Marine Ecological Modelling
Global Climate Change

Ecological niches and geographic distributions

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Macroecology

It’s a big-picture statistical approach to the study of ecology (not a separate field or sub discipline; coined ~30 years ago).

Focuses on **patterns and processes** operating **at large spatial and temporal scales** and ignores localized and fine-scaled details.

Aims to **uncover the relationship between** complex ecological systems (**organisms**, **populations**, **species**) **and their environment**, and to characterise and explain statistical patterns of abundance, distribution and diversity.

e.g.,

How global climate change may affect marine biodiversity?

Which environmental drivers explain the distribution of a species?

Macroecology

Comparisons across **numerous locations, communities, populations** and **species to scale up** results and hypotheses **from local to global processes**.

In opposition to reductionalist experimental approaches, which have difficultly in generating predictive theory.

Niche concept is central in macroecology

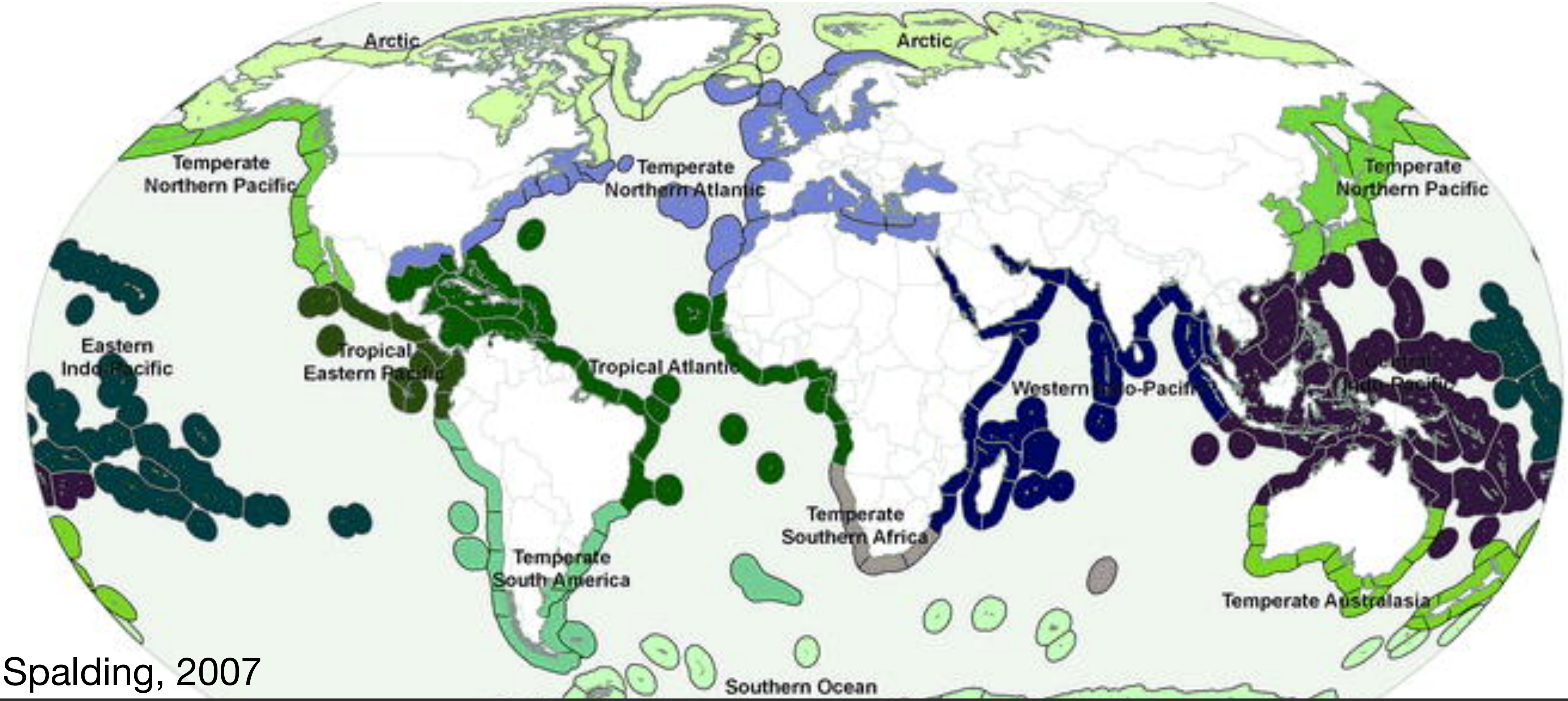
Distributional limits are shaped by constrains on dispersal (i.e., the process by which species fulfil distributional ranges, including both the **movement of individuals** and their **successful establishment**);

With no dispersal limits, every species could potentially be distributed everywhere, and spatial patterns of distribution and diversity would be absent or random.

Well defined biogeographic patterns of diversity and distribution.

Classification systems based on species composition proposed the definition of sharp **biogeographic regions.**

e.g. **Marine Ecoregions of the World**; nested system of 12 realms, 62 provinces, and 232 ecoregions. A standard for conservation planning.



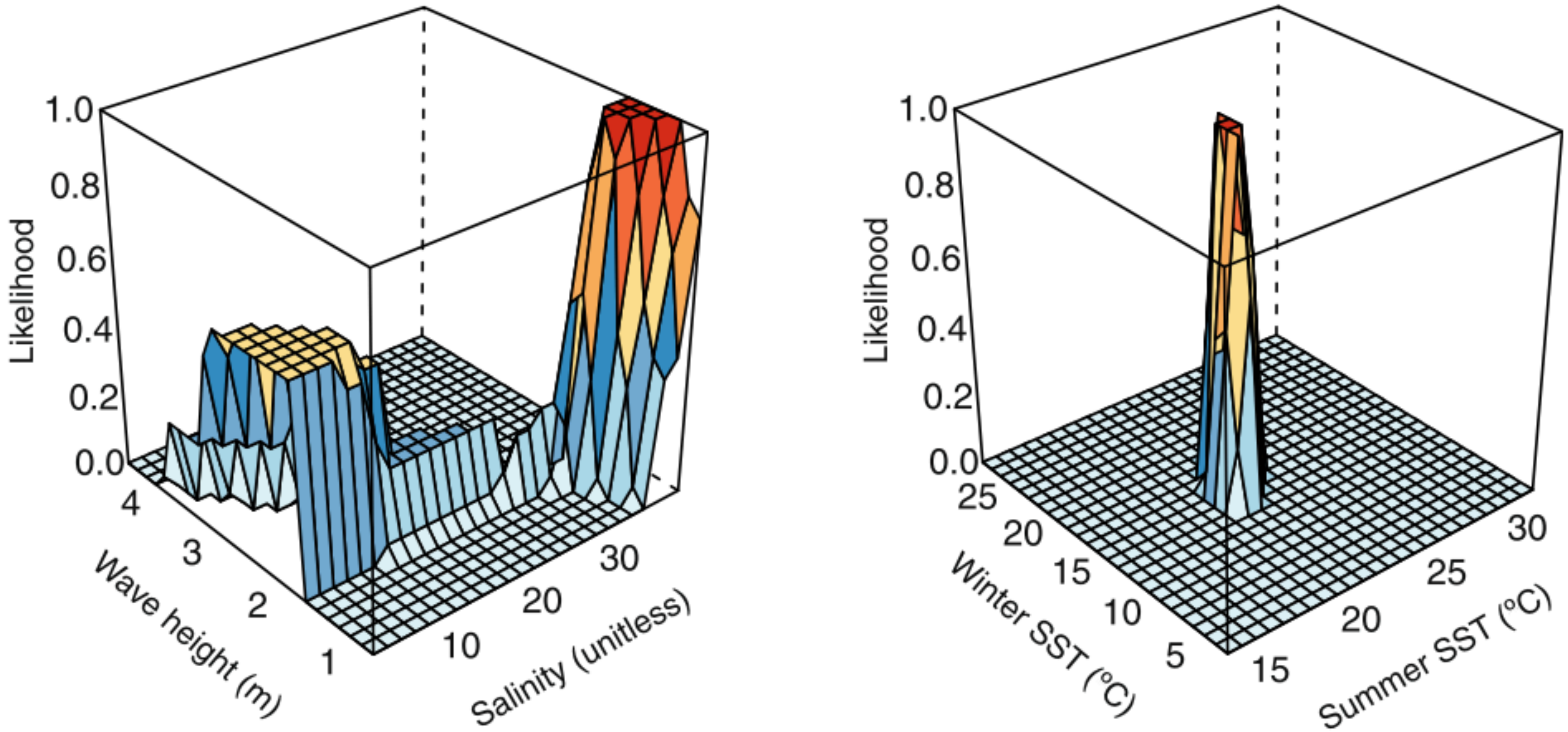
Spalding, 2007

Niche concept is central in macroecology

Hutchinson (1987; the classic reference), defined the niche as **the hypervolume defined by the environmental space where a species can survive and reproduce.** The niche is a property of a species, not the environment.

Fundamental niche: the response of species to the environment in absence of biotic interactions (competition, predation, facilitation);

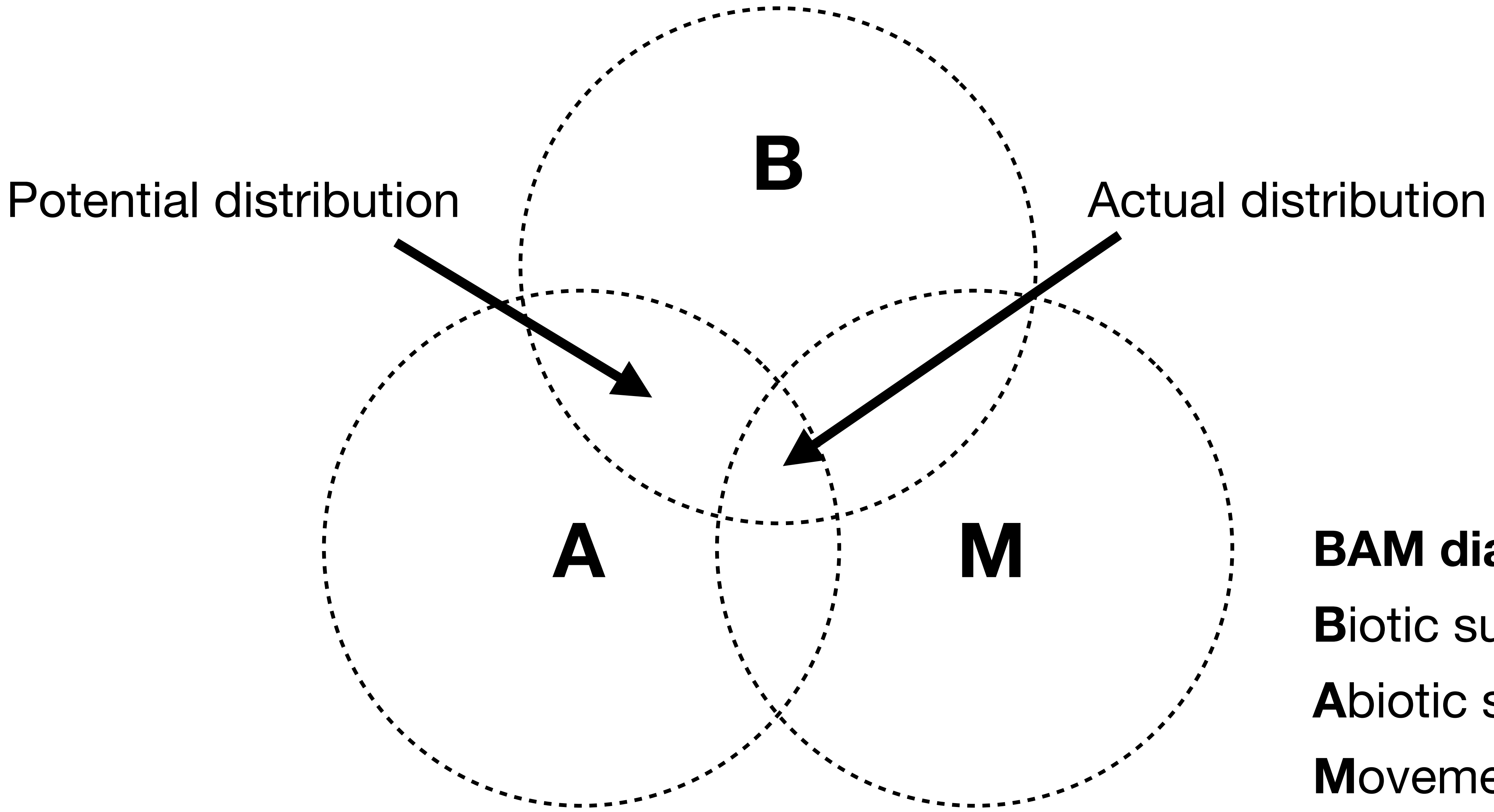
Realized niche: the environmental dimensions where species can survive and reproduce, including the effects of biotic interactions (realised niche often smaller than the fundamental niche due to negative interspecific interactions).



Hypervolume of environmental dimensions where species can survive and reproduce (fundamental niche).

e.g.,

A Mediterranean coral with the niche defined by thermal conditions, wave intensity and salinity.



BAM diagram

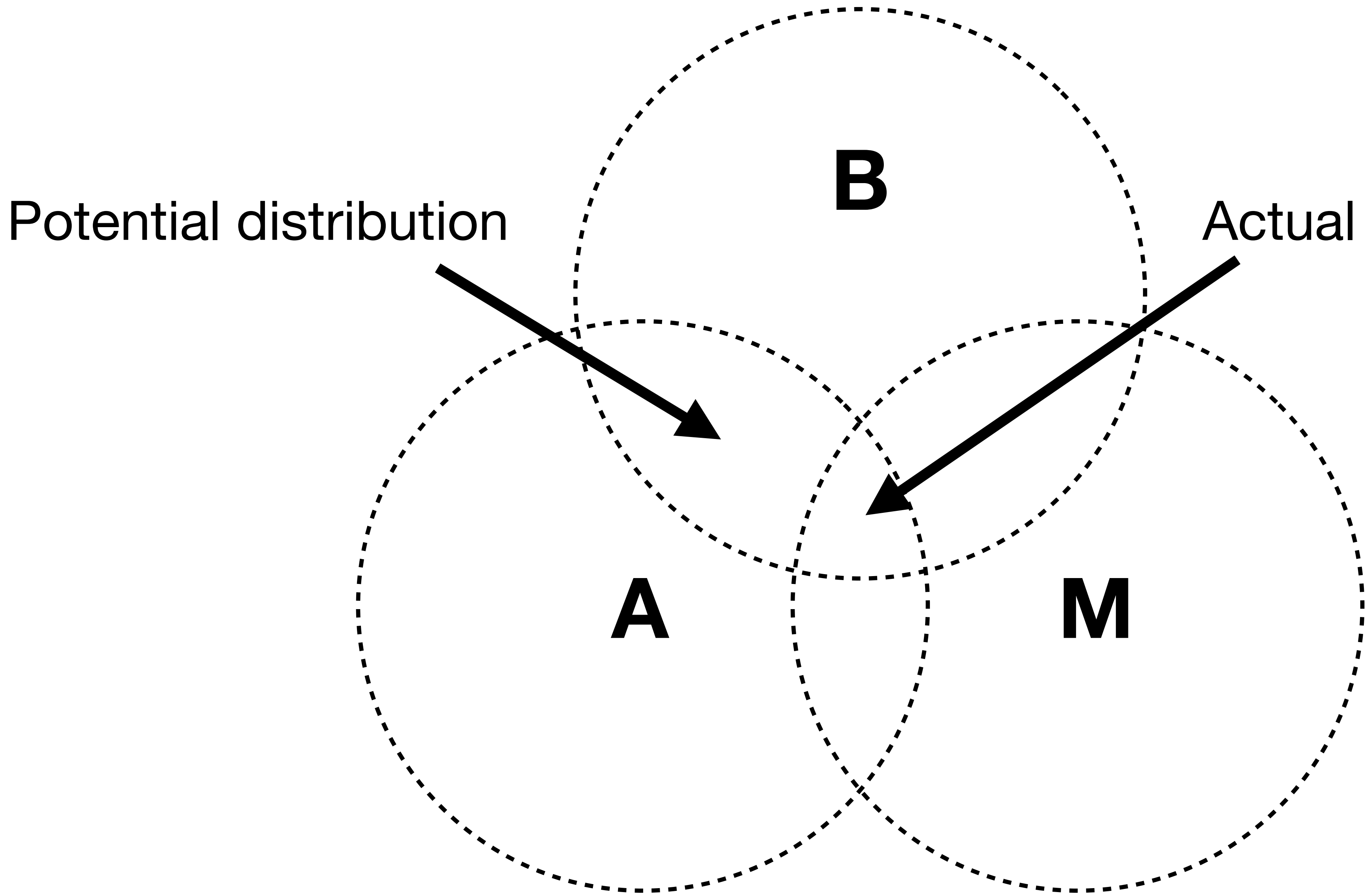
Biotic suitability

Abiotic suitability

Movement

BAM (biotic-abiotic-movement) diagrams depicts the complex interplay of factors that limit species distributions.

Species can only survive where both the abiotic conditions (A) and the prevailing biotic interactions (B) allow positive population growth.



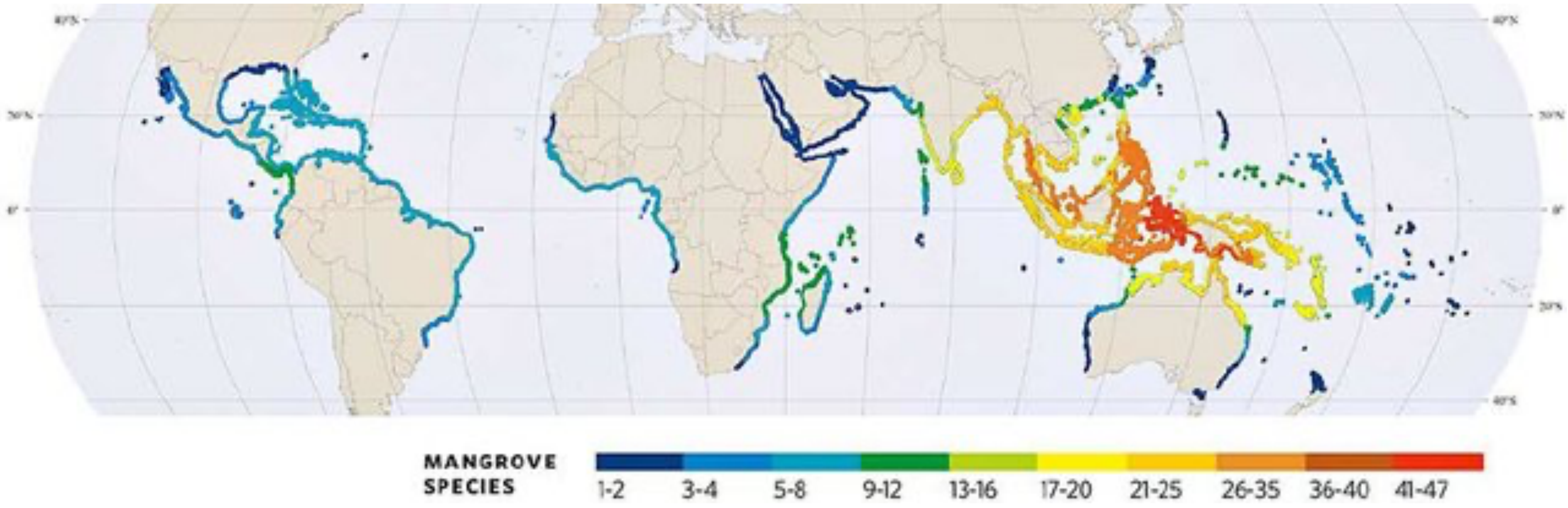
BAM diagram

Biotic suitability

Abiotic suitability

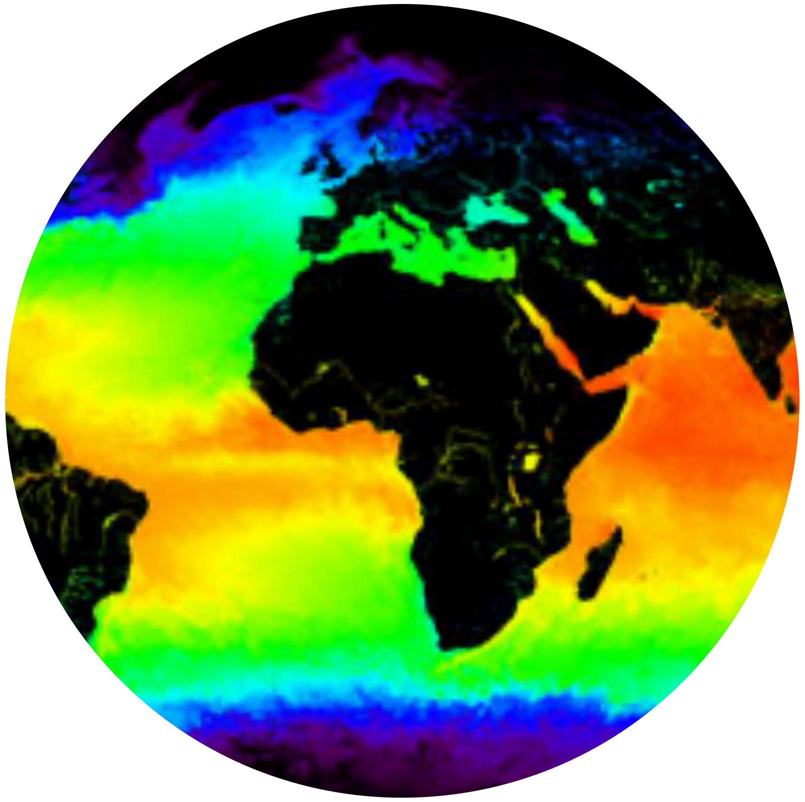
Movement

Movement determines whether a species is present in suitable habitats: **a species can be absent from a suitable habitat due to dispersal limitations.** When populations go locally extinct in response to stochasticity, dispersal determines how fast the empty suitable habitats will be recolonised.



Movement

Younger species (evolutionary speaking) **occupy less of their potential range extents than older species**: **species ranges likely determined by time for dispersal** (i.e., potentially species can get to suitable habitats, but it may take time to get there).

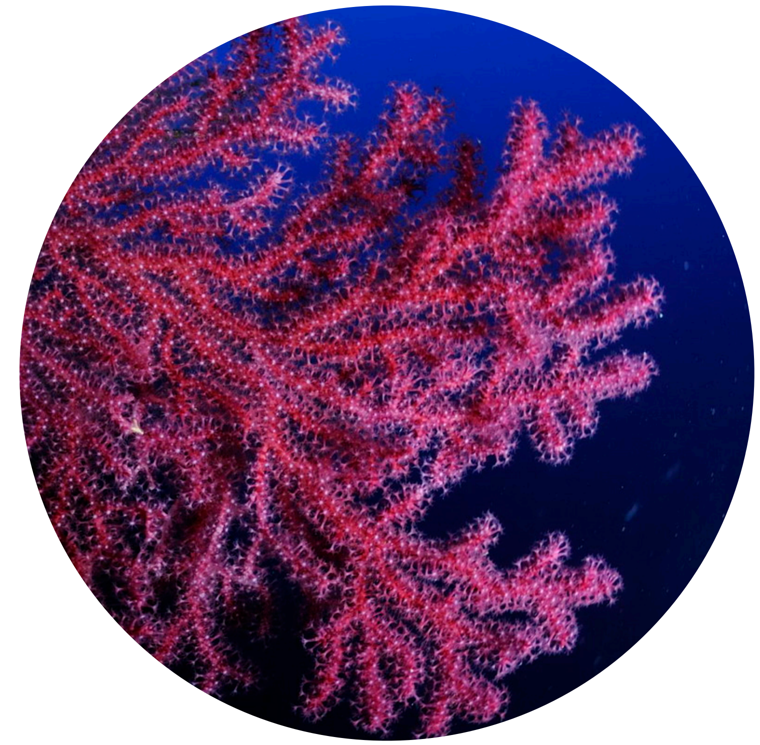


Which abiotic factors set range limits?

Multiple abiotic factors may set the range limits of species to create biogeographic patterns (macroecological scales). These may depend on the species / part of that species' range that is being considered.

e.g.,

Poleward limits set by tolerance to ice scouring and extreme minimum temperatures, low latitude limits set by maximum temperatures and western limits set by limiting nutrient conditions.



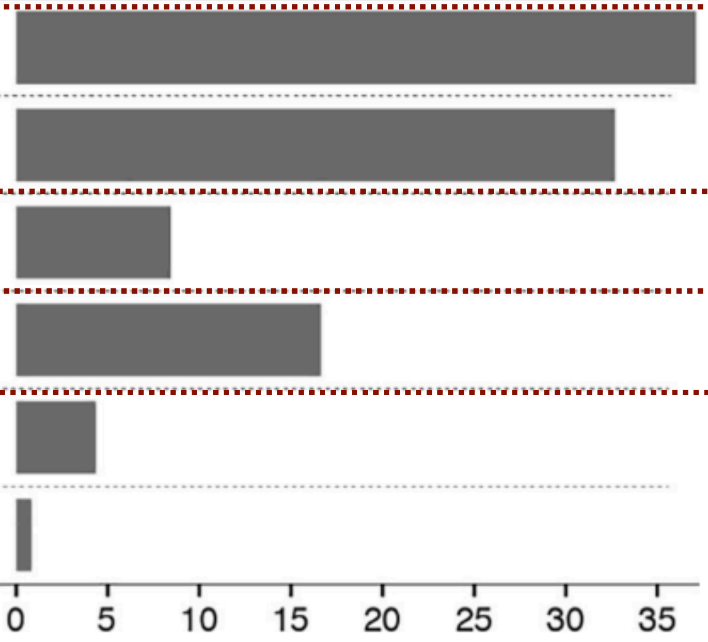
Mediterranean coral

Predictor (unit)	Oc. range	LP model	LP literature	Relative contribution(%)
Temperature min. (ºC)	11.4 - 16.0	<11.5	<12.0 [1,2]	
Temperature max. (ºC)	14.1 - 24.4	>25.5	>25.0 [1,3,4]	
Slope (degree)	$3.2e^{-2}$ - 22.2	<0.1	steep [1]	
Silicate max. (µmol/L)	1.6 - 19.9	>20.1		
Productivity min. (gC/m³/day)	$7.5e^{-6}$ - $3.3e^{-3}$	$<4.0e^{-6}$		
Phosphate min. (µmol/L)	$1.6e^{-4}$ - 0.5	$<2.2e^{-5}$	< 0.08 [5]	
Phosphate max. (µmol/L)	$2.4e^{-2}$ - 0.77	>0.6		
Nitrate min. (µmol/L)	$1.0e^{-6}$ - 5.2	$<7.2e^{-7}$	< 2.0 [5]	
Nitrate max. (µmol/L)	$2.5e^{-3}$ - 10.9	>5.4		

Boavida et al., 2016

Agressive invasive macroalgae

Environmental predictor	Unit	Tipping points	Relative importance (%)
Long-term min. Light at bottom	$E . m^{-2} . yr^{-1}$	4.04	
Long-term max. Ocean Temperature	°C	26.55	
Long-term min. Ocean Temperature	°C	2.20	
Long-term min. Ocean Salinity	PSS	31.05	
Long-term min. Nitrate concentration	$mmol . m^{-3}$	0.42	
Long-term min. Phosphate concentration	$mmol . m^{-3}$	0.06	



Koerich et al., 2019

Layer
Temperature
Salinity
Sea ice concentration
Sea ice thickness
Current velocity
Nitrate
Phosphate
Silicate
Dissolved molecular oxygen
Dissolved iron
Chlorophyll
Phytoplankton
Primary productivity
Light at the bottom

Abiotic factors setting range limits?

Non-estuarine cold-temperate fish (N Atlantic)

Non-estuarine tropical fish (Equator)

Cold-temperate macroalgae (N Atlantic)

Warm-temperate seagrass (Mediterranean)

Cold-temperate coral (Mediterranean)

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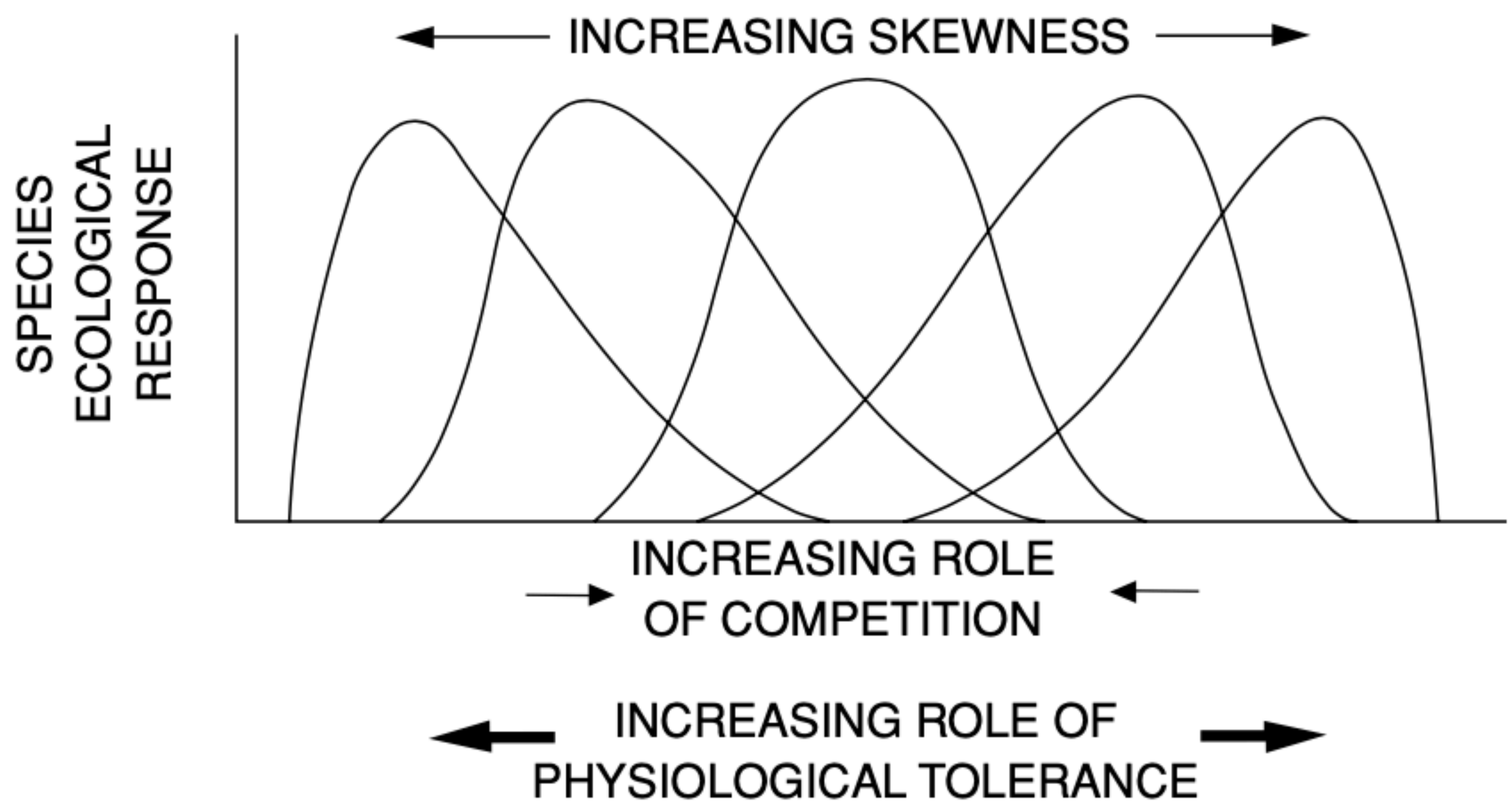
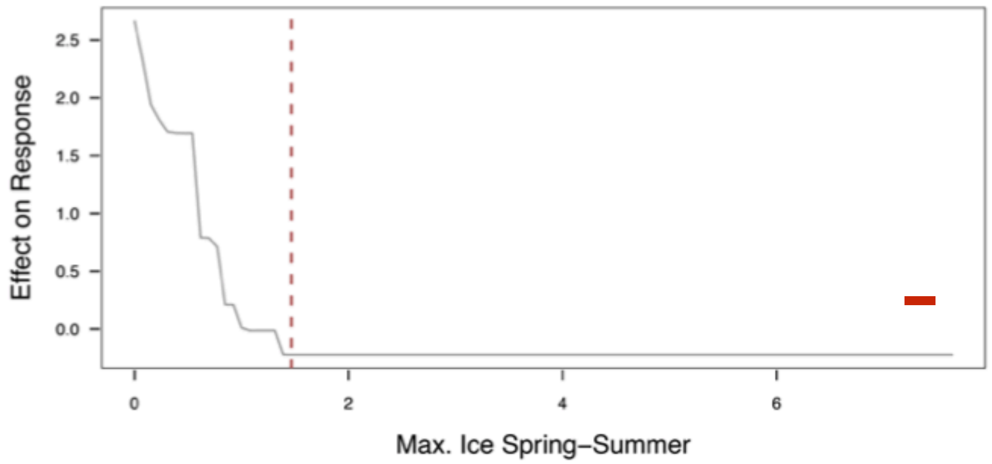
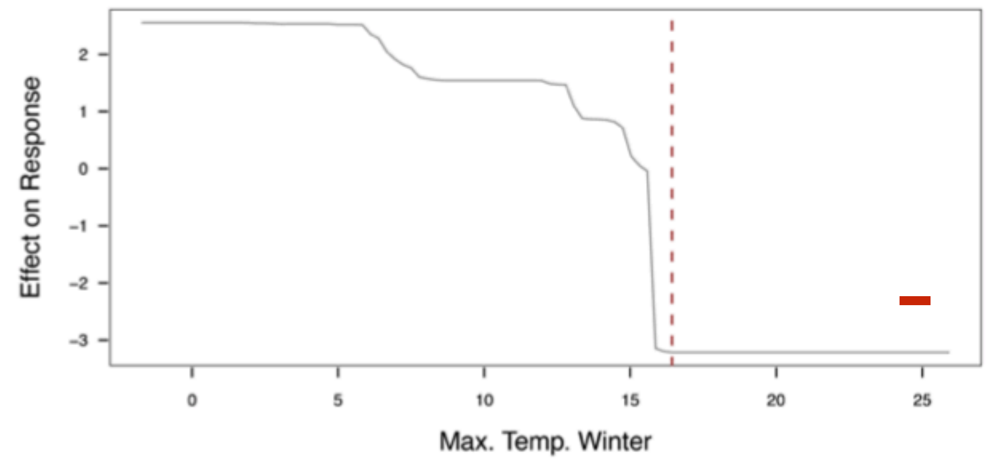
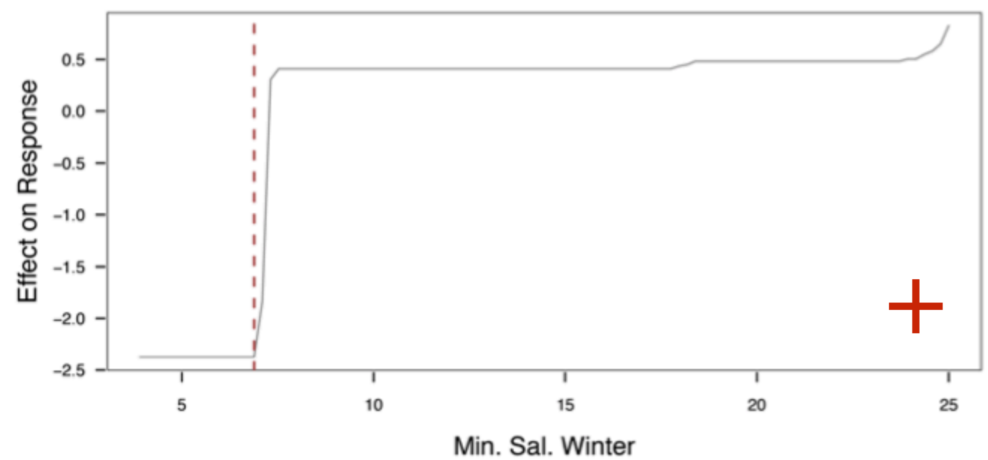


Species response functions

Whittaker (1956, 1960, 1967) developed key ideas to analyse the **relationship between the distribution of species and** the actual **environmental gradients**. It has been hypothesized that species responses are bell-shaped (Gaussian), **equally spaced and of equal amplitude, with their width restricted by competition**.







Species response functions

Yet, **unimodal responses are the most common**, typically, **positive or negative.** Skewed response curves are expected (physiological stress limiting occurrence at the “harsh”). Bimodal or multimodal response curves have also been hypothesized to result from competition.

Liebig’s law of the minimum suggests that **the true response** of species **to one factor can only be detected when all other factors are non-limiting**.

Modelling with abiotic conditions

Ecophysiological knowledge should guide the modeller to characterize potential interactions of factors determining the distribution of species.

My main questions

Which environmental variables drive the distribution of my model species?

Which response I expect for each environmental variable?

My main hypotheses based on ecophysiological knowledge

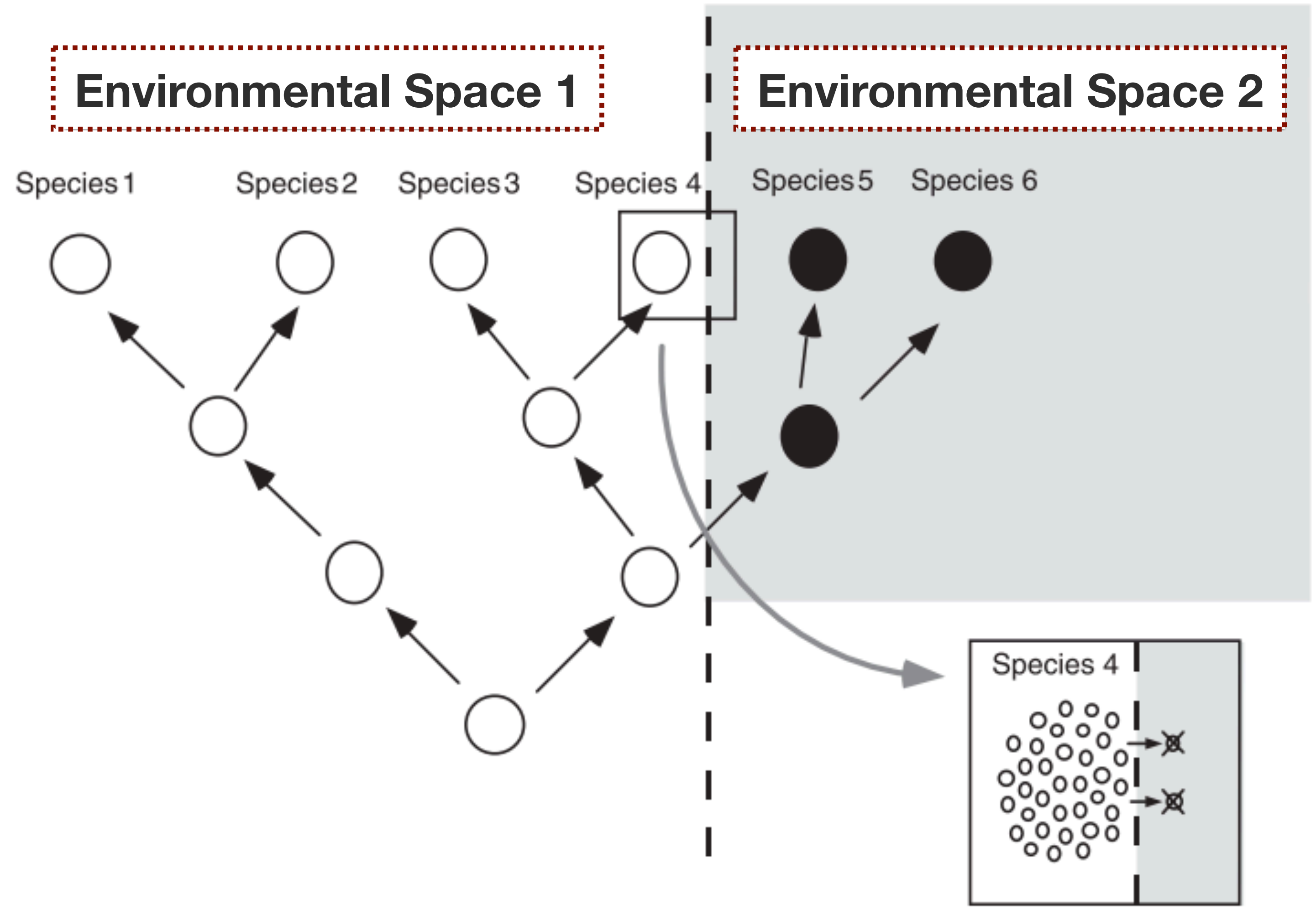
(…)

Niche conservatism

Species range limits are not simply set by unsuitable abiotic and biotic conditions at their range margins, but also by the **failure of organisms to adapt to unsuitable conditions**.

Niche conservatism is the tendency of species to retain ancestral ecological traits; the idea that **species physiological tolerance limits will remain similar over time**.

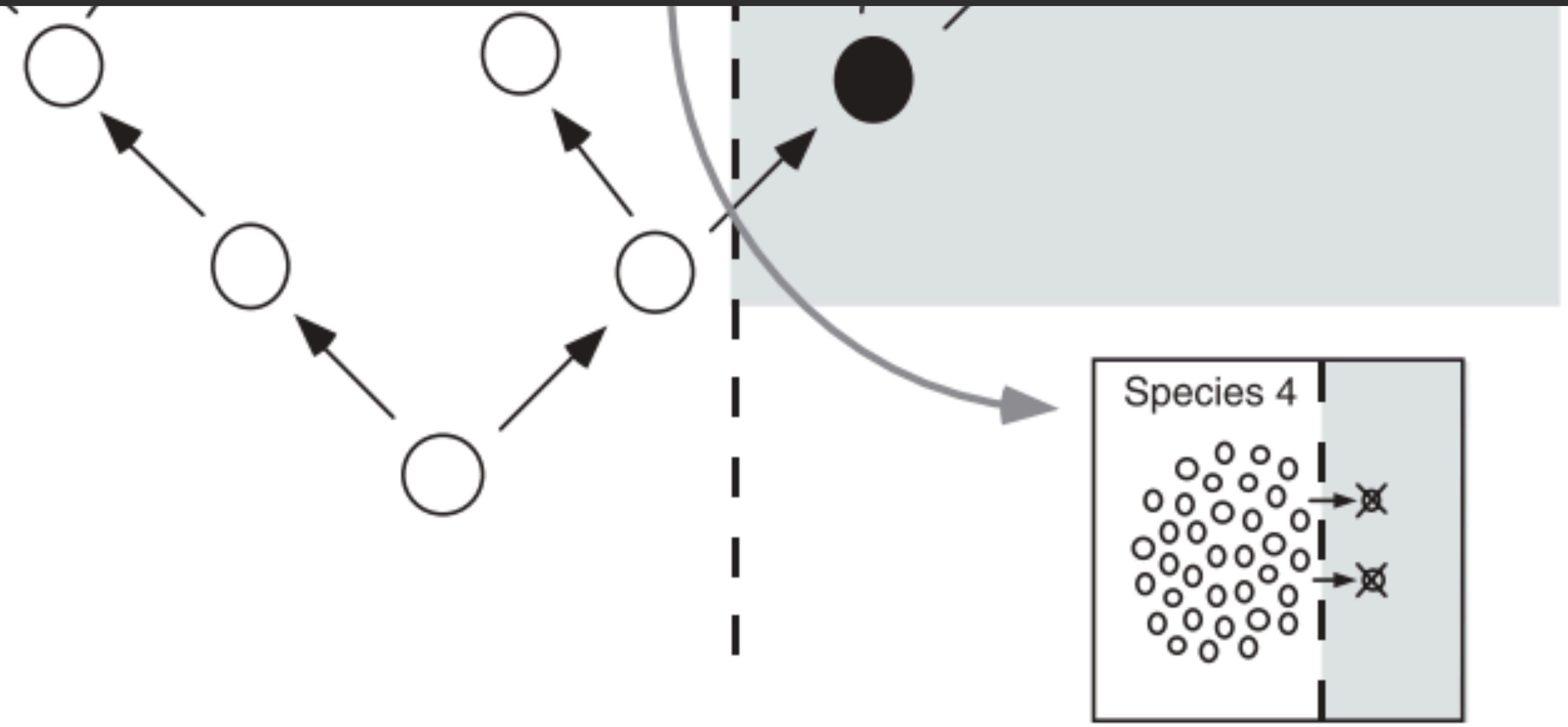
(proposed and tested 20 years ago; Peterson et al., 1999)



Niche conservatism

For a given environmental space, the clade originates as a single ancestral species. In time, there is an evolutionary niche shift to use a different environment. At the present time, there are 4 species using the ES 1 and 2 species using ES 2. Niche conservatism in species 1-4 limits the individuals of using ES 2.

Wiens et al., 2010



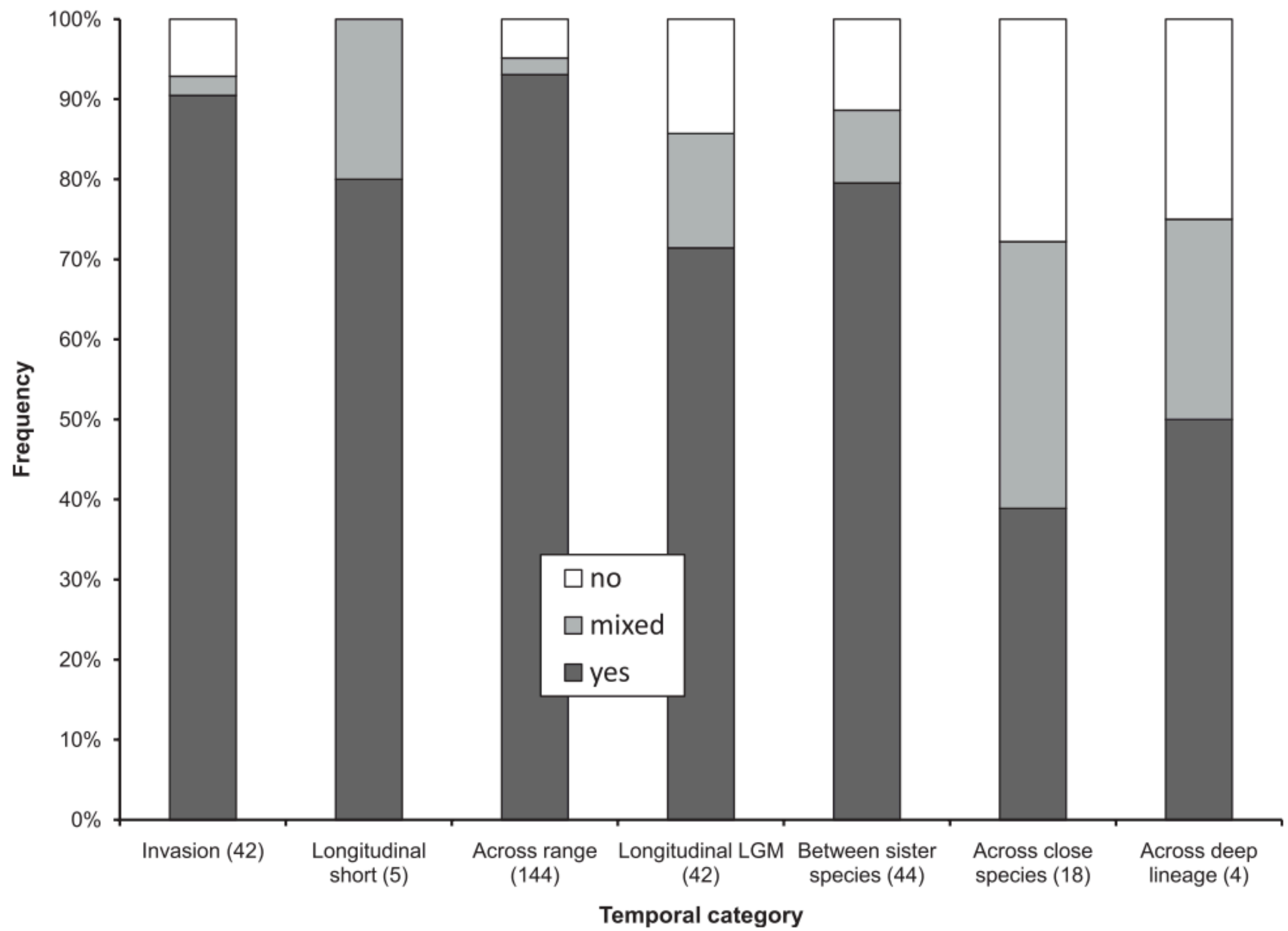
Niche conservatism

Species may adapt to different conditions over time, but biogeographic patterns show **well defined physiological tolerances at range margins.**

Without such limits, every species could be everywhere, and again there would be few non-random biogeographic patterns.

Communities become saturated with ecologically similar species over evolutionary time (e.g. given tens of millions of years): not possible for "new species" to invade the ecological space - competitive exclusion.

Wiens et al., 2010



Niche conservatism

An extensive review shows evidence for ecological niches being highly conserved over short-to-moderate time spans (i.e., from individual life spans up to tens or hundreds of thousands of years).

Peterson et al., 2011

Niche conservatism

A clear evidence for niche conservatism is how ongoing warming is shifting the distribution of species globally, particularly at low latitude range edges.

Without niche conservatism, species would persiste locally while climate conditions shift.