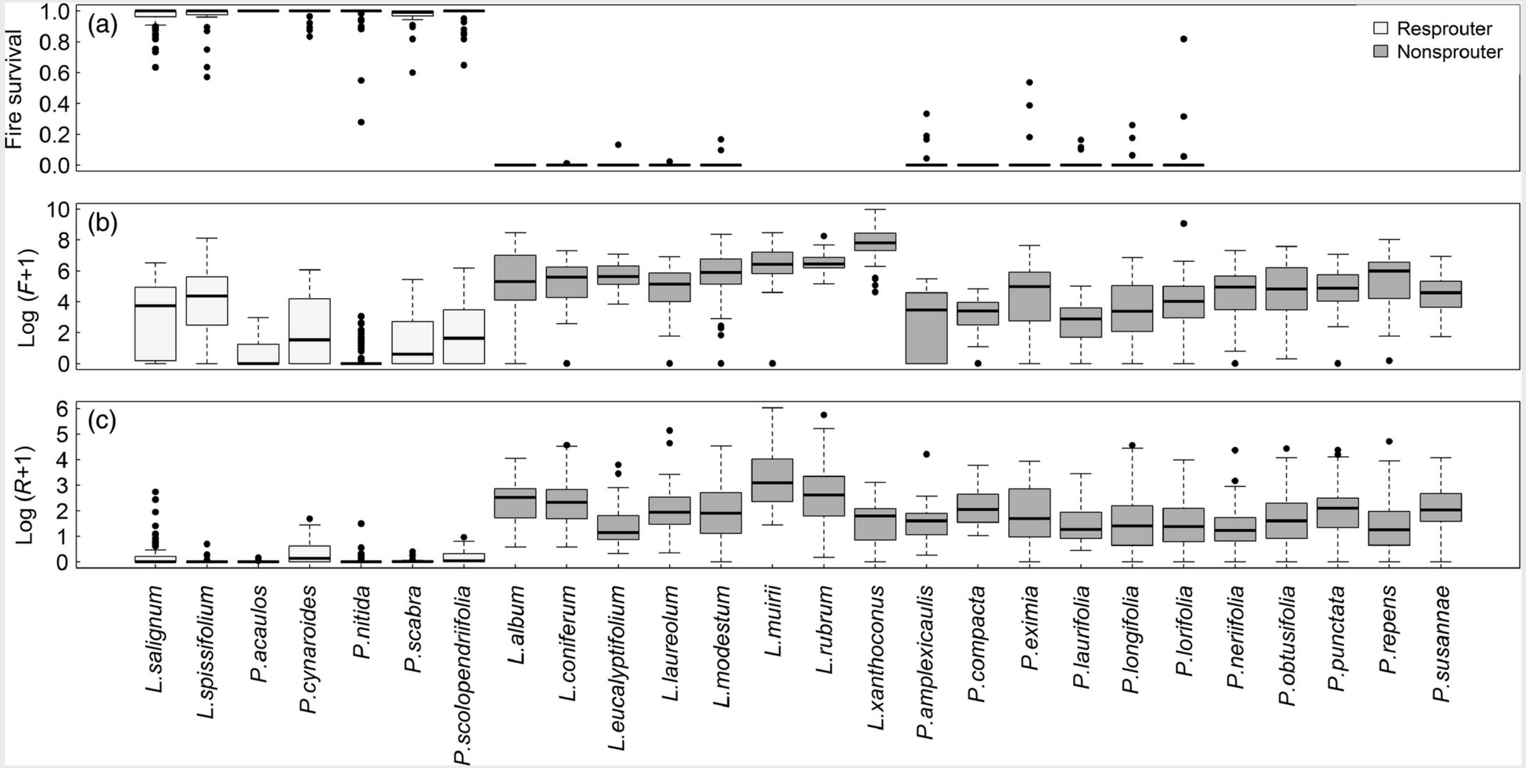
These types of SDMs are often called Demographic Distribution Models (DDMs), and can tell us where species should be able to maintain a viable population!



Schurr et al. 2012

How does this relate to SDMs?

Interestingly, positive population growth can be maintained using very different strategies.



Here seeding vs sprouting serotinous Proteaceae show classic differentiation on the r (invest in recruitment) vs K (invest in survival) life history strategy spectrum **(Treurnicht et al. 2020)**.

Take-home

> *If population growth were density-independent, it would be exponential…*
>
> *Most species exhibit density-dependent population growth due to intraspecific competition and other density-dependent factors (e.g. disease transmission), thus self-regulating their population size.*
>
> *Density-dependence creates an endogenous control on populations and has big implications for their size and stability.*
>
> *One needs estimates of population growth rates to know whether populations can be maintained and define the environmental conditions of the Hutchinsonian niche. This can be done if you can estimate birth, death and dispersal rates.*
>
> *Newer SDMs can include a demographic modelling component to map species distributions based on the Hutchinsonion niche.*

Thanks!

Slides created via the R packages:

xaringan
gadenbuie/xaringanthemer

The chakra comes from remark.js, **knitr**, and R Markdown.