6. Geographic Distributions and Niche Modelling

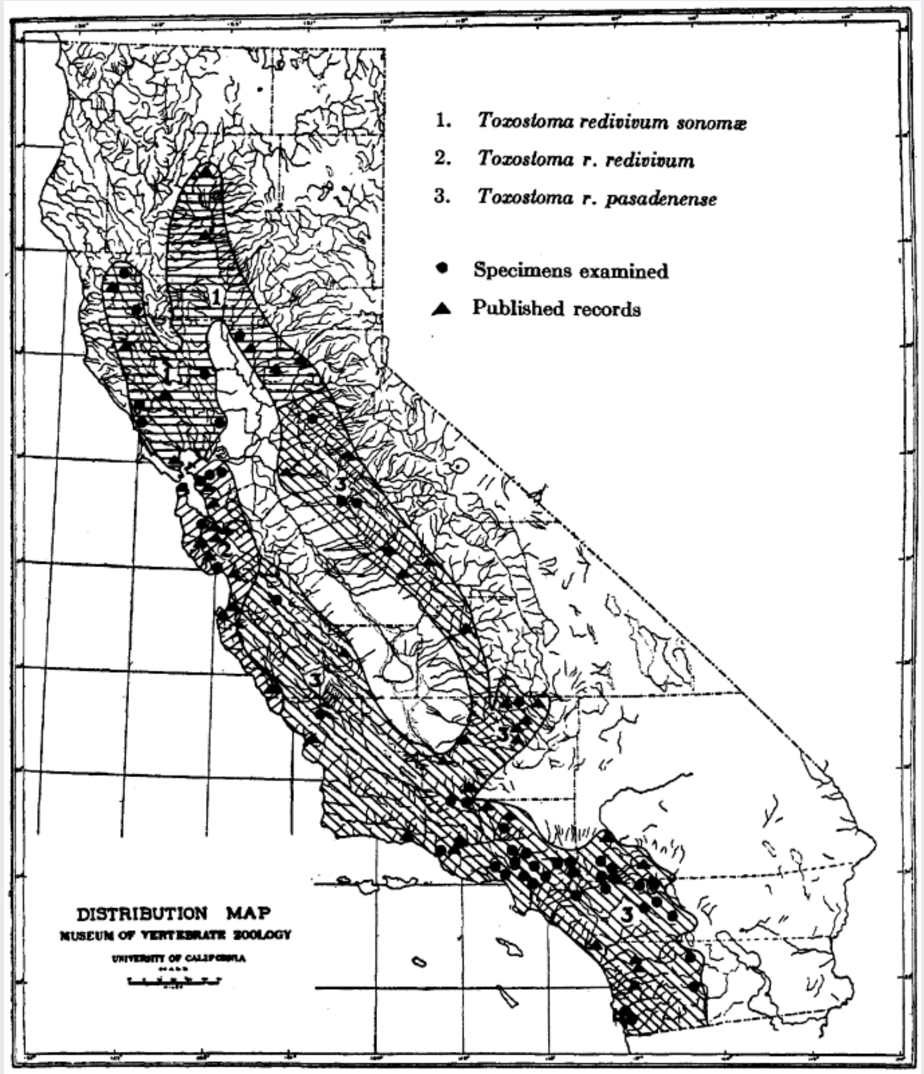
Jasper Slingsby, BIO2014F

2025-05-06

The Grinnellian Niche

Focused on the **abiotic** by exploring species *habitat* based on the environmental requirements of organisms (temperature, rainfall, soils, etc).

Has largely become synonymous with species' geographic distributions.



Grinnell 1917

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**

This both aids our ability to think about the niche, but also allows us to explicitly **quantify the niche and niche space**.

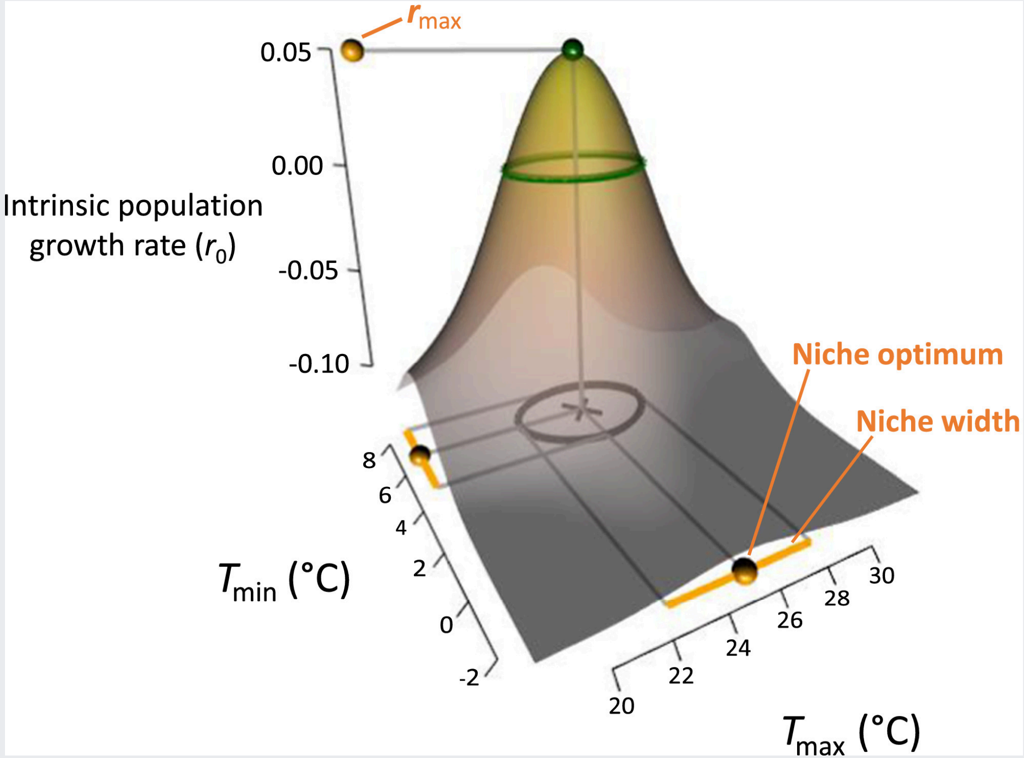


Figure from **Treurnicht et al. 2020**

Species Distribution Models (SDMs)

Also referred to as Ecological Niche Models.

Utilise concepts proposed by Grinnell and Hutchinson to predict the geographic distribution (or range) of species.

SDMs propose that a species' distribution can be predicted based on the environmental conditions at localities where they have been observed.

The "prediction" is usually based on a statistical model that uses the known localities to estimate the probability of a species occurring across the given environmental space.

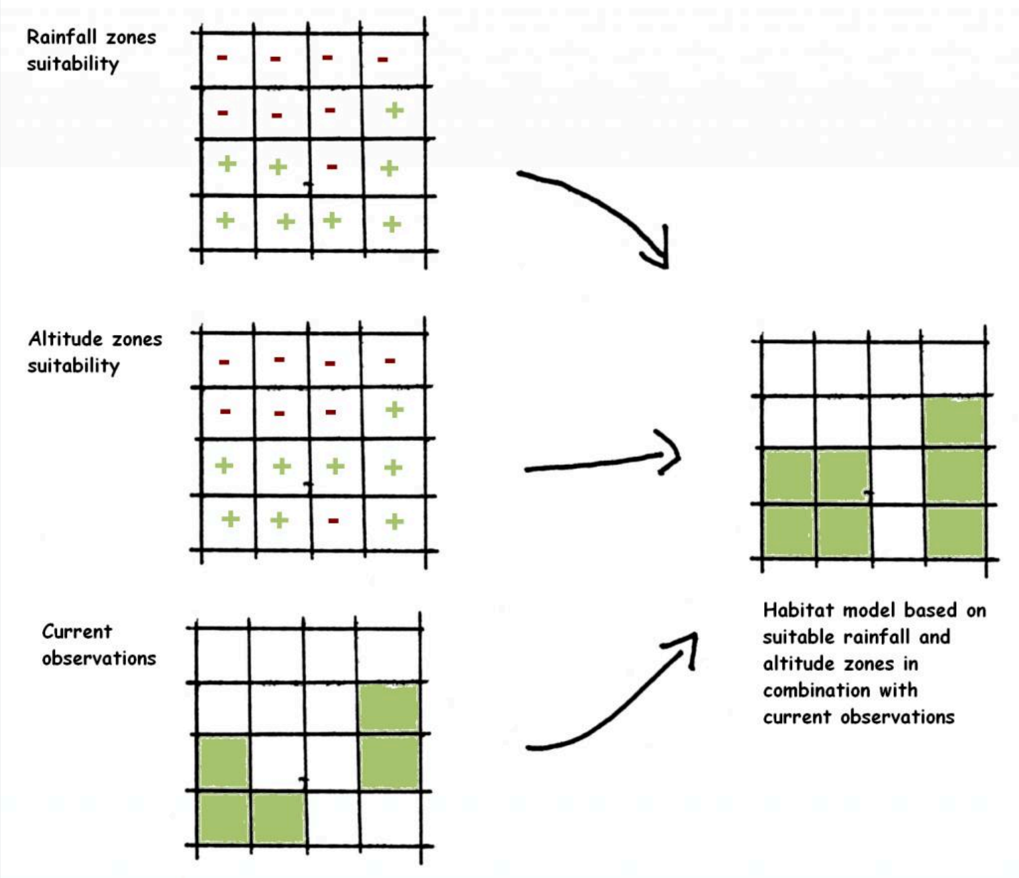
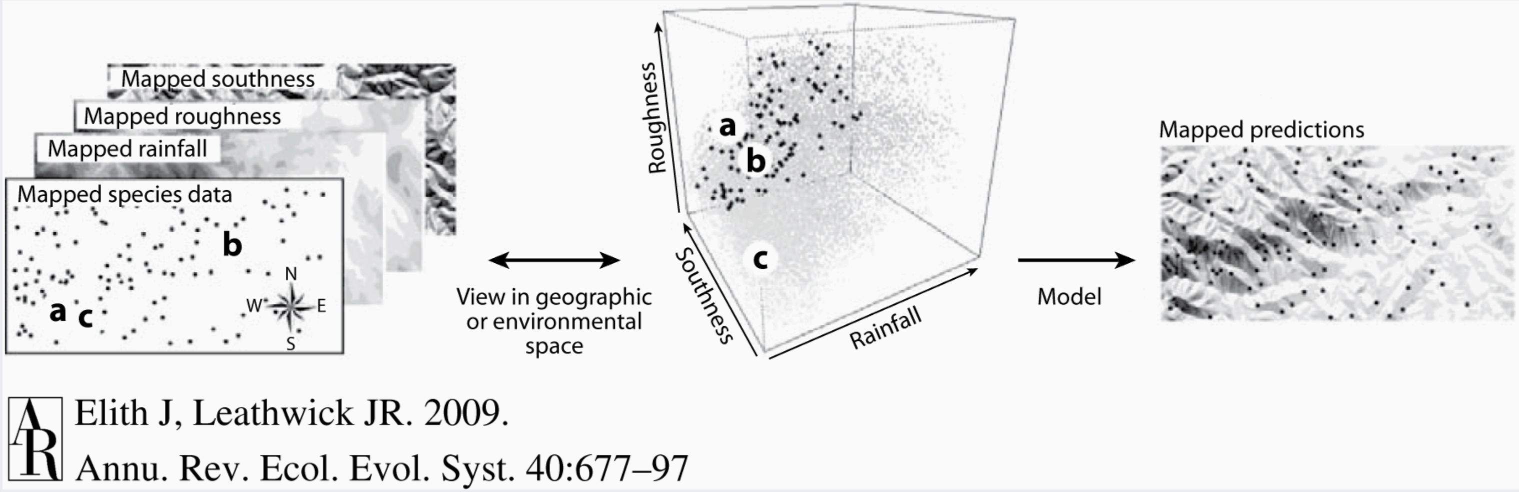


Figure by **Ragnvald**

Species Distribution Models (SDMs)



Left: mapped species occurrences plus spatial data for environmental variables across a particular area.

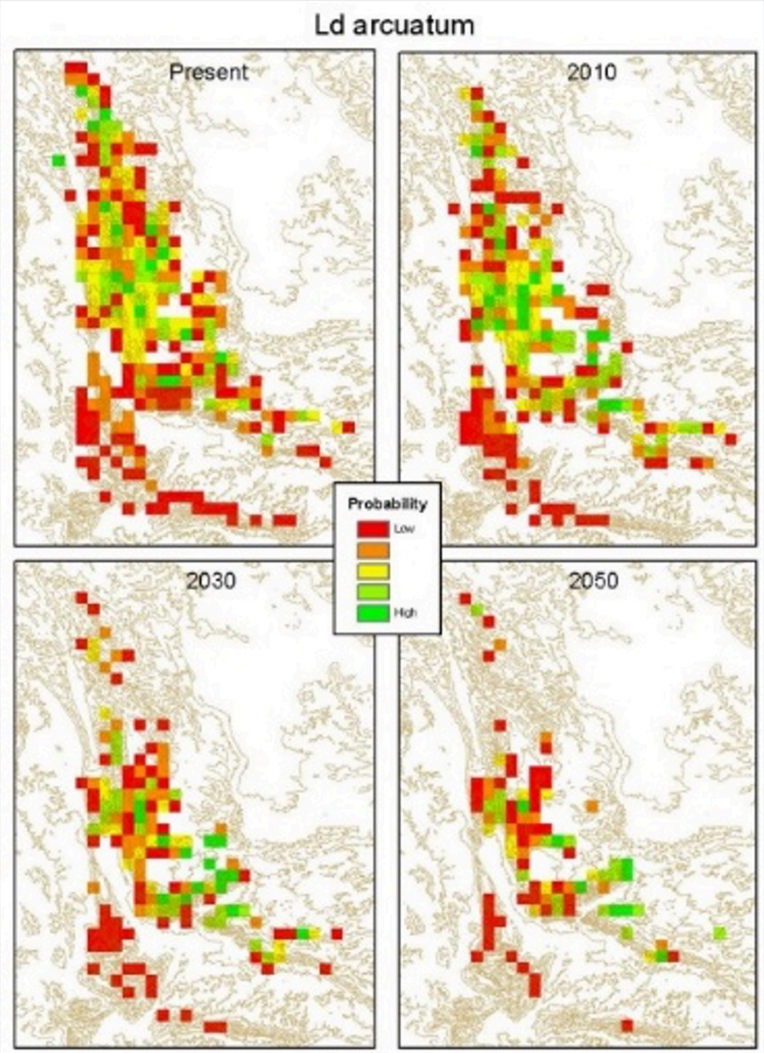
Centre: a 3-dimentional volume showing species occurrences (black) in environmental space (grey). Occurrences are clearly non-random, allowing us to predict the probability of species occurrence at any point.

Right: The predicted geographic distribution of the species, with dark regions representing a high probability of species occurrence and light areas a low probability.

Elith and Leathwick. 2009

What are SDMs used for?

SDMs can predict the present distribution of a species if it is poorly known, but have also been used extensively to explore species' vulnerability to climate change by projecting their potential range under future climates, among other uses.



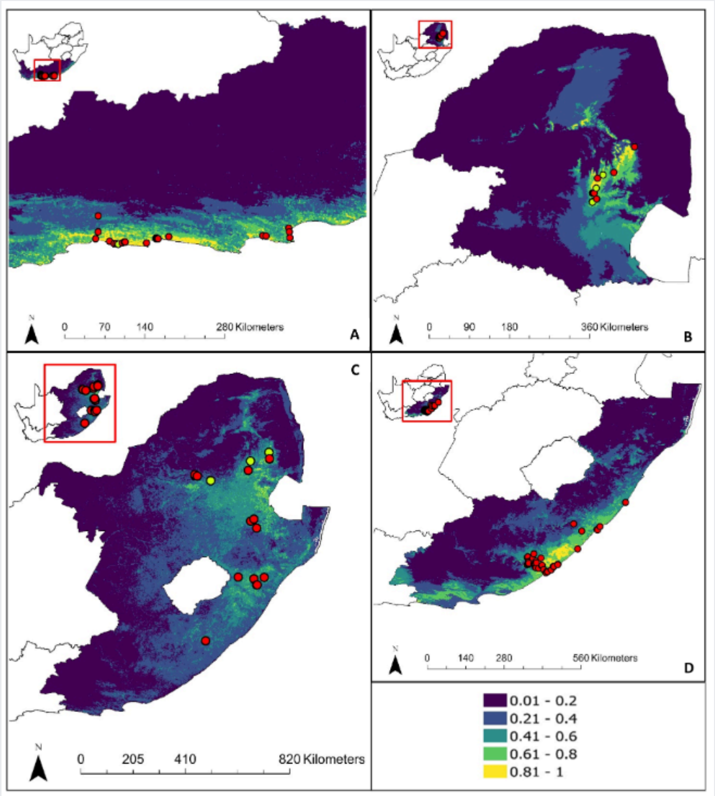
Leucadendron arcuatum by **Francois du Randt, iNaturalist**

Figure from **The Protea Atlas Project**

What are SDMs used for?

Projected species distributions are used in many ways, including in conservation. Our National Screening Tool for environmental impact authorizations for developments includes modelled distributions of animals. Sites where sensitive species occur are required to do more thorough site inspection studies.

Cape Golden Mole, **JP le Roux, iNaturalist**



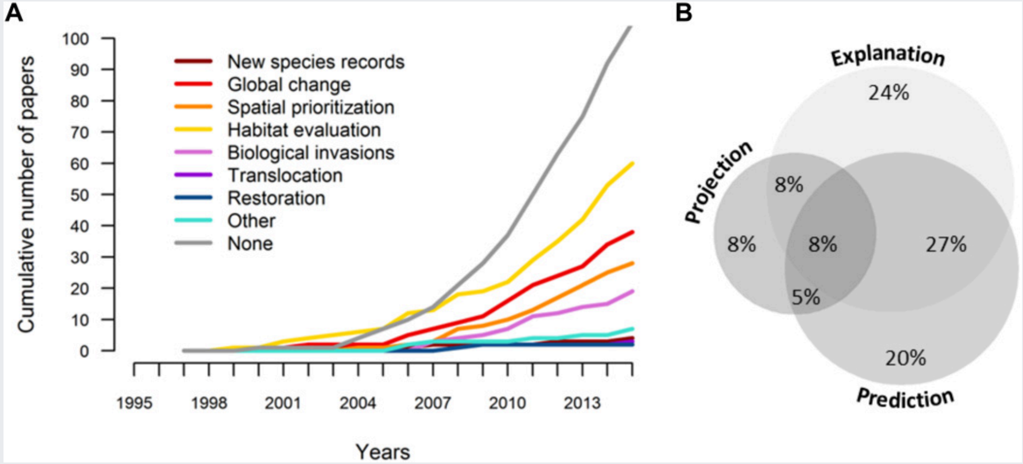
Golden mole distributions, **Cowan et al. 2021**

What are SDMs used for?

> *"A search of articles in peer-reviewed journals over the past 20 years found more than 6000 studies using or mentioning one of the most common classes of biodiversity modeling: species distribution models (SDMs)."*

Araújo et al. 2019

They are clearly very useful in many fields!!!



A) type of biodiversity assessment accomplished with the trend in the numbers of studies shown over time

B) purpose of the model

Figure from **Araújo et al. 2019**

Can you foresee any issues with SDMs?

1. Models vs reality?

Models are simplifications of reality, and their predictions always come with some error (i.e. uncertainty).

Some sources of error in SDMs:

- the type and structure of the model, e.g.
    - statistical (e.g. a correlation) vs mechanistic (i.e. based on first principles)
    - modelling continuous (abundance) vs discrete (presence/absence) only
    - frequentist vs Bayesian (different statistical approaches - wait for BIO3019F for explanation of this…)
- the choice of variables included in the model
    - have all of the most important determinants of a species distribution been included?
    - are all the variables independent? Correlation among variables (autocorrelation) creates bias

1. Models vs reality?

Models are simplifications of reality, and their predictions always come with some error (i.e. uncertainty).

Some sources of error in SDMs ***(continued)***:

- quality of the occurrence and environmental data... - GIGO (garbage in - garbage out)
    - taxonomic accuracy (are you modelling the same thing?)
        - Have they been misidentified?
        - Is the taxonomy any good in the first place (i.e. could be separate species, etc)
    - spatial accuracy/resolution
        - e.g. 10 km accuracy of species localities vs 1 km environmental grid cells
        - in this case you're very likely to extract the wrong environmental data and thus train a poor model
    - biases in the occurrence data
        - easy-to-access areas are usually over-represented (e.g. near roads or paths) and bias the models
    - inaccurate environmental data layers?
        - e.g. climate data is often interpolated from weather stations, which are not evenly distributed, and may be poor estimates of the actual conditions at a locality

There are ways to account for some of these issues, if you are aware of them.

Ideally one quantifies and reports the uncertainty for your model, but that is a topic for **BIO3019S**...

2. SDMs and the realised niche?

Hutchinson made a distinction between the *fundamental* versus the *realised* niche - **Hutchinson 1957**

- The ***fundamental niche*** is the range of conditions (biotic and abiotic) and resources in which a species could survive and reproduce if free of interference from other species.
- The ***realised niche*** is a subset of the fundamental niche where a species actually occurs due to interference from other species (e.g. interspecific competition).

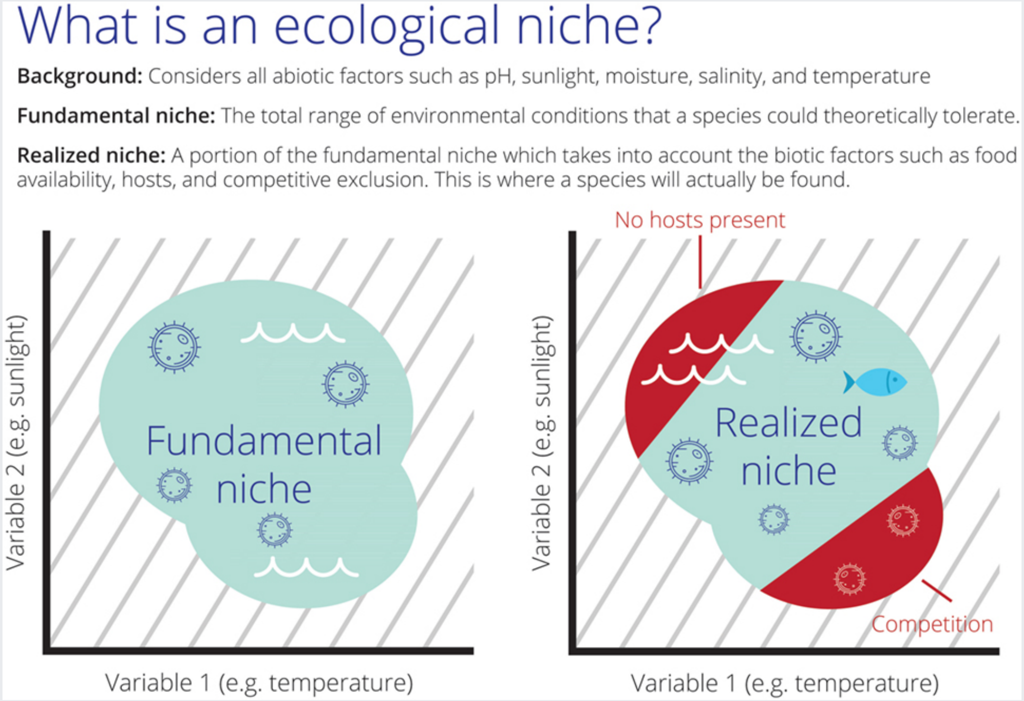
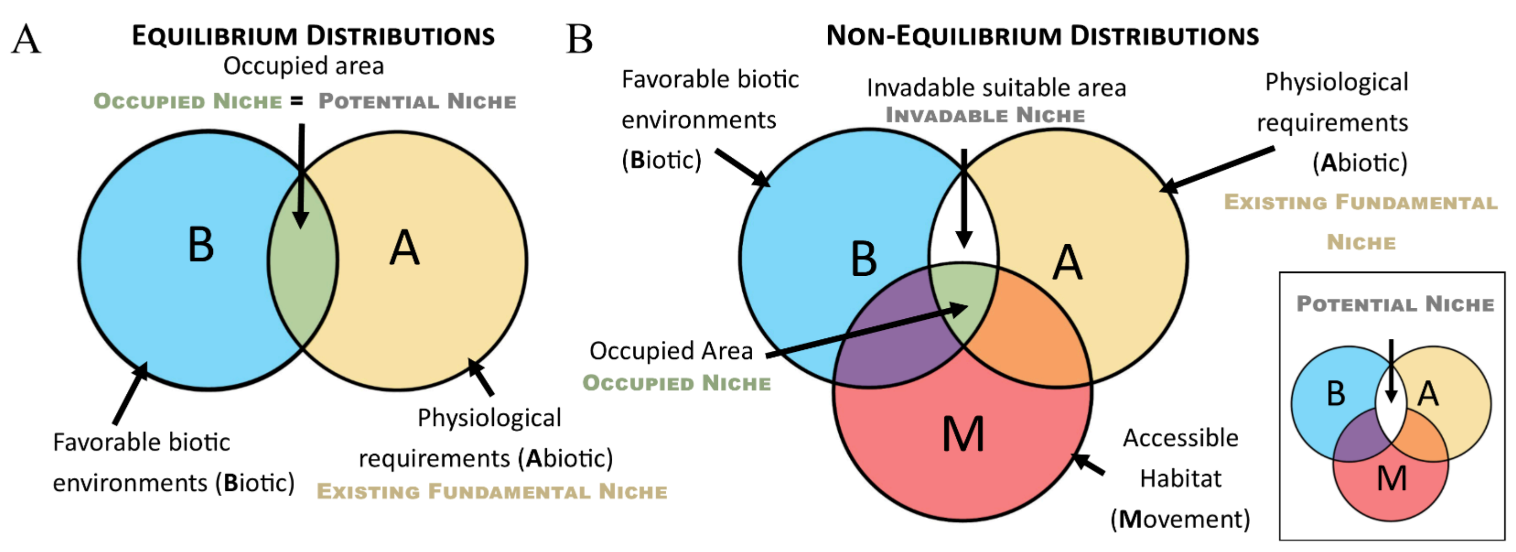


Figure from **Escobar et al 2017**

Which do SDMs represent? Why is this a problem?

Answer: The model is trained on where the species actually occurred (i.e. the realised niche). This can be a problem, because the model doesn't usually include spatial information about factors that determine the realised niche (competition, etc), so the predicted/projected distribution may be neither the fundamental nor the realised niche...

3. SDMs and the assumption of equilibrium?



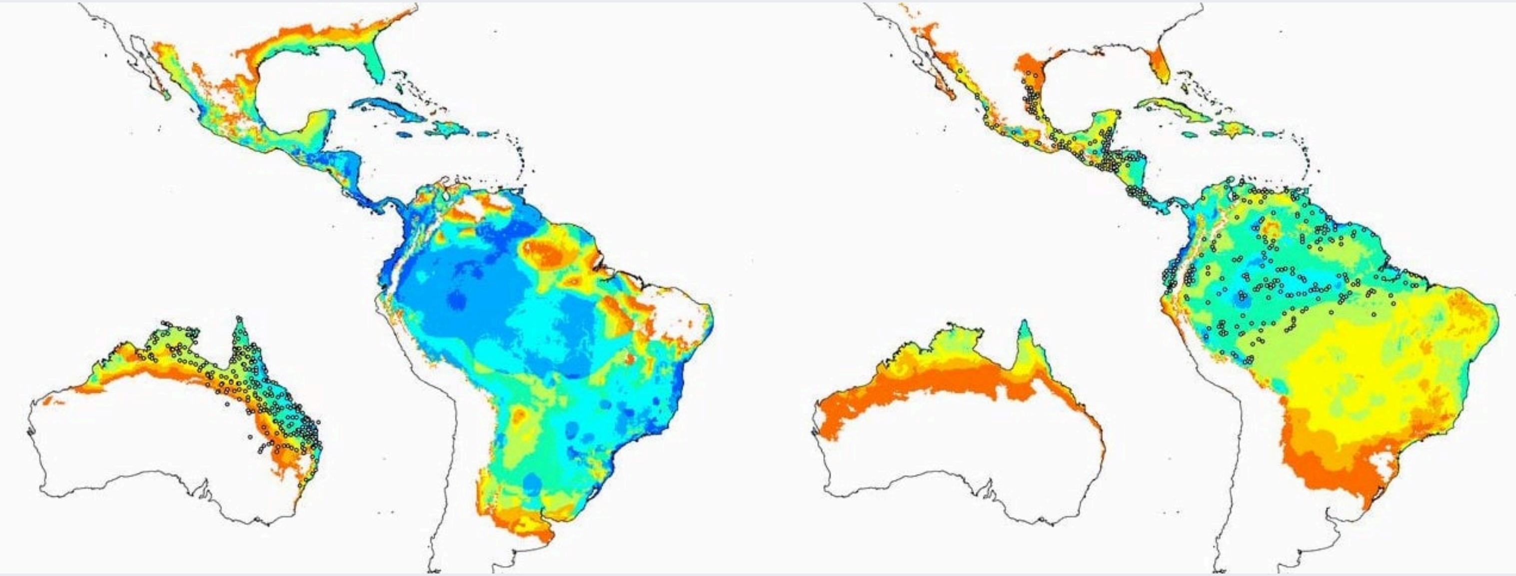
A) If a species has an equilibrium distribution, it is occupying all of the potentially suitable habitats in the world (the potential niche is completely filled).

B) If a species is in a non-equilibrium distribution, its potential niche is not fully occupied due to inaccessible habitat due to dispersal (movement) constraints: distance or barriers to dispersal, inability to recolonise habitats affected by seasonal or long-term dynamism.

Species rarely occupy their full potential niche!

Figure from **Brown and Carnaval 2019**

e.g. Invasive species and the assumption of equilibrium



Reciprocal projections of models calibrated using data from either the invasive Australian (left) or native South American (right) occurrence of the cane toad, *Rhinella marina*, and projected into the other.

Invasive (left): predicted a broader latitudinal distribution in the native South American range than is observed

Native (right): failed to predict invasive populations in drier and cooler regions to the SE of Australia

- Why???

Tingley et al. 2014

e.g. Invasive species and the assumption of equilibrium

Why the difference between the native and invasive realised niches of the cane toad? - **Tingley et al. 2014**

Hypothesis 1

Dispersal limitation or absence of drier, cooler climate in South America?

Hypothesis 2

Difference in biotic interactions experienced on each continent?

e.g. Invasive species and the assumption of equilibrium

Why the difference between the native and invasive realised niches of the cane toad? - **Tingley et al. 2014**

Hypothesis 1

Dispersal limitation or absence of drier, cooler climate in South America?

> *"...our findings demonstrate that novel climates colonized by R. marina in Australia were available, but unoccupied, in the species' native range..."*

Hypothesis 2

Difference in biotic interactions experienced on each continent?

> *"One possibility is that the presence of a closely related species (R. schneideri) in cooler and drier regions of Southern Brazil may be preventing R. marina from colonizing suitable environments south of its present range. ...these two species hybridize..., and even low rates of interspecific hybridization can enforce stable range boundaries"*

This example highlights that acknowledging the issues or assumptions of SDMs can be very useful for learning about the species and testing hypotheses. The issues are only a problem if not acknowledged and accounted for in some way!

What else have we missed?

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...?

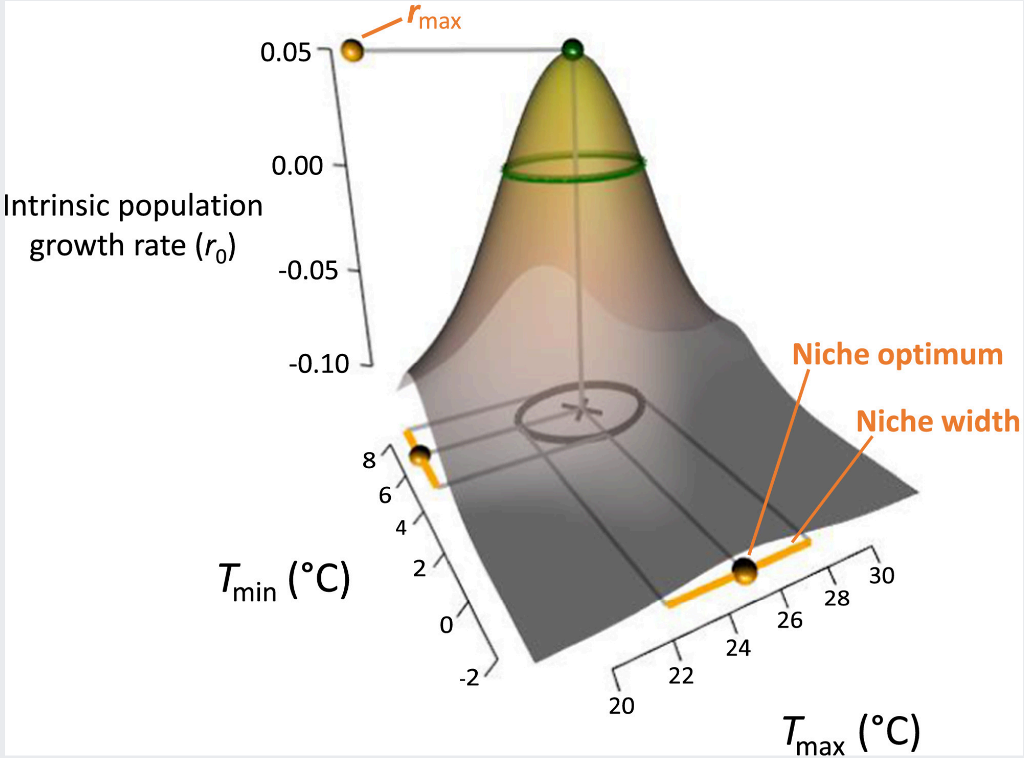


Figure from **Treurnicht et al. 2020**

The Hutchinsonian Niche

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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.

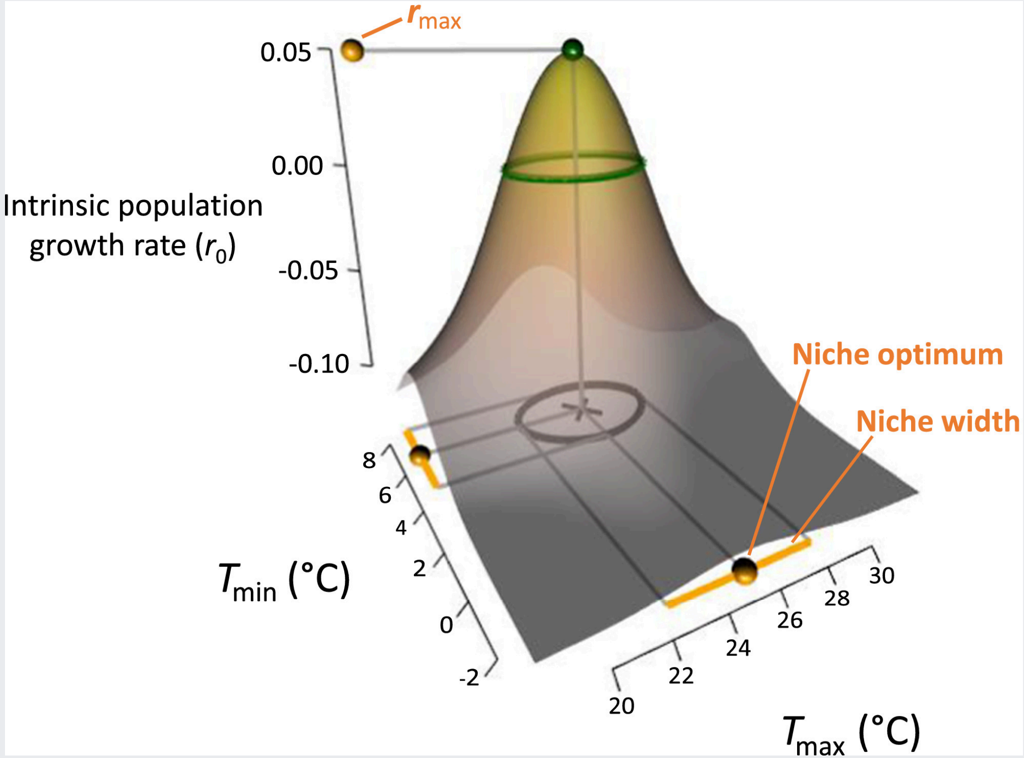


Figure from **Treurnicht et al. 2020**

How does this relate to SDMs?

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

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!

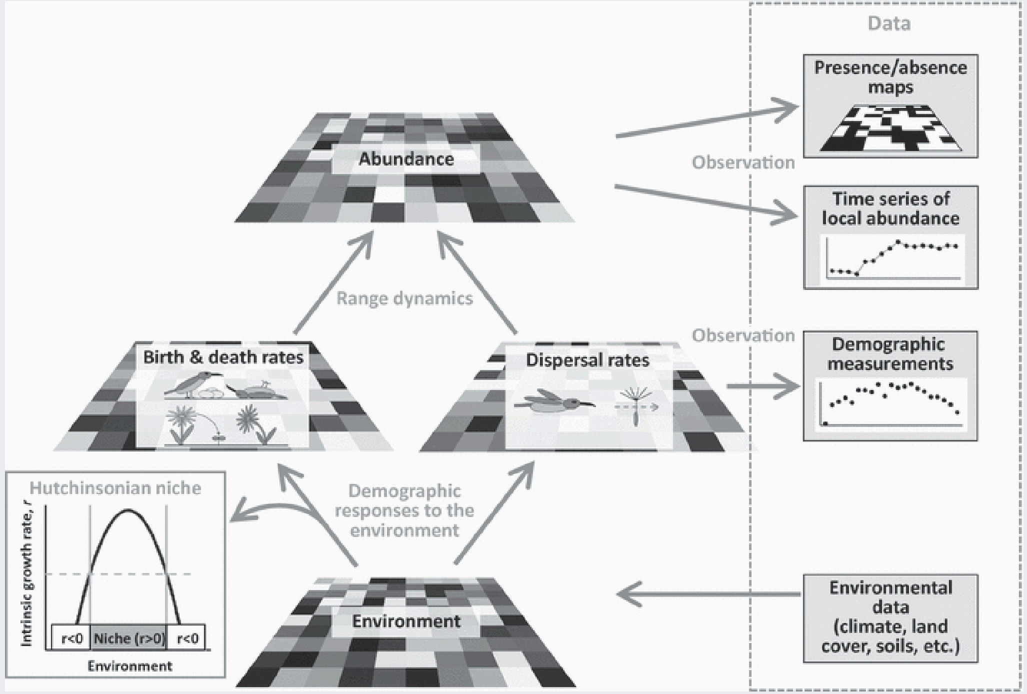
While they are still typically modelled statistically, by including the underlying biology of the species and its interactions with the environment they are also partly mechanistic.


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

SPECIAL ISSUE

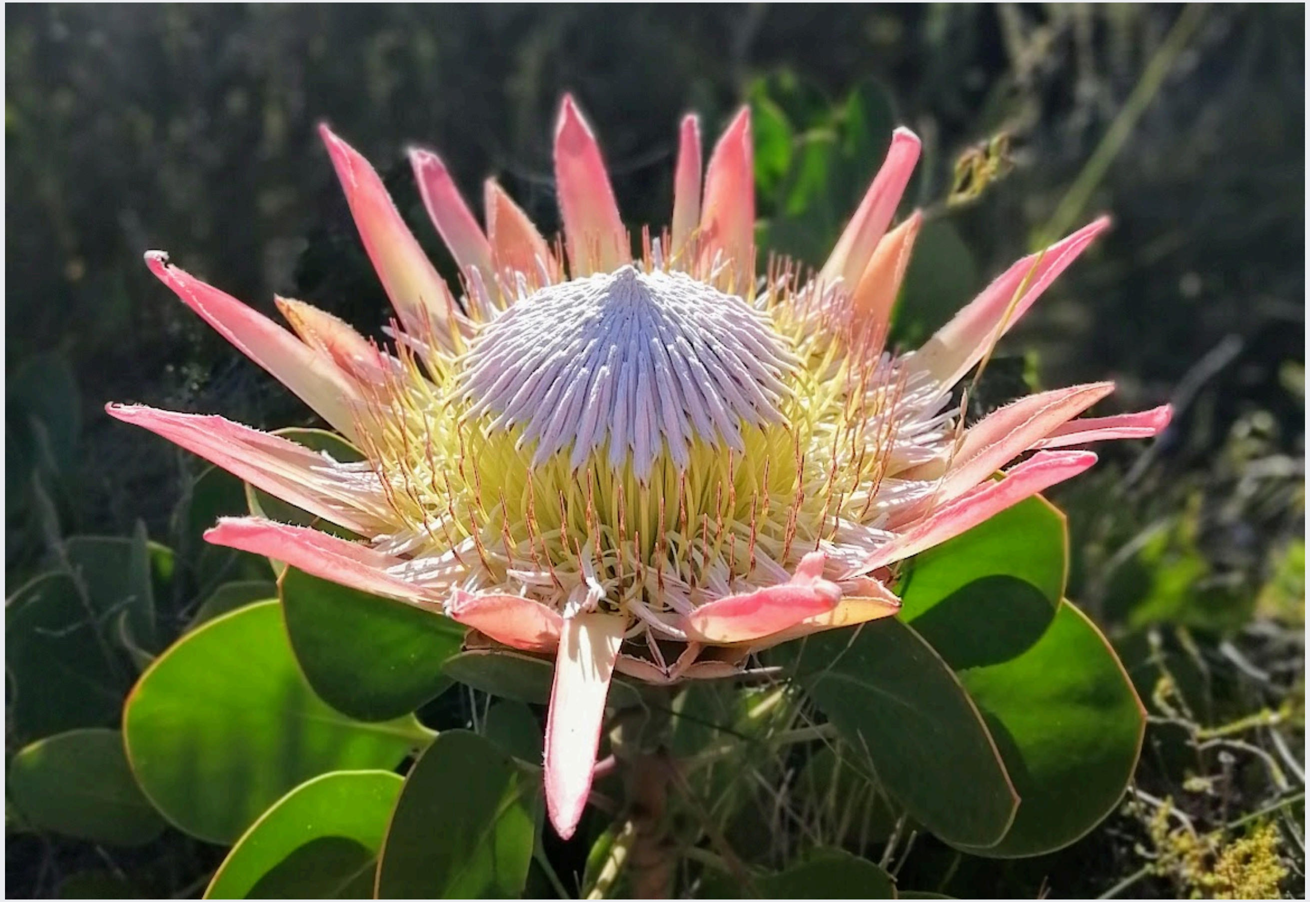
How to understand species' niches and range dynamics: a demographic research agenda for biogeography

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]

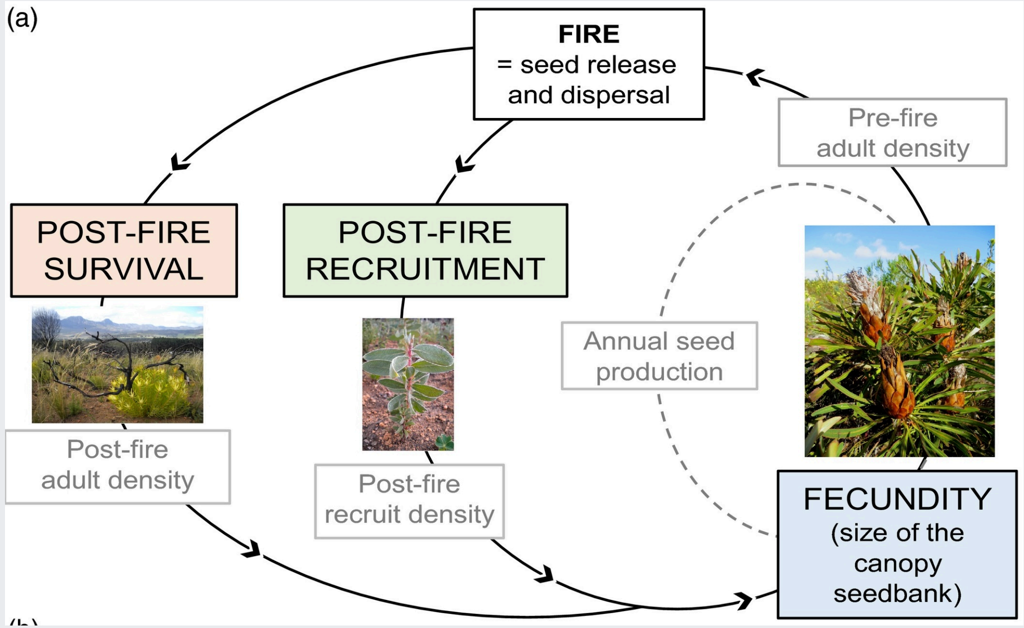


Schurr et al. 2012

How this is done with *Protea* species?



Proteaceae life cycles and demography



from **Treurnicht et al 2021**

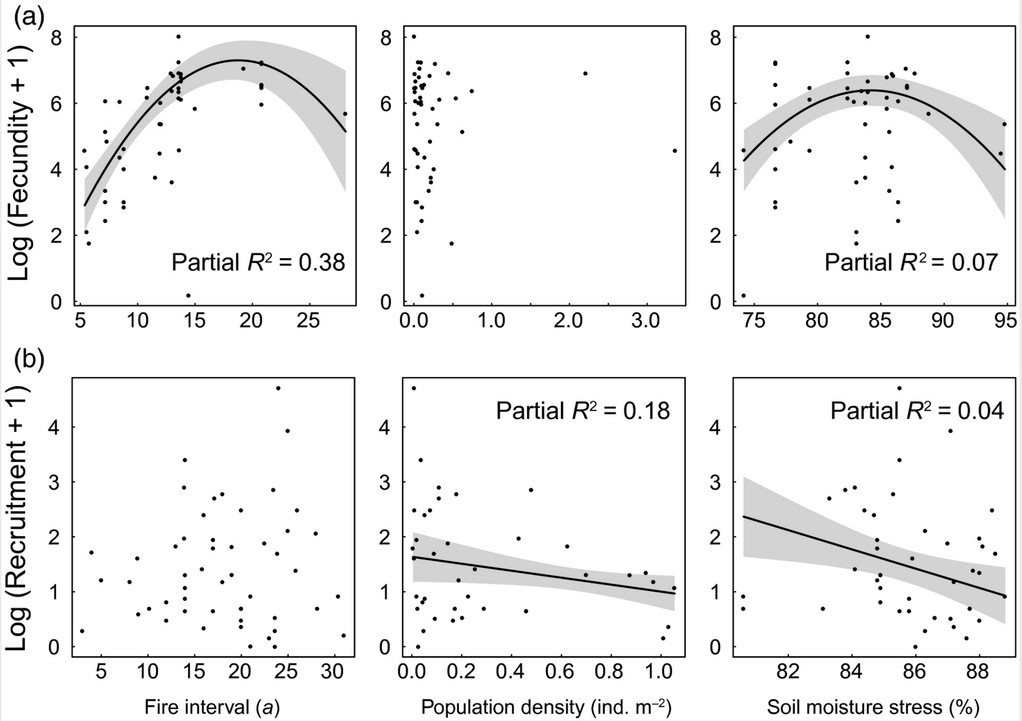
The fire-driven life-cycle of Fynbos Proteaceae species.

Population size/stability are determined by ***key demographic rates***:

- adult **fecundity** (size of the canopy seed bank)
  - mean number of cones $*$ mean seeds per cone $*$ number of plants
- post-fire seedling **recruitment**
- adult **survival** (especially through fire)

These rates are affected in various ways by environmental conditions, life-history traits, density dependence, the timing, intensity and severity of fire, pathogens, wildflower harvesting, etc.

Intraspecific variation in demographic parameters



Intraspecific variation in (a) fecundity and (b) recruitment in response to range-wide variation in fire return interval (time since fire), adult population density and soil moisture stress (% days with soil moisture stress) for *Protea punctata*.

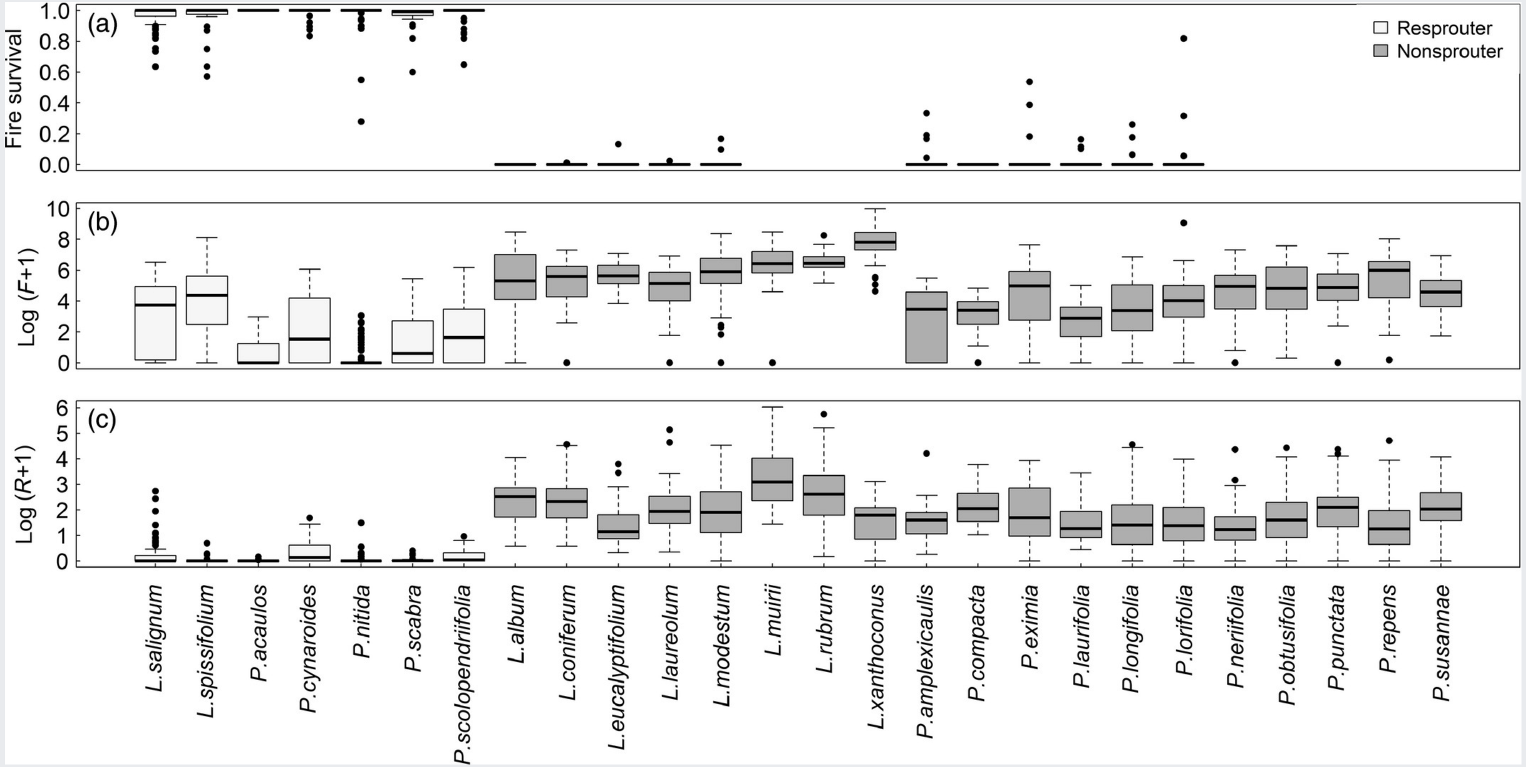
Together * , the covariation between these parameters and environmental variables can be used to determine where the population growth rate (λ) of *Protea punctata* allows the species to occur.

* Note that this species is killed by fire, so there is no adult survival to consider.

from **Treurnicht et al 2016**

This approach also allows us to learn about the species' strategies!

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)**.

Joint Species Distribution Models (JSDMs)

Joint Species Distribution Models (JSDMs) are a new generation of SDMs that allow us to model the distributions of multiple species simultaneously. They are based on the idea that species distributions are not independent of each other, and that the presence or absence of one species can influence the distribution of another.

These approaches model multiple species at the same time, considering the interactions between species and the environment.

They estimate co-occurrence patterns among species while also accounting for environmental and spatial structure and attempt to decompose variation in species composition into components attributable to abiotic, spatial, and biotic factors.

This is a promising and cutting-edge avenue for better understanding the realised niche of species, and how they interact with each other (in multispecies communities rather than pairs only) and their environment, but there are persistent issues in trying to disentangle the effects of the environment, space and species interactions.

Take-home

> *One of the most common applications of the concept of the niche is Species Distribution Modelling (also known as Ecological Niche Modelling).*
>
> *While SDMs can be very useful, they have many issues and assumptions that need to be taken into account.*
>
> *Acknowledging the issues or assumptions of SDMs can actually be very useful for learning about species and testing hypotheses.*
>
> *Newer SDMs can include a demographic modelling component to estimate population growth rates to know whether populations can be maintained under different environmental conditions, allowing them to map species distributions based on the Hutchinsonion niche.*
>
> *Joint Species Distribution Models (JSDMs) are a promising and cutting-edge avenue for better understanding the realized niches of multiple species across their range, and how they interact with each other and their environment.*
>
> ***Proviso:** There are many ways to build SDMs and it is a rapidly moving field. There are methods to address some of the issues I highlight, but they are less commonly used and since I am covering SDMs in one lecture for this course I'm not going to go there...*

Thanks!

Slides created via the R packages:

xaringan
gadenbuie/xaringanthemer

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